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International benchmarking of private investments in Digital Decade thematic areas

Torrecillas Jodar, J., Papazoglou, M., Calza, E., Cardona, M., Vazquez-Prada Baillet

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Contents

Abstract

This report presents a wide-ranging analysis of private investments related to the Digital Decade thematic areas in the European Union (EU) in comparison with other relevant economic actors. The report examines investments in gigabit, 5G, semiconductors, edge computing, quantum technology, and the adoption of cloud computing, big data, and artificial intelligence by businesses. Results reveal that the EU presents lower levels of investments than the US and China in several digital sectors, particularly in fixed broadband coverage, 5G, and semiconductors. While European firms perform well in edge computing investments, they lag behind in venture capital funding compared to the US and China. Additionally, the EU faces investment shortages in the adoption of cloud computing, big data, and AI, with Chinese firms showing substantial investments and revenues in these areas. These results suggest that increased investments and support to enhance the EU's digital competitiveness could be needed in order to achieve the objectives of the Digital Decade Policy Programme.

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Authors

Torrecillas Jódar, Juan

Papazoglou, Michail

Calza, Elisa

Cardona, Melisande

Vázquez Prada-Baillet, Miguel

López Cobo, Montserrat (Editor)

De Prato, Giuditta (Editor)

Executive summary

Policy context

The Digital Compass Communication ([1]) and the recently adopted Digital Decade Policy Programme 2030 ([2]) establish targets and general objectives for a successful digital transformation of the European Union (EU) by 2030. The Policy Programme also establishes a governance mechanism, together with Member States, to ensure that those targets and objectives are achieved. The targets are based on the four main cardinal points defined in the Digital Compass: digital skills, digital infrastructures, digitalisation of business, and digitalisation of public services. Additional tools are set out, including a monitoring mechanism and the possibility to launch Multi-Country Projects through which Member States can work together to remedy gaps and accelerate progress.

This report aims to provide an overview of the level of private investments related to the following Digital Decade thematic areas: gigabit, 5G, semiconductors, edge computing, quantum and adoption of technologies (cloud, big data and artificial intelligence (AI)) by businesses. It offers a comparison of the EU's level of private investment with respect to a group of benchmark countries, including the United States (US), China (including all provinces but Taiwan), the United Kingdom (UK), South Korea, and Japan. Using data from several data sources such as Orbis BvD or Crunchbase, the study contributes to shedding a light on the disparities in several types of investments, such as venture capital (VC) funding, fixed assets growth, and gross fixed capital formation (GFCF) among the considered countries over the time period 2009-2021. Finally, we use the JRC's Digital Techno-Economic ecoSystem (DGTES) analytical approach to identify the firms active in each of the considered Digital Decade areas.

Due to the lack of global comparability in the measurement of Digital Decade key performance indicators (KPIs) (as non-EU countries may have their own definitions and sources), the study proposes estimating investments in the broader thematic areas associated with the aforementioned Digital Decade targets. These estimations do not necessarily reflect investments in the selected Digital Decade KPIs, which follow a clear formalised definition. This report provides a comparative framework to assess and contextualise the EU's situation in terms of private digital investment.

Key Conclusions

When looking at the digital landscape, the EU faces challenges in catching up with the US and China in the level of investments relative to their GDP. This correlates with a secondary position of the EU in the development of several critical technologies when compared to China and the US ([3]) (Gaida et al., 2023). These gaps are consistent across all areas, but of different magnitude, suggesting that focused policy interventions may be more needed in certain areas to accelerate the digital transition.

Main Findings

This report shows that the EU is systematically behind the US or China in all the areas studied (except for venture capital in gigabit where the EU ranks better than the US and China). Aggregating data from the sample of firms active in all DD-relevant areas studied in this report — gigabit, 5G, semiconductors, edge computing, quantum and adoption cloud, big data and AI technologies—, EU firms present a fixed assets growth as share of GDP in the period 2009-2021 that is 30% lower than the one of US firms in the same period, and US firms received six times more VC investments as share of US GDP than their EU counterpart. Also, Chinese firms' growth of fixed assets as a share of GDP was 3.5 times larger than the one in the EU and VC investments as a share of GDP were 3.7 times larger.

<u>Broadband coverage</u>

The EU falls behind the United States in terms of private investment levels in fixed broadband coverage in two out of the three investment measures compared: in fixed assets growth, and investments in telecommunication

[1] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and The Committee of the Regions 2030 Digital Compass: the European way for the Digital Decade (COM/2021/118 final) https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021DC0118

[2] Decision (EU) 2022/2481 of the European Parliament and of the Council of 14 December 2022 establishing the Digital Decade Policy Programme 2030 (OJ L 323, 19.12.2022, pp. 4–26). http://data.europa.eu/eli/dec/2022/2481/oj

[3] The Australian Strategic Policy Institute (ASPI), in its 2023 Critical Technology Tracker, finds that citations of scientific publications in most critical technologies are from Chinese or US institutions.

equipment by the ICT sector. Additional investments of up to €116 bn would bring the EU at the same level as the US in terms of cumulative fixed assets growth, and €227 bn would be needed to match US investments in GFCF in telecommunication equipment. In venture capital investments, UK firms outpace EU firms, raising 7.5 times the amount raised by EU firms.

5G coverage

The EU lags behind in 5G private investment, especially with lower levels of assets growth (after the US, South Korea and China), and venture capital (after the UK and the US). In GFCF in telecommunications equipment, the EU shows a better positioning, following the US in investment levels with respect to GDP, but showing a level similar to China's, and ahead of the UK. Significantly increasing investments would help the EU to match the intensity of investment in 5G technologies seen in the US, the UK and China.

Semiconductors

Overall, the EU shows lower investment in the semiconductor industry compared to the US, China, South Korea, and Japan. In particular, additional investments of approximately €60 bn would help the EU to match the cumulative fixed assets growth in semiconductors of the US, and over €500 bn to match China. The gap is specially high in semiconductor equipment spending, where the EU trails behind South Korea, Japan, China and the US , with a difference in investment of over €1.3 tn compared to South Korea. In venture capital, Chinese firms raise 6 times the funding raised by EU firms, and Us firms do 4.5 times more than the EU.

Edge

European firms have emerged as leaders in cumulative fixed assets growth in the edge computing sector, closely matched by China. However, the EU lags behind the US, China, South Korea and the UK in terms of venture capital funding received by firms active in edge computing.

Quantum

In the quantum technology, the US leads in venture capital investments, followed by the UK and the EU in third place. Asian countries show very low venture capital funding, which may indicate an underestimate due to Crunchbase's delay in capturing Asian firms active in very new technologies.

Adoption of technologies by businesses (cloud computing services, big data and AI)

Concerning the cloud services, US, Chinese and UK firms demonstrate significantly higher assets growth and revenues compared to their European counterparts. In venture capital funding, the distance between the EU and these countries is even higher. The market share is largely concentrated among a few major players, such as Amazon Web Services, Google, Microsoft Azure, Alibaba, and VMware. The limited presence of European cloud providers implies that European firms may have to rely on foreign providers, hindering their competitiveness and adoption of cloud services.

Regarding big data, the EU shows significantly lower investments compared to China and the US. European firms struggle to attract venture capital funding and generate revenues at a similar scale as their international competitors. The findings highlight the need for increased investments and support to bolster the big data ecosystem in the EU.

In the field of AI, Chinese firms exhibit substantial investments and revenues, surpassing those of the EU and even the US. European AI firms face challenges in terms of venture capital funding and revenue generation, falling behind their US and Chinese counterparts. However, it is important to note that AI adoption is still at an early stage globally (when compared to other digital technologies), and widespread implementation may take more time.

Tables 1-2 summarise the position of the EU in all the respective DD thematic areas, compared with the benchmarking countries, namely United States, China, United Kingdom, South Korea and Japan, when considering the total investments (or revenues) in relation to the size of the economy (i.e., as a share of GDP).

Table 1. Fixed assets growth ranking for all the benchmarking countries (total investments as a share of GDP)

Thematic area	Ranking					
	1st	2nd	3rd	4th	5th	6th
Gigabit	🇺🇸	🇪🇺	🇬🇧	🇰🇷	🇨🇳	🇯🇵
5G	🇺🇸	🇰🇷	🇨🇳	🇪🇺	🇬🇧	🇯🇵
Semiconductors	🇨🇳	🇰🇷	🇺🇸	🇪🇺	🇯🇵	🇬🇧
Edge computing	🇨🇳	🇪🇺	🇺🇸	🇬🇧	🇰🇷	🇯🇵
Quantum	🇨🇳	🇬🇧	🇰🇷	🇯🇵	-	-
Adoption of technologies: cloud	🇨🇳	🇺🇸	🇬🇧	🇰🇷	🇪🇺	🇯🇵
Adoption of technologies: big data	🇨🇳	🇬🇧	🇺🇸	🇪🇺	🇰🇷	🇯🇵
Adoption of technologies: Artificial intelligence	🇨🇳	🇺🇸	🇪🇺	🇬🇧	🇰🇷	🇯🇵

Table 2. Venture capital ranking for all the benchmarking countries (total investments as a share of GDP)

Thematic area	Ranking					
	1st	2nd	3rd	4th	5th	6th
Gigabit	🇬🇧	🇪🇺	🇺🇸	🇯🇵	🇰🇷	🇨🇳
5G	🇬🇧	🇺🇸	🇪🇺	🇨🇳	🇯🇵	🇰🇷
Semiconductors	🇨🇳	🇺🇸	🇬🇧	🇪🇺	🇰🇷	🇯🇵
Edge computing	🇺🇸	🇨🇳	🇰🇷	🇬🇧	🇪🇺	🇯🇵
Quantum	🇺🇸	🇬🇧	🇪🇺	🇨🇳	🇰🇷	🇯🇵
Adoption of technologies: cloud	🇺🇸	🇨🇳	🇬🇧	🇪🇺	🇯🇵	🇰🇷
Adoption of technologies: big data	🇺🇸	🇬🇧	🇨🇳	🇪🇺	🇰🇷	🇯🇵
Adoption of technologies: Artificial intelligence	🇺🇸	🇨🇳	🇬🇧	🇰🇷	🇪🇺	🇯🇵

1 Introduction

Following the 2030 Digital Compass Communication ([4]), the Decision establishing the Digital Decade Policy Programme 2030 ([5]) aims at accelerating the digital transformation of Europe by fostering investments and interventions in key digital areas. The objective is to achieve strategic autonomy and to empower European people and businesses. In this context, the Digital Decade Policy Programme 2030 sets a series of targets to meet by 2030, while also addressing vulnerabilities and dependencies. The Digital Decade Policy Programme establishes a governance framework to foster cooperation between the European Union institutions and the Member States for the achievement of the Digital Decade objectives. The allocation of investments is key to advance the digital transformation, as is done through different EU funding instruments, such as the Recovery and Resilience Facility, but also by mobilising investments from the Member States and the private sector.

Since 2006, the Joint Research Centre (JRC)'s study "Prospective Insights in ICT R&D" (PREDICT) analyses the supply of Information and Communications Technologies (ICT) and the investments in Research and Development (R&D) in ICT in Europe, with comparison to major competitors worldwide. The PREDICT dataset and its accompanying reports provide a permanent monitoring tool of the ICT sector. Since 2006, they have served to monitor and assess the impact of related policies: the 3% R&D (Lisbon Agenda and EU2020), the Digital Agenda for Europe (Chapter 5), the Member States digital progress in the European Semester through the Digital Economy and Society Index (DESI) and its horizontal chapter 'The EU ICT Sector and its R&D Performance'. As a continuation of the work of previous years, PREDICT has expanded its scope to support the shaping and monitoring of the Digital Decade.

This report is the third of a series of three aimed at supporting the Digital Decade Policy Programme and feeding the Report on the state of Digital Decade 2023 ([6]). The first one (Torrecillas et al., 2023) develops the methodology to project the trajectories of the EU towards the 2030 Digital Decade targets ([7]). The second report (Papazoglou et al., 2023) develops and implements a methodology to map EU investments to the targets.

This report presents a benchmarking approach to compare the level of private investments in some of the Digital Decade thematic areas between the EU and other countries with advanced digital economies. To evaluate the performance of EU and non-EU countries on Digital Decade targets is not straightforward, as the Digital Decade (DD) key performance indicators (KPIs) defined and used to monitor the evolution within the EU are not measured by the countries covered in the benchmarking exercise. Indicators defined nationally may widely differ from what is measured by the Digital Decade KPIs. Consequently, this study proposes a comparison based on an objective keyword-based approach to identify firms active in the thematic areas covered by the Digital Decade targets. While this will results in comparable figures of investment, the digital areas covered depart from the well-defined Digital Decade KPIs. Therefore, to avoid confusion, the results are presented as an international investment analysis in the thematic areas associated to the Digital Decade targets.

Using data from Bureau van Dijk (BvD) Orbis dataset and Crunchbase; complementing it with the JRC Twin Transition Dataset, and Statista's Semiconductor Equipment and Materials International (SEMI); and using the JRC Digital Techno-Economic ecoSystem (DGTES) in order to identify firms in the digital ecosystem, we calculate several indicators to benchmark the EU position with respect to other relevant countries in eight Digital Decade thematic areas for which we could identify firms in DGTES: 5G, gigabit, quantum computing, semiconductors, edge computing and adoption of cloud, big data and artificial intelligence. Among them, we calculate the amount needed for the EU to have the same level of investments as a share of GDP of the benchmarked country or the ratio of investments as a share of country GDP. Given the characteristics of the country comparison method proposed, the analysis does not answer the question on how much additional investment is needed to reach a Digital Decade target, as closing the gap does not guarantee reaching it, nor reaching the level of performance of the benchmark country. Therefore, results should be interpreted as indicative of the positioning of the EU vis-à-vis other countries of interest. When possible, the results are accompanied with information about the

[4] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and The Committee of the Regions 2030 Digital Compass: the European way for the Digital Decade (COM/2021/118 final) https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021DC0118

[5] Decision (EU) 2022/2481 of the European Parliament and of the Council of 14 December 2022 establishing the Digital Decade Policy Programme 2030 (OJ L 323, 19.12.2022, pp. 4–26). http://data.europa.eu/eli/dec/2022/2481/oj

[6] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Report on the state of the Digital Decade 2023 (COM(2023) 570)

[7] Communication from the Commission establishing the Union-level projected trajectories for the digital targets, C(2023) 7500

performance level of the benchmark country, although these may be not fully comparable. This report provides a useful comparative framework to contextualise an assessment of the EU's digital investment needs.

We present below the main characteristics of the approach followed in the benchmarking of investment levels.

Benchmark countries: the approach uses countries of reference to calculate the investment disparities between the EU and these countries. If investment levels of a region are below those of other that is performing better, it can be concluded that there is an investment gap; and its size is the difference in investments between these two regions. We apply the methodology to the following benchmark countries: the United States, China, the United Kingdom, South Korea, and Japan.

Pros and cons of the method: the use of the country comparison method presents several advantages over other methods. First, its simplicity makes it appropriate for settings where limited information is available. This is the case when calculating investment needs in such specialised industries, where data availability is limited, as is the case of the Digital Decade study setting. Second, this method has been widely tested and used in the existing literature on investment gaps, like for instance by the European Bank for Reconstruction and Development (EBRD) to calculate investment gaps for EBRD regions (EBRD, 2016) ([8]). Finally, this method avoids the use of demanding assumptions. For example, to estimate the actual investments needed to reach a certain value in an indicator, we would need to make assumptions on the elasticity of the indicator evolution on an additional euro invested, i.e., how much an additional euro invested would raise the value of such indicator. This approach would require robust studies based on econometric techniques and detailed microdata, which do not exist for the Digital Decade targets. Therefore, we avoid relying on arbitrary assumptions on how much an additional euro invested increases the value of an indicator. The methodology we propose compares actual investment levels in two regions, thus giving a reliable picture of the international landscape.

Conceptual limitation: the country comparison method offers a direct and practical way to estimate a benchmark in absence of quality data. However, a theoretical limitation is that increasing the level of investment to that of a country of reference would not necessarily mean that this is the investment level needed to reach the Digital Decade target, or even to reach the performance of the country of reference. Additional assumptions would be needed to circumvent this issue. Hence, even if reaching the level of investments of the world leader in a certain thematic area does not guarantee that the EU reaches the associated Digital Decade target, the estimations provide a useful overview of the international investment landscape in digital technologies.

Combination of approaches / triangulation: there is not a single solution suitable for all targets, so the study uses tailor made approaches with a common methodological base. The concept of triangulation is the idea behind using several data sources, reflecting different perspectives on investment. For each Digital Decade thematic area we propose to apply different conceptual approaches to investment to reach an understanding of the overall investment differences with other countries. But, as we would be measuring different concepts, a quantitative triangulation (understood as an average or other type of summarisation) is not feasible.

Time frame: The main time reference of the study is 2009-2021 (other time periods are explicitly reported when used). The estimations are provided as an aggregate of investments by each country in the whole period.

[8] Comparing EBRD countries with non-EBRD groups of countries with similar characteristics, they find that investment gaps are of similar size than using the theoretical benchmark method, of a magnitude of about 1.5% of the region's GDP. In the Staff Working Document *Identifying Europe's recovery needs*, the European Commission (2020) estimates investment gaps for digital transformation by calculating the difference between what China-US and the EU invest, including both public and private investment, concluding that biggest investment gaps appear in connectivity and network infrastructure. Investment gaps in AI and Blockchain present the second largest gap, of about €23 bn. Other reports using this method also distinguish between equity and debt investment. This is the approach taken by Verbeek and Lundgvist (2021). They use venture capital (VC) investment data for the EU and compare it to the US and China to calculate investment gaps in equity and debt. Using Crunchbase and Preqin data for the number of AI and blockchain firms and investments respectively, they estimate an investment gap of up to €10 bn, ranging from €4-8 bn in AI and €1-2 bn in blockchain technology. In a study on future agricultural needs, the EIB also estimates financing gaps in agricultural SMEs. They compare debt and equity investments levels between the US and the EU by venture capital funds, private equity funds and "similar investors" in the agro-food sector in 2017. They estimate a gross difference of €2.8 bn of investment gap. When this result is adjusted by size of the economy, in the US there is about €11-13 bn of additional equity invested. Finally, they use results from McCahery et al. (2015) to estimate the debt financing gap in the agro sector. As said, McCahery et al. (2015) find that there exists a 3.7% of GDP debt funding gap in European SMEs. Correcting this result for the agro-food share sector, they estimate a €21-25 bn per annum investment gap in debt financing. Finally, the EIB report "Restoring EU Competitiveness" (2016) provides figures for investment gaps calculated as the difference between actual and "required" investments. Required investments are calculated as US investments in most cases. In other cases, required investments are just EU Digital Agenda investment targets. Finally, they show investment gap numbers for a variety of targets. Among them, it could be highlighted that there is an investment gap in R&D of € 130 bn, where €60 bn are attributed to the public sector.

2 Methodology and data sources for the estimation

2.1 Types of investments and data sources

The application of the country comparison method makes use of several types of investments from different data sources. The data used has to be available and comparable for the countries involved. As overall there are not such comparable sources for public investments, we limit the comparison to investments made by private entities ([9]). Due to the nature of the type of investments considered, the methodology is implemented for the following Digital Decade thematic areas:

- Digital infrastructure: Gigabit, 5G, semiconductors, edge computing, quantum
- Digitalisation of businesses: adoption of technologies (cloud computing, big data, AI)

The methodology considers two main types of investment:

- Venture capital: a form of private equity financing that investors generally provide to start-up companies and/or businesses that have growth potential, such as technologically dynamic and early-growth stage entrepreneurial venues. It covers both early and late stages of venture capital investment rounds, hence targeting companies in different maturity level. Data source: Crunchbase.

- Fixed assets growth (as proxy of fixed capital formation): fixed assets are long-term tangible properties or equipment that a firm uses to generate revenue (purchases for long-term use, such as land, buildings, and equipment), plus intangible assets (non-physical assets such as intellectual property, computer software, licenses, trademarks…). Growth of fixed assets in a time period represents investments made by firms in their own production processes. In the case of digital firms active in a specific thematic area, we can consider them as investments that support the development of the technological domain. Data source: Orbis BvD.

Additionally, we complement the investments figures for some thematic areas with alternative data sources:

- Gross fixed capital formation (GFCF) in telecommunication equipment: according to Eurostat, GFCF is defined as resident producers' investments, deducting disposals, in fixed assets during a given period. Fixed assets are tangible or intangible assets produced as outputs from production processes that are used repeatedly, or continuously, for more than one year ([10]). Concretely, we use GFCF in telecommunication equipment to benchmark EU's investments with respect to other countries in the area of connectivity. To narrow down the investments made by firms active in broadband and 5G coverage, we use GFCF in telecommunication equipment only by the ICT sector (defined as section *J Information and communication* (division 58 to 63) of the NACE ([11]) Rev.2). Data are available for the period 2014-2020. Data source: JRC Twin transition Dataset (López-Cobo et al., 2023), based on official statistics and other complementary sources.

- Semiconductor equipment spending: semiconductor equipment is defined as any manufacturing equipment used for the fabrication, testing and fixing of semiconductors. Data covers the period 2008-2021. Data source: Statista.

When referring to the adoption of technologies (cloud computing, big data, AI) thematic areas, we also consider the operating revenue (turnover) as an indirect proxy of the level of investment as described below:

- Operating revenue (turnover): it is defined as the revenue generated by the primary activities of the firm. We consider that the level of revenues of firms supplying cloud computing, big data or AI technologies and related services reflects the adoption of these technologies by their clients, and therefore, the level of investment of technology adopters. The main assumption here is that all revenues come only from the adoption of technologies by their clients. To limit the implications of the assumption as much as possible, the selection of firms is constrained to firms whose main activity is the provision of these technologies and related services (i.e., firms whose activity description refer to these advanced technologies). Even if there is no direct link between revenues of service providers and the adoption of technologies, revenues could be considered an indirect proxy assuming that the firms'

[9] Although private entities are owned by private agents, it is true that they can receive public funding and use it to invest. Since we cannot differentiate the origin of the money invested, we classify all investments made by private entities as private investments.

[10] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Gross_fixed_capital_formation_(GFCF)

[11] Statistical classification of economic activities in the European Community.

revenues developing and supplying technologies could be translated into higher adoption of these technologies from their clients. Nevertheless, this approach presents important challenges to take into consideration. First, there is not any information on the origin of the revenues, meaning that it is not possible to identify whether they come from EU firms or not, as a firm operating in the EU could provide services outside the EU and vice versa. Moreover, a large increase in the revenues of a firm can either reflect a few clients buying expensive services (few firms adopting), or many clients buying off-the-shelf cheap services or products (many firms adopting). Therefore, we consider revenue data a proxy with non-negligible constraints, but in absence of a better alternative, we include it in the analysis. Data source: Orbis BvD.

To put the methodology in place, we use the JRC analytical approach DGTES to identify firms active in each thematic area and extract the investment data. As DGTES connects different data sources, including Orbis and Crunchbase, after identifying the firms we extract the relevant information from the linked database. Firms are detected by DGTES using a keyword-based approach on multiple microdata sources covering different types of digital activities (business, innovation and research activities: patents, firm activity, firm funding, publications, EU projects…). The keyword-based approach allows identifying actors that leave a digital trace in microdata and text repositories (the digital ecosystem is mapped using a list of ~800 keywords). This way, we do not rely on how digital technologies are defined or ruled in each country, but on an objective process to detect digital firms specialized in each technology or digital area. In particular, firms are identified as related to a technology when keywords associated to the technology are used in the description of the firms activities in the repositories (Orbis and Crunchbase in this case). This results in a worldwide comparable database.

A short description of the main data sources used follows.

DGTES

DGTES is the application of the Techno-Economic ecoSystem (TES) analytical approach designed by the Digital Economy Unit of the JRC to map and explore complex techno-economic ecosystems of dynamic and emerging technologies. TES has been already applied to the segment of photonics, earth observation, and AI. DGTES allows mapping the digital ecosystem through the detection of digital activities and players that engage in the ecosystem and leave a digital footprint, and it also identifies the interlinkages and relations resulting from shared activities, locations and technological fields. With a keyword-based query approach, DGTES identifies, from various repositories of textual documents digital activities and, digital players (including firms) relevant for the definition of the digital ecosystem. The digital ecosystem is then systematised around 15 digital areas corresponding to "informal, internally-coherent, techno-economic categories used to cluster digital technologies that relate to the same technological domain (e.g. "Artificial Intelligence") or to the same type of application or final use (e.g. eHealth solutions). The 15 digital areas in DGTES are compliant with the two criteria of being forward-looking and policy-relevant. Each digital area is associated to a unique list of keywords" ([12]) (Calza et al., 2022). In the most updated analysis of the digital ecosystem, DGTES maps over a million digital activities and 625,000 digital players worldwide (Calza et al. 2023).

Orbis

The Orbis database is compiled by Bureau van Dijk (a Moody's Analytics Company) and offers comprehensive information on the balance sheets of companies operating in the private sector. It has wide geographical coverage: in total, it has information on close to 400 million companies and entities across the globe, which enables comparisons between the US and European firms. For 41 million of firms, the database includes detailed financial information. This includes data on the firms' balance sheets and income statements, which are available at an annual frequency. Bureau van Dijk collects information directly from multiple sources including the company (annual reports, web sites) and official regulatory bodies (when they are in charge of collecting this type of information). Therefore, available income information on balance sheets depends on the legal requirements of financial statements and size of the company. Generally, the most complete information is available for publicly listed companies.

[12] The 15 digital areas are: *"3D Printing, Additive manufacturing"; "Data, Dynamic Data"; "Artificial Intelligence" "eBusiness, e-Commerce"; "Internet of Things, AIDC"; "Blockchain, Distributed Ledger"; "Autonomous Systems, Robotics"; "Quantum Technologies"; "Extended Reality, Virtual Reality, Augmented reality"; "Verticals"; "Cybersecurity, Safety & Security, Digital Identity"; "Electronics, Semiconductors, Power Electronics"; "5G and beyond, Autonomous Networks, Communications, Telecommunications and connectivity"; "Advanced Computing, High Performance Computing (HPC), edge computing"; "Infrastructure, Cloud Computing, Digital Platform, IaaS, SaaS, PaaS, on-line platforms, Social "Networks, Internet".*

The relevant variables to estimate investments from the Orbis database are fixed assets (tangible and intangible), we use investment data measured as the fixed asset annual growth of a given firm. For the adoption of technologies, we also use the level of revenues of firms supplying cloud computing, big data or AI technologies and related services to proxy investments for the adoption of these technologies by their clients.

Crunchbase

Crunchbase is a comparatively newer firm database created in 2007, which has quickly reached a lot of popularity within the scientific community. The data are sourced through three main channels: a large investor network (4,000 global investment firms that submit monthly portfolio updates), community contributors and news tracking. Compared to Orbis, Crunchbase has a higher coverage of young and small start-ups. Unlike Orbis, it does not provide financial statement data, but gives some basic company information (location, number of employees, founding date) and collects detailed funding data. It has very good coverage of the US and the EU, and better coverage of Asia than other venture capital sources (e.g. Dealroom). However, coverage of Asian countries in the Crunchbase-DGTES merged dataset is still worse than that of Western countries, which explains the relatively worse performance of China, South Korea and Japan; and suggests that VC investments in those countries are likely to be underestimated.

Table 3 summarises the approaches and sources used for each Digital Decade thematic area.

Table 3. Summary of approaches and sources applied

Digital Decade thematic area	Data source	Type of investment	Identification of firms (when applicable)
Connectivity (gigabit & 5G)	PREDICT	GFCF on telecommunication equipment in the ICT sector (*)	-
	Orbis	Fixed assets growth	DGTES
	Crunchbase	Venture capital (seeds and series)	DGTES
Semiconductors	Orbis	Fixed assets growth	DGTES
	Crunchbase	Venture capital (seeds and series)	DGTES
	Statista	Semiconductor equipment spending	-
Edge computing	Orbis	Fixed assets growth	DGTES
	Crunchbase	Venture capital (seeds and series)	-
Quantum computing	Orbis	Fixed assets growth	DGTES
	Crunchbase	Venture capital (seeds and series)	DGTES
AI/Cloud/Big Data	Orbis	Fixed assets growth	DGTES
	Orbis	Firm revenue	DGTES
	Crunchbase	Venture capital (seeds and series)	DGTES

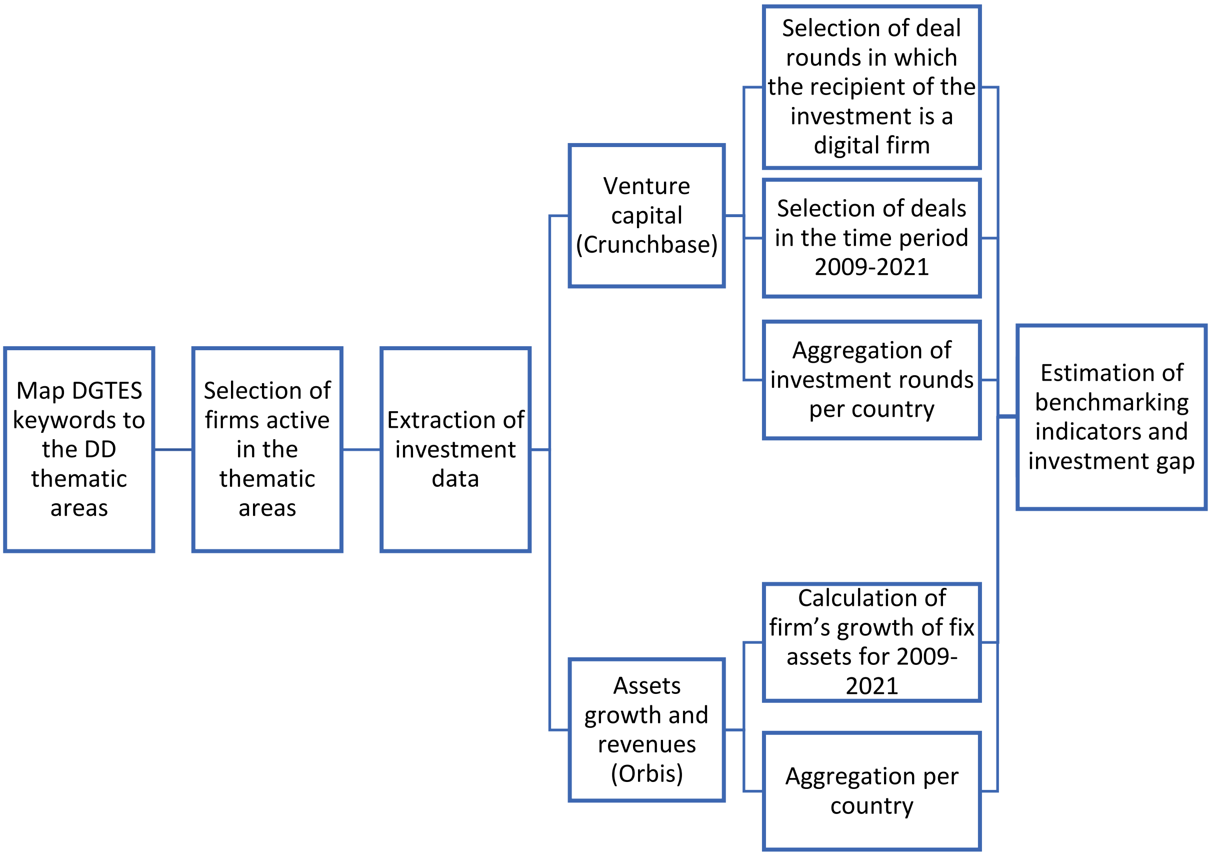
(*) ICT sector defined as section *J Information and communication* (divisions 58 to 63) of the NACE Rev.2.

2.2 Outline of the methodology

As outlined in Figure 1, for the main two types of investment we follow these steps:

1. Map the DGTES keywords to the Digital Decade thematic areas
2. Selection of firms active in the thematic areas using the related keywords from step 1
3. Extraction of investment data from Crunchbase and Orbis
    a. For venture capital (Crunchbase):
        i. Selection of deal rounds in which the recipient of the investment is a digital firm (i.e., a firm in DGTES)
        ii. Selection of deals in the time period 2009-2021 ([13])
        iii. Aggregation of investment rounds per country (the country refers to location of the firm)
    b. For assets growth and revenues (Orbis):
        i. Calculation of firm's growth of fix assets between start and end of the time period considered: 2009-2021
        ii. Aggregation per country (the country refers to location of the firm)
4. Estimation of benchmarking indicators and of the investment gap.

Figure 1. Outline of the methodology (for the main two data sources)



[13] While the period 2009-2021 has been considered for fixed assets growth and venture capital data, we use the available time periods for other types of investments and data sources when evaluating additional indicators, as specified in their respective descriptions.

2.3 Indicators

We compare the level of investments of the EU and the benchmark countries for the considered period (2009-2021), and calculate the difference between investments in the EU and the level of investments of the benchmark country. In order to account for the size of the compared countries, the comparison is made based on the level of investments relative to the country's GDP. To do that, we compute four indicators:

- Total amount (TOT): absolute value of total private investment of a country (in million euros). By investment, we refer to the different types of private investment considered: venture capital, assets growth, GFCF in telecommunication equipment, semiconductor equipment spending. For venture capital, assets growth and revenues, the figures on investment come from a sample of firms for which financial or funding data are available; therefore, this indicator should not be considered as the actual total private investment of the country in those cases. Its interest lies in contrasting the figure with other countries as a share of their GDP (indicator (ii)). We also consider the supplying firms' operating revenue (turnover) as an indirect proxy of the level of investment of firms adopting technologies (cloud computing, big data, AI) thematic areas.
- Amount as a share of GDP (TOT/GDP): the total investments (or revenues) are put in relation to the size of the economy.
- Ratio of amount as share of GDP ($TOT/GDP_{benchmark\_country}$)/($TOT/GDP_{EU}$): ratio between the level of investment (or revenues) of the benchmark country as a share of its GDP and the level of investment of the EU as a share of its GDP. This ratio answers the question: how many times the benchmark country is investing (as a share of GDP) in comparison to the EU. E.g., if the ratio is 2, then the benchmark country is investing twice as much as the EU (as share of their GDP).
- Gap ($GAP_{shareGDP}$): the amount in million euros needed for the EU to reach the level of investment (or revenues) as a share of GDP of the benchmark country.

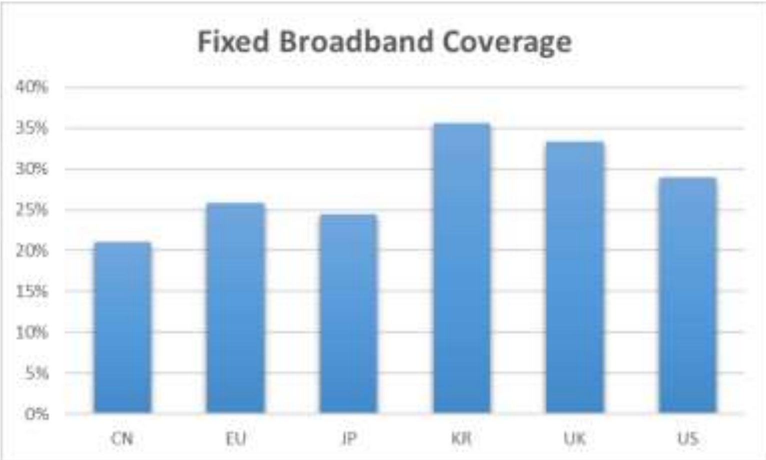
3 Investment benchmark results

This section presents the results of the estimation. The country comparison method is applied to compare the investment level between the EU and other countries of interest. Table 4 to present the values of the four indicators defined in section 2.3, for all benchmark countries and from the sources used in each thematic area. Figure 3 to show the indicator *Ratio of investment as share of GDP* for all benchmark countries and investment sources used. When data are available, the performance level of each country in the related KPI is used to contextualise the results, although it is available in very few cases.

3.1 Connectivity: Gigabit

The i-DESI indicator “1a1 Fixed Broadband Coverage” provides a proxy indicator for the Digital Decade Gigabit KPI. It is defined as “% of households covered by broadband: xDSL, cable (basic and NGA), FTTP or WiMax networks” (Tech4i2, 2020). The Digital Decade KPI for gigabit is defined as the percentage of households covered by any fixed Very High Capacity Network (VHCN) ([14]). Figure 2 shows that the EU is lagging behind South Korea, the UK and the US, but ahead of China and Japan in fixed broadband coverage.

Figure 2. Percentage of households covered by broadband: xDSL, cable (basic and NGA), FTTP or WiMax networks (2018)



Source: Authors elaboration based on i-DESI data

According to Table 4, the sample of EU firms active in gigabit during the period from 2009 to 2021 have made significant investments of €61.66 bn in cumulative fixed assets growth and have received €2 bn in funding from venture capital (VC). Another type of investment that we can consider for connectivity is Gross fixed capital formation (GFCF) in telecommunications equipment in the ICT sector for the period 2014-2020, an indicator of investment in physical assets. The EU ICT sector as a whole has invested €277.1 bn in GFCF in telecommunication equipment.

To better gauge the scale of these investments in relation to the size of each country's economy, Table 4 also shows that the cumulative fixed assets growth amounts to 0.0347% of the EU's GDP. This figure represents investments made by firms in their own production processes. When compared to other countries, only the US has a higher share to GDP of assets growth (0.1002%, which is 2.88 times higher than that of the EU). This could be attributed to the US's strategy towards the enhancement of broadband and 5G networks to meet escalating demand, as suggested in a report by the US’s Federal Communications Commission (Federal Communications Commission, 2023). For the EU to have reached this same level of growth assets as a share of GDP in 2009-2021 (0.1002%), the EU would have needed to increase the assets growth in the period 2009-2021 by additional €116 bn, i.e., almost double the amount actually invested. China and the UK trail with investments of €13.29 bn and €9.78 bn, respectively, and in terms of share to GDP they are 0.26 and 0.75 times that of the EU.

[14] The technologies considered as VHCN are fibre to the premises (FTTP) and DOCSIS (Data Over Cable Service Interface Specification.) 3.1.

Table 4. Gigabit - Investment indicators

Indicator	Country	Investment type		
		Assets growth	Venture capital	GFCF on telecommunication equipment by ICT sector (*) (2014-2020)
Amount (m €)	EU	61,663	2,082	277,114
Amount (m €)	United States	236,423	1,656	589,975
Amount (m €)	China	13,295	46	440,417
Amount (m €)	United Kingdom	9,785	3,315	25,822
Amount (m €)	South Korea	2,103	0	n.a.
Amount (m €)	Japan	-83	30	n.a.
Amount as share of GDP	EU	0.0347%	0.0014%	0.3431%
Amount as share of GDP	United States	0.1002%	0.0009%	0.6239%
Amount as share of GDP	China	0.0091%	0.0000%	0.4466%
Amount as share of GDP	United Kingdom	0.0261%	0.0108%	0.2006%
Amount as share of GDP	South Korea	0.0111%	0.0000%	n.a.
Amount as share of GDP	Japan	-0.0001%	0.0001%	n.a.
Ratio of amount as share of GDP	United States	2.88	0.60	1.82
Ratio of amount as share of GDP	China	0.26	0.03	1.30
Ratio of amount as share of GDP	United Kingdom	0.75	7.53	0.58
Ratio of amount as share of GDP	South Korea	0.32	0.00	n.a.
Ratio of amount as share of GDP	Japan	0.00	0.04	n.a.
Gap (m €)	United States	116,135	-839	226,786
Gap (m €)	China	-45,426	-2,026	83,619
Gap (m €)	United Kingdom	-15,333	13,597	-115,040
Gap (m €)	South Korea	-42,001	-2,081	n.a.
Gap (m €)	Japan	-61,921	-1,990	n.a.

(*) ICT sector defined as section *J Information and communication* (divisions 58 to 63) of the NACE Rev.2.

Figure 3. Gigabit: Ratio of investment as share of GDP

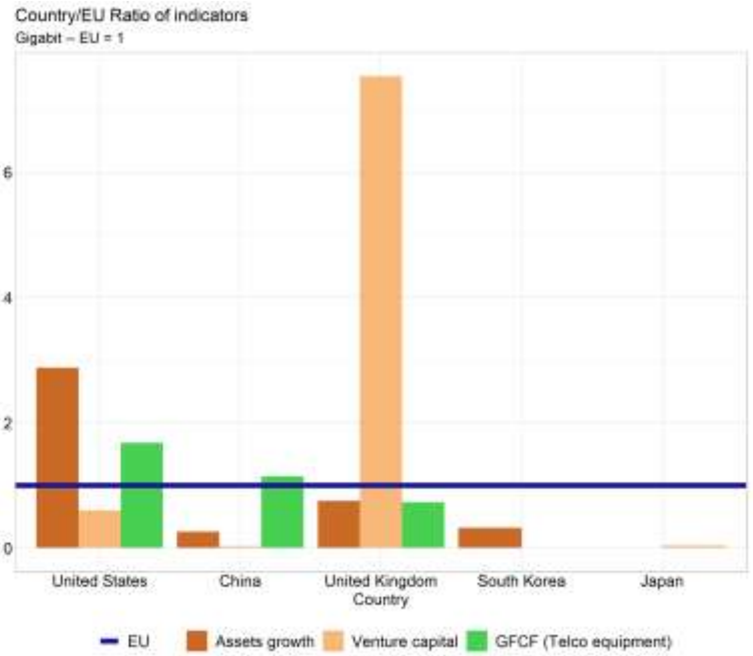
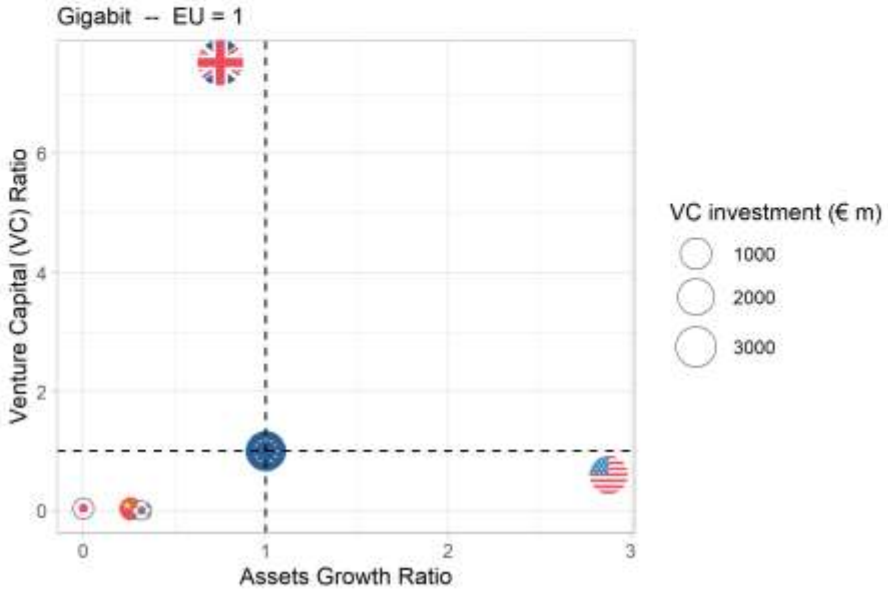


Figure 4. Gigabit: EU relative position compared with benchmarking countries: Country/EU ratio of venture capital (as share of GDP) vs Country/EU ratio of assets growth (as share of GDP)



Note: The figure presents the relative position of the EU compared with the benchmarking countries considering both fixed assets growth ratio (x-axis) and venture capital (VC) ratio (y-axis). The EU is located at the intersection of the vertical and horizontal dashed line in point (1,1). The size of the points represents the total VC investments.

Focusing on the GFCF investments in telecommunication equipment, the US, once again, takes the lead by a significant margin with an investment of €590 bn in the period 2014-2020. This is slightly more than double that of the EU, which has a GFCF of €277.1 bn. However, China is not that far behind the US, with a substantial investment of €440.4 bn, aligning with its infrastructure expansion plan noted in a report by the China Academy of Information and Communications Technology. The UK, however, lags significantly behind with just €25.8 bn, suggesting a potential shift towards innovative start-ups rather than infrastructure and equipment. For the EU to have reached the level of the US in the period 2014-2020, the investments on telecommunication equipment by the ICT sector should have almost doubled, with additional €227 bn on top of the actually invested €277 bn.

Shifting the focus to VC investments EU firms were able to gather €2.1 bn between 2009 and 2021, outpacing US firms in the sector (€1.65 bn). Surprisingly, the UK stands out with the highest VC investment among the listed countries, amounting to €3.3 bn. This confirms a TechNation report revealing that the UK startups raised more than $40 bn across all sectors in 2021 (The UK tech ecosystem is currently valued at just over $1 tn) (TechNation, 2023). In stark contrast, China and South Korea depict minimal VC investments, which can be partially explained by the lower coverage of Asian countries by Crunchbase, as discussed in section 2.1. EU firms would have reached the level of the UK if they had gathered VC funding by additional €13.6 bn, a value almost 7 times higher than the VC funding collected by EU firms in the same period.

In sum, the investment indicators presented show different perspectives of investments made in and by firms operating in the broadband sector in the EU, in comparison with other countries with advanced digital economies. Overall, they show that the EU is in a middle position and would have needed to make higher investments to have ended 2021 in the same situation as e.g. US or China. The amounts needed to reach the level of Gross Fixed Capital Formation of other advanced economies lie between €83 bn (China) and €227 bn (US).

Figure 3 shows the indicator *Ratio of investment as share of GDP*, calculated as the ratio between the level of investment of the benchmark country as a share of its GDP and the level of investment of the EU as a share of its GDP. This ratio answers the question: how much the benchmark country is investing (as a share of GDP) when compared to the EU. E.g., if the ratio is 2, then the benchmark country is investing twice as much as the EU (as share of their GDP). Figure 3 shows, for instance, that investments by the US are 2.88 and 1.82 times higher than investments by the EU in fix assets and telecommunication equipment by the ICT sector respectively.

Furthermore, Figure 4. presents in a more intuitive way the relative position of the EU compared with the benchmarking countries considering only two investment measures: fixed assets growth ratio (x-axis) and VC ratio (y-axis). The EU is located at the intersection of the vertical and horizontal dashed line in point (1,1). The size of the points represents the total VC investments. In both figures we can observe that the EU is lagging behind the UK in terms of VC ratio while trailing only the US in terms of fixed assets growth ratio.

3.2 Connectivity: 5G

Table 5 provides a comprehensive overview of the investment landscape in 5G across the different benchmark countries. It presents data on three types of investments: assets growth, venture capital, and GFCF in telecommunications equipment by the ICT sector.

Table 5. 5G: Investment indicators

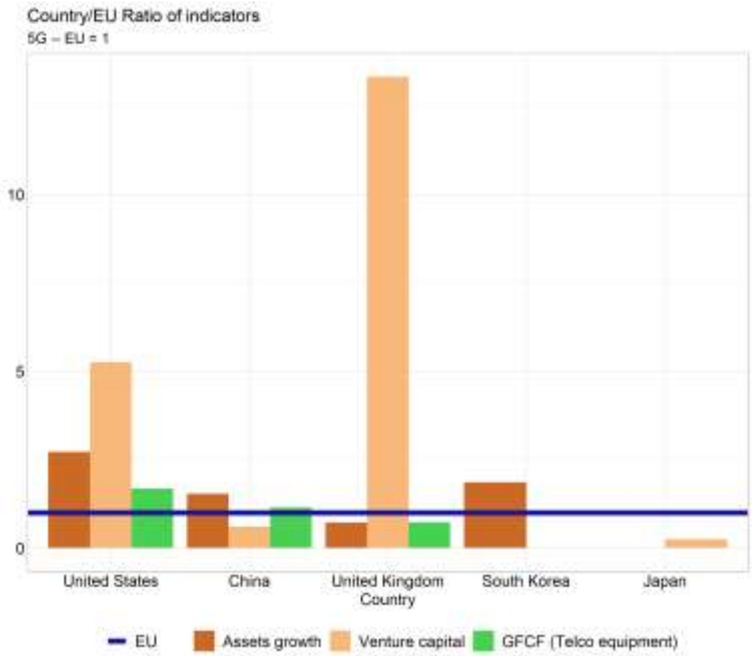
Indicator	Country	Investment type		
		Assets growth	Venture capital	GFCF on telecommunication equipment by ICT sector (*) (2014-2020)
Amount (m €)	EU	58,673	387	277,114
Amount (m €)	United States	212,250	2,706	589,975
Amount (m €)	China	73,982	193	440,417
Amount (m €)	United Kingdom	8,952	1,088	25,822
Amount (m €)	South Korea	11,662	0	-
Amount (m €)	Japan	-6,440	31	-
Amount as share of GDP	EU	0.0331%	0.0003%	0.3431%
Amount as share of GDP	United States	0.0899%	0.0014%	0.6239%
Amount as share of GDP	China	0.0509%	0.0002%	0.4466%
Amount as share of GDP	United Kingdom	0.0239%	0.0035%	0.2006%
Amount as share of GDP	South Korea	0.0614%	0.0000%	-
Amount as share of GDP	Japan	-0.0113%	0.0001%	-
Ratio of amount as share of GDP	United States	2.72	5.25	1.82
Ratio of amount as share of GDP	China	1.54	0.60	1.30
Ratio of amount as share of GDP	United Kingdom	0.72	13.32	0.58
Ratio of amount as share of GDP	South Korea	1.86	0.00	-
Ratio of amount as share of GDP	Japan	-0.34	0.25	-
Gap (m €)	United States	100,946	1,645	226,786
Gap (m €)	China	31,685	-154	83,619
Gap (m €)	United Kingdom	-16,286	4,762	-115,040
Gap (m €)	South Korea	50,338	-385	-
Gap (m €)	Japan	-78,737	-290	-

(*) ICT sector defined as section *J Information and communication* (divisions 58 to 63) of the NACE Rev.2.

EU firms in the sample have invested €58.6 bn in fixed assets growth, and have raised €387 funding from venture capital. The EU ICT sector has invested €277.1 bn in GFCF in telecommunication equipment. To gain a deeper understanding of the investment landscape, it is convenient to consider the size of each country's economy. Therefore, Table 5 also presents investment as a share of GDP, which provides a more accurate measure of investment intensity relative to the overall economy, and allows a better international benchmarking. For the EU, the investment in assets growth represents 0.033% of its GDP. In comparison, the US allocates a larger share of its GDP, with investments in assets growth amounting to 0.0899%. This indicates that US firms are devoting a higher proportion of its economic resources to 5G investments compared to the EU. A key driver behind the US's commitment to 5G deployment is its strategic focus on enhancing broadband and 5G networks to meet escalating demand. The US's Federal Communications Commission has implemented the 5G FAST Plan, which includes measures to free up spectrum, promote wireless infrastructure, and modernize regulations ([15]).

Similarly, the investment as a share of GDP for VC funding and GFCF on telecommunication equipment follows a similar pattern. The US exhibits a higher investment intensity in VC and GFCF compared to the EU. This underscores the US's dedication to fostering innovation and infrastructure development in the 5G sector. Turning to other countries, Chinese firms have invested €73.9 bn in assets growth, and have received €193 from VC, and the Chinese economy has invested €440 bn in telecommunication equipment. The investment as a share of GDP for assets growth is 0.0509%, indicating a moderate investment intensity relative to its economy. China's focus on economic output and technological leadership has driven its substantial investment in 5G infrastructure. Reports from the China Academy of Information and Communications Technology (CAICT) highlight China's ambitions for economic growth and technological advancement in the 5G sector ([16]). In addition, the CAICT estimates that the total investment in 5G infrastructure projects could reach ¥1.2 tn (over $170 bn) by 2025 ([17]).

Figure 5. 5G: Ratio of investment as share of GDP



In the case of the UK, the investment in assets growth amounts to €8.9 bn, with VC funding totalling €1.1 bn and GFCF investments in telecommunication equipment reaching €25.8 bn. The investment as a share of GDP for assets growth is 0.0239%, suggesting a comparatively lower investment intensity than the EU and other countries. However, it is worth noting that the UK's focus on 5G lies in nurturing early-stage companies and fostering innovation ([18]).

Finally, in order for the EU to have reached during 2009-2021 the same level of US's growth assets as a share of GDP, the EU would have needed to increase the assets growth by €100 bn (an increase of 172% of the actual investment of €58.6 bn). Similarly, the EU would have needed to get additional €1.6 bn from VC funding (more than four times the €387 actually received) or additional €4.8 bn to compare to the UK. An increase of €226 bn investments in telecommunication equipment would have brought the EU to the same level of investments relative to the GDP than the US.

15 Federal Communications Commission (FCC). The FCC's 5G FAST Plan. Available at: https://www.fcc.gov/document/fccs-5g-fast-plan

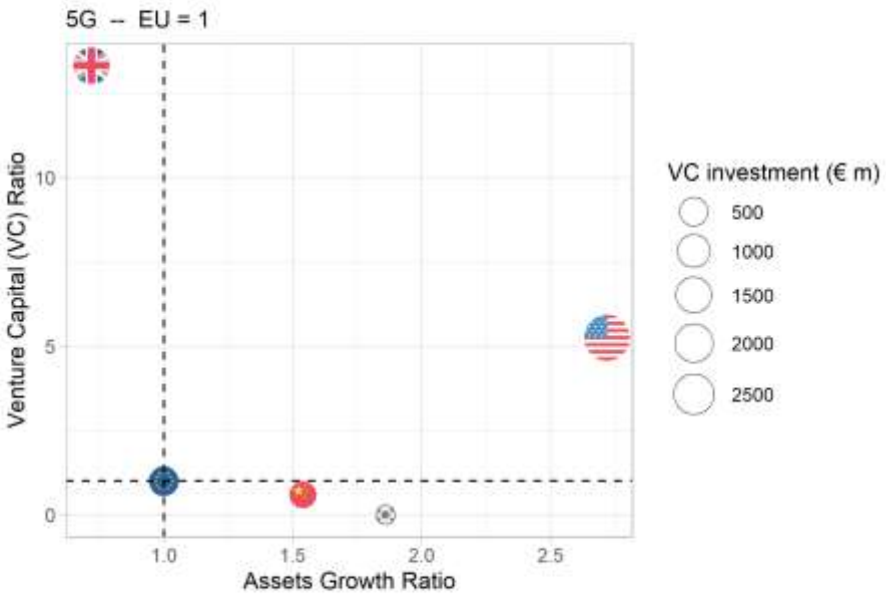
16 China Academy of Information and Communications Technology (CAICT). Made in China 2025: A New Era for China's Technological Innovation. Available at: https://english.ckgsb.edu.cn/knowledges/made-in-china-2025-a-new-era-for-chinese-manufacturing/

17 https://www.ibanet.org/article/0FE64200-BE7D-4FC4-88A9-77581323D232

18 5G Testbeds and Trials Programme. Available at: https://www.gov.uk/guidance/5g-testbeds-and-trials-programme

When looking at Figure 5 and Figure 6, we can conclude that overall, the EU lags behind in 5G private investment. The EU presents lower levels of assets growth than the US, South Korea and China, of venture capital (after the UK and the US), and GFCF in telecommunications equipment (after the US). The EU shows higher levels than China in venture capital; than the UK in assets growth and GFCF in telecommunication equipment by the ICT sector; and than Japan in all investment measures observed.

Figure 6. 5G: EU relative position compared with benchmarking countries: Country/EU ratio of venture capital (as share of GDP) vs Country/EU ratio of assets growth (as share of GDP)



Note: The figure presents the relative position of the EU compared with the benchmarking countries considering both fixed assets growth ratio (x-axis) and venture capital (VC) ratio (y-axis). The EU is located at the intersection of the vertical and horizontal dashed line in point (1,1). The size of the points represents the total VC investments.

3.3 Semiconductors

Table 6 offers an overview of the investments by firms active in semiconductors, considering the EU and benchmark countries. Three forms of investments are considered: fixed assets growth, venture capital, and semiconductor equipment spending.

The cumulative fixed assets growth of EU firms is about €86.5 bn in the period 2009-2021 --representing investments made by firms active in semiconductors in their own production processes--. Looking at benchmark countries, the EU lies in the middle. European firms invested much less than Chinese and US firms, whose cumulative fixed asset growth investment over the same period is more than 5 and 2 times larger, respectively. At the same time, the UK (with about €1 bn), South Korea and Japan present a lower amount of cumulative fixed asset growth investments than the EU (€30 bn and €2.8 bn, respectively). To get a better idea of the magnitude of these investments relative to the overall size of each country's economy, also presents the investments in fixed asset growth as share of GDP. For the EU, the investment in fixed assets growth represents 0.0487% of GDP in the period 2009-2021. Even when considering the investments in assets growth as share of GDP, China remains the leading country with 0.3352%, which is about 7 times larger than the share in the EU (Figure 7, Figure 8). Although the investment in fixed asset growth of South Korean firms is less than half of the one of EU firms, South Korea displays the second largest investments in assets growth as share of GDP (after China), with 0.1543% of GDP, which is more than 3 times that of the EU. The US follows China and South Korea (still ahead of the EU), with investments in assets growth corresponding to 0.0821% of GDP, while UK and Japan have a lower investment/GDP ratio than the EU, with 0.0031% and 0.0048%, respectively.

These figures are in line with the large investments that world's leading economies have been undertaking during the past decade in the semiconductor global market, setting a trend that is likely to continue in the future. As leading economies in the semiconductor industry, in 2020 the global market shares of the US, South

Korea and Taiwan accounted for 73% of the whole global industry, with the US leading with 47% and Korea with 20%; they were followed by China, Japan and the EU, with the EU's share being around 10% ([19]). During the past decade, these countries have been rolling out public support and financing in order to enhance their production capacity and competitiveness, with the aim of mobilizing private investment in semiconductors. For instance, since 2014 China has set up the National Integrated Circuit Industry Investment Fund, a $47 bn State-owned fund aiming at expanding and modernising the whole value chain of the integrated circuit industry, from chip design to production, packaging and testing, through investments in selected companies operating in semiconductors and related industries ([20]) (Tong and Wan 2023). Following this trend, the US approved the CHIPS and Science Act, which is going to allocate $52 bn in federal subsidies to semiconductors manufacturing and R&D until 2026. South Korea will bolster its domestic companies' private investments in R&D and manufacturing with tax incentives, for an amount estimated at $450 bn until 2030 ([21]). In the EU, the EU Chips Acts estimated an overall level of public investment and leveraged equity support for more than €43 bn up to 2030, which is expected to attract and leverage further long-term private investments of a commensurate volume ([22]).

Table 6. Semiconductors: Investment indicators

Indicator	Country	Investment type		
		Assets growth	Venture capital	Semiconductor equipment spending (*) (2008-2021)
Amount (m €)	EU	86,436	539	37,000
Amount (m €)	United States	193,727	3,230	88,920
Amount (m €)	China	487,169	2,705	114,880
Amount (m €)	United Kingdom	1,167	181	-
Amount (m €)	South Korea	29,294	30	147,320
Amount (m €)	Japan	2,759	77	78,180
Amount as share of GDP	EU	0.0487%	0.0004%	0.0194%
Amount as share of GDP	United States	0.0821%	0.0017%	0.0352%
Amount as share of GDP	China	0.3352%	0.0022%	0.0758%
Amount as share of GDP	United Kingdom	0.0031%	0.0006%	-
Amount as share of GDP	South Korea	0.1543%	0.0002%	0.7308%
Amount as share of GDP	Japan	0.0048%	0.0002%	0.1276%
Ratio of amount as share of GDP	United States	1.69	4.50	1.82
Ratio of amount as share of GDP	China	6.88	6.05	3.91
Ratio of amount as share of GDP	United Kingdom	0.06	1.59	-
Ratio of amount as share of GDP	South Korea	3.17	0.51	37.66
Ratio of amount as share of GDP	Japan	0.10	0.45	6.58
Gap (m €)	United States	59,253	1,886	30,179
Gap (m €)	China	508,568	2,721	107,529
Gap (m €)	United Kingdom	-80,912	319	-
Gap (m €)	South Korea	187,388	-262	1,356,441
Gap (m €)	Japan	-77,841	-299	206,324

(*) EU data refers to Europe

Another type of investment displayed in Table 6 is venture capital. This shows a similar pattern than investment fixed asset growth in terms of the EU's relative position with respect to the benchmark countries. The sample of European firms active in semiconductors captured by the study received €539 of venture capital financing

19 Digital Economy and Society Index (DESI) 2022. Available at: https://digital-strategy.ec.europa.eu/en/library/digital-economy-and-society-index-desi-2022

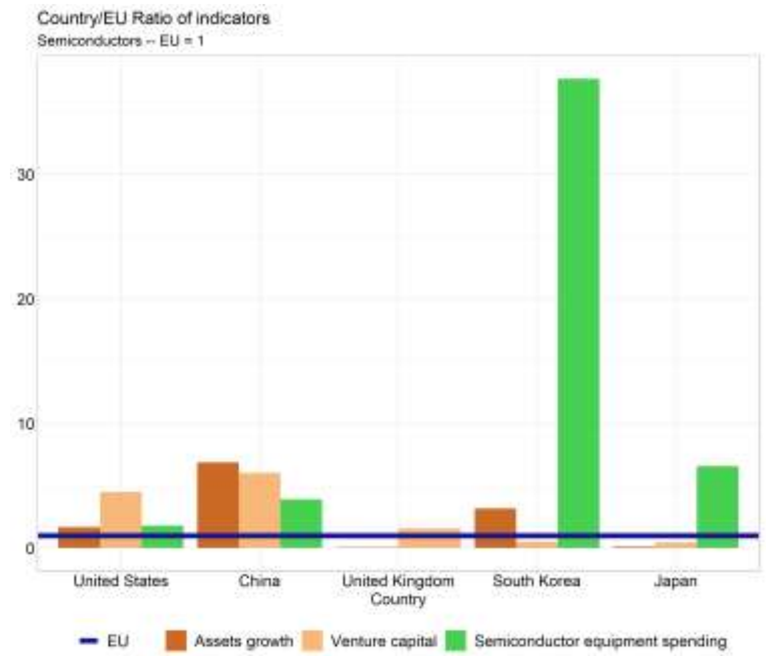
20 Financial Times, 24 March 2023: https://www.ft.com/content/ffb81a37-5239-4d5b-80b6-2b318084b460

21 Digital Economy and Society Index (DESI) 2022. Available at: https://digital-strategy.ec.europa.eu/en/library/digital-economy-and-society-index-desi-2022

22 Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2022). A Chips Act for Europe, COM(2022) 45 final

in the period 2009-2021. US firms are significantly ahead of the EU in terms of VC investments, with €3.2 bn (about 6 times that of the EU, as shown also in Figure 7 and Figure 8), followed closely by Chinese firms with €2.7 bn (about 5 times that of the EU). At the same time, the EU lies ahead of the UK, South Korea and Japan in terms of venture capital funding received by firms active in semiconductors. The lower amounts invested through VC with respect to fixed asset growth should not surprise, as the semiconductor industry tends to be less attractive for investors than other sectors because of high capital intensity, high risks, complex technical projects and longer times for return on investment ([23]). However, the sample of firms captured by the study only covers a part of the global VC funding, as according to several sources (Hess et al., 2023) ([24, 25]), global VC funding for semiconductor startups reached very high levels in the last years, raising billions (between $8 bn and 14 bn depending on the source) every year since 2020. These numbers are, for one year alone, larger than our VC investment results for the whole 2009-2021 period, so they should be taken with extra caution. The share of GDP for venture capital provides a slightly different perspective of the position of the EU with respect to benchmark countries. In the EU, VC investment received by firms active in semiconductor represent the 0.0004% of GDP in the period 2009-2021. China and the US are –once again- leading in terms of share of GDP, with 0.0022% and 0.0017%, respectively. These shares are about 6 and 4.5 times the share of the EU. This time the UK follows China and the US in terms of share of GDP corresponding to VC investments (0.0006%, 1.6. times the share of the EU). This time, not only Japan, but also South Korea has a smaller share than the EU (0.0002%). This suggests the existence of a relatively less developed VC market in the latter Asian countries, although this form of financing is becoming more important ([26]).

Figure 7. Semiconductors: Ratio of investment as share of GDP



The third type of investment, semiconductor equipment spending, defined as any manufacturing equipment used for the fabrication, testing and fixing of semiconductors, returns a rather different pattern. With €37 bn in the period 2009-2021, the EU is the country with the lowest amount invested in semiconductor equipment. South Korea exhibits the largest investment in semiconductor equipment spending (€147 bn), followed rather closely by China (€114,880 bn), the US (€89 billon), and Japan (€78,180 bn). In terms of share of GDP, South Korea is confirmed as the country with the highest investment intensity relative to its economy (0.7308%), followed by Japan (0.1276%), China (0.0758%) and the US (0.0352%), while the EU lags behind with 0.0194%.

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23 Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2022). A Chips Act for Europe, COM(2022) 45 final

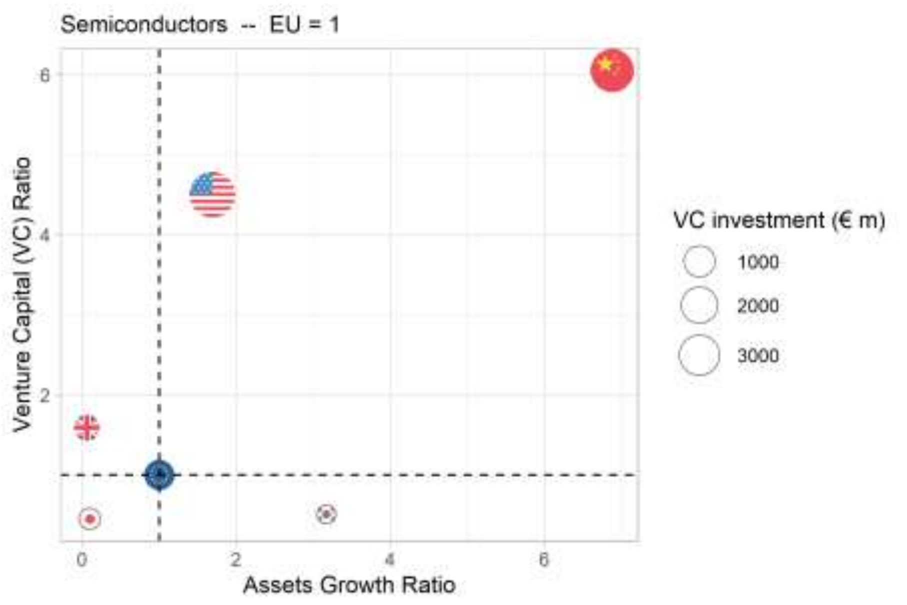
24 https://www.theregister.com/2022/12/10/semiconductor_vc_funding_down_startups/

25 https://pitchbook.com/news/articles/vc-startups-semiconductor-ai-ml-innovation

26 https://medium.com/venture-beyond/south-korea-venture-capital-landscape-2022-9af49c73b909

These figures confirm the strong push of South Korea, China and the US in order to remain or become leaders in the global production of semiconductors. Since early 2002s the increase in the share of the Asian countries in semiconductor global revenues has been impressive, but the US succeeded to maintain and even slightly increase its shares since 2004, representing 21% of the global billings in 2017. On the contrary, the EU's share of revenues from the production of semiconductor has been declining during the last 20 years: from a peak of 22% in 1998 to 13% in 2010, and down to 9% in 2017 (Decision SARL, 2020). This decline of the EU is in part due to the offshoring of production-related parts of the semiconductor value chain to Asia due to the high cost of manufacturing in the EU and the Asian countries benefitting from lower costs and higher public support (Decision SARL, 2020). In fact, a significant portion of manufacturing still occurs in Taiwan, China, or South Korea (Grimes and Du, 2020). At the same time, also the absence of large European computing companies and insufficient investment has been a major factor in the EU's inability to keep up with the sector's growth, with only 3% of global investment in foundry equipment being directed toward European firms in 2020 (Poitiers & Weil, 2021). Although the EU has maintained a strong position in semiconductor research and may possess the necessary know-how for semiconductor design (Kleinhans 2021), it currently lacks the capacity to compete in the fabrication of advanced microchips.

Figure 8. Semiconductors: EU relative position compared with benchmarking countries: Country/EU ratio of venture capital (as share of GDP) vs Country/EU ratio of assets growth (as share of GDP)



Note: The figure presents the relative position of the EU compared with the benchmarking countries considering both fixed assets growth ratio (x-axis) and venture capital (VC) ratio (y-axis). The EU is located at the intersection of the vertical and horizontal dashed line in point (1,1). The size of the points represents the total VC investments.

Figure 7 and Figure 8 summarise the relative position of the EU when compared to the benchmark countries in the different investment measures used in the study. In sum, the investment indicators presented show different perspectives of investments made in and by firms active in semiconductors in the EU, in comparison with other countries with advanced digital economies. Overall they show that the EU is in a middle position for what concerns fixed asset growth invested by firms and VC financing received by firms. This implies that the EU would have needed to make higher investments to have ended 2021 in the same situation of the leading countries in these types of investments – that is, the US or China. For instance, in order for the EU to have the same level of US's growth assets as a share of GDP the EU would have had to increase the assets growth by almost €60 bn (an additional 58% of what actually invested); to match the level of China, this increase should have been of more than €500 bn. The EU is, instead, lagging behind all benchmark countries in terms of semiconductor equipment spending. In this case, narrowing the gap with respect to the leading country in this type of investment – South Korea – would have required more than €1.3 tn extra investments over the period 2008-2021.

3.4 Edge computing

Table 7 offers an overview of the investments by firms active in edge computing, considering the EU and the usual benchmark countries. Two forms of investments are considered: fixed assets growth and venture capital funding received.

In terms of cumulative fixed assets growth, EU firms active in edge computing have invested about €129 bn over the period 2009-2021. This makes the EU the leading country in this type of investment, almost matched by China with €128 bn. The US follows with €57.5 bn, and the UK with €2 bn. Japan and South Korea display a negative fixed asset growth, suggesting a lack of new investments by edge computing-related firms in these countries. In the case of South Korea, these results do not reflect the recent "edge computing revolution" in the country ([27]), which could be due to a combination of factors such as a reporting lag in the source (Orbis), or the fact that the main activity of the newly adopters is in another digital or non-digital domain, hence not identified as edge computing firms (e.g. Hanwha Techwin is a global video surveillance company, Daedong Corporation produces agricultural equipment), and in these cases industry experts confirm that edge solutions introduced by these firms are designed by Intel ([28]). When looking at investments in fixed assets growth as share of GDP, China is the country with the largest share, 0.0881%, as the EU displays a slightly lower share (0.0726%). The US and the UK follow with 0.0244% and 0.0061%, respectively.

Table 7. Edge computing - Investment indicators

Indicator	Country	Investment type	
		Assets growth	Venture capital
Amount (m €)	EU	128,927	513
Amount (m €)	United States	57,570	5,592
Amount (m €)	China	128,064	2,276
Amount (m €)	United Kingdom	2,305	350
Amount (m €)	South Korea	-316	180
Amount (m €)	Japan	-3,182	62
Amount as share of GDP	EU	0.0726%	0.0004%
Amount as share of GDP	United States	0.0244%	0.0029%
Amount as share of GDP	China	0.0881%	0.0019%
Amount as share of GDP	United Kingdom	0.0061%	0.0011%
Amount as share of GDP	South Korea	-0.0017%	0.0012%
Amount as share of GDP	Japan	-0.0056%	0.0001%
Ratio of amount as share of GDP	United States	0.34	8.18
Ratio of amount as share of GDP	China	1.21	5.35
Ratio of amount as share of GDP	United Kingdom	0.08	3.23
Ratio of amount as share of GDP	South Korea	-0.02	3.27
Ratio of amount as share of GDP	Japan	-0.08	0.38
Gap (m €)	United States	-85,633	3,684
Gap (m €)	China	27,484	2,230
Gap (m €)	United Kingdom	-118,012	1,142
Gap (m €)	South Korea	-131,877	1,164
Gap (m €)	Japan	-138,842	-320

The large amount invested by firms in the EU and China may be better understood when considering the accelerated growth of the market for edge computing in these regions in recent years, as their market size was still lagging behind compared to the US one. In fact, most of key players that are significantly active in edge computing are US companies – such as Cisco, HPE, Dell -, while Huawei is the only Chinese one ([29]). Yet, although the US still represents the largest market for edge computing, China is the fastest growing one: according to the International Data Corporation (IDC), the market size of China's edge computing servers reached $1.68 bn

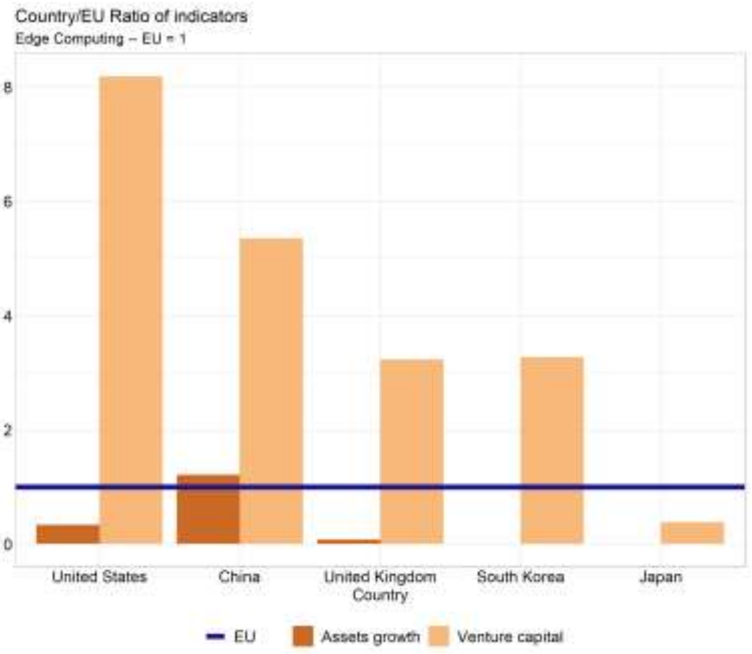
[27] https://www.kedglobal.com/cloud-computing/newsView/ked202106280010

[28] https://www.kedglobal.com/cloud-computing/newsView/ked202106280010

[29] https://www.mordorintelligence.com/industry-reports/edge-computing-market

in the first half of 2022 and it is expected to increase its size by three times, reaching $4.27 bn by 2024 ([30]). In the case of the EU, the large fixed assets growth may be driven by an increasing demand of cloud and edge services. In fact, as noticed by Kalal et al. (2020), cloud and edge technologies can reinforce each other's growth and open opportunities for firms, which is drawing interest from investors into European firms. In this regard, according to Eurostat data ([31]), the use of cloud computing services increased in each EU Member State between 2020 and 2022, reaching the average of 41% of EU enterprises using cloud computing in 2021. Moreover, the leading position of European firms active in edge computing in terms of fixed asset growth investments may be better understood when considering the importance of electronic control systems or sensing and automation sectors for the EU's industry, which opens up opportunities for growth in the edge computing market ([32]). These factors suggest that Europe could strengthen its position in the edge market over the next years.

Figure 9. Edge - Ratio of investment as share of GDP



The second type of investment displayed in Table 7, venture capital, shows a very different pattern in terms of the EU's relative position with respect to the benchmark countries. European firms active in edge computing received €513 m of venture capital financing in the period 2009-2021. US firms are significantly ahead of the EU in terms of VC investments received, with €5.5 bn (about 10 times larger that of the EU) followed by Chinese firms with €2.3 bn (about 4 times that of the EU). The large amount of VC investments in China is in line with the already commented growth of the domestic edge computing market, which is sustained by the surge of numerous Chinese edge computing companies ([33]). European firms remain ahead of the other benchmark countries in terms of VC investments received, as the UK, South Korea and Japan follow with €350 m , €180 m, and €62 m, respectively. The lower amount received by South Korean and Japanese firms active in edge-computing through VC investments is consistent with the already observed sluggish investment in fixed asset growth in these countries. When looking at the share of GDP for venture capital, all benchmark countries but Japan display a higher share than the EU. With 0.0029%, the US's share is 8 times the one of the EU, while China's share is more than 5 times larger (0.0019%). Both the UK's and Korea's share are 3 times the one of the EU (with 0.0011% and 0.0012%, respectively). Japan lags behind all considered countries with a share of GDP of venture capital of 0.0001%.

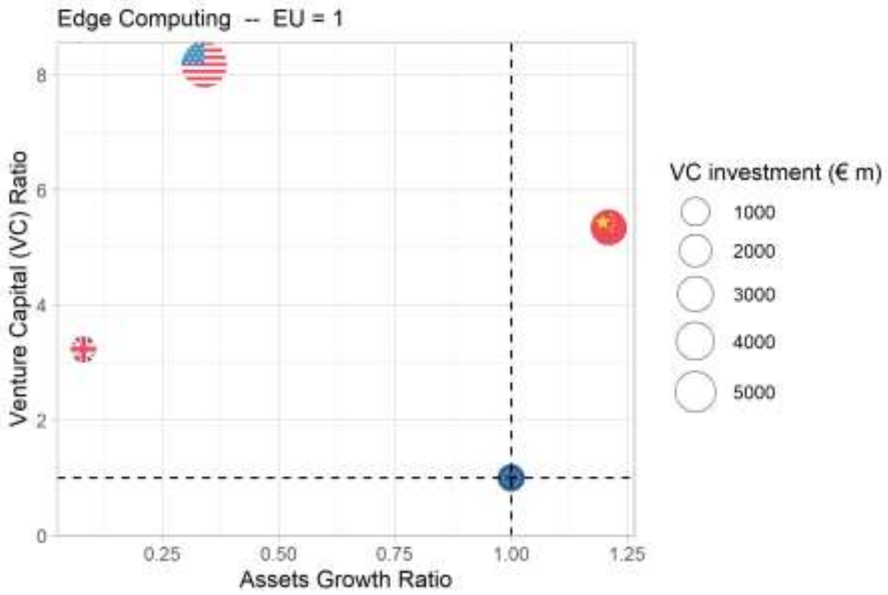
[30] https://equalocean.com/analysis/2023022019475

[31] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Cloud_computing_-_statistics_on_the_use_by_enterprises

[32] https://aioti.eu/wp-content/uploads/2020/10/IoT-and-Edge-Computing-Published.pdf

[33] https://equalocean.com/analysis/2023022019475

Figure 10. Edge computing: EU relative position compared with benchmarking countries: Country/EU ratio of venture capital (as share of GDP) vs Country/EU ratio of assets growth (as share of GDP)



Note: The figure presents the relative position of the EU compared with the benchmarking countries considering both fixed assets growth ratio (x-axis) and venture capital (VC) ratio (y-axis). The EU is located at the intersection of the vertical and horizontal dashed line in point (1,1). The size of the points represents the total VC investments.

In sum, the investment indicators presented show different perspectives of investments made in and by firms active in edge computing in the EU, in comparison with other countries with advanced digital economies. The fact that the EU is in a leading position – shared with China – with what concerns fixed asset growth invested by firms active in edge computing (Figure 9, Figure 10) suggests that Chinese and European firms are anticipating and "getting ready" for the expected large increase of edge computing markets in the upcoming years. In fact, the magnitude of the global edge computing market has been estimated to be between $9 bn ([34])-11 bn ([35]) in 2022 and it is expected to grow at an accelerated rate in the upcoming years (about annual rate of 45% between 2023 and 2028) to reach $58.60 bn by 2028. Consistently, also edge investment are expected to increase in double digit figures between 2022 and 2025 ([36]). This sharp acceleration is due to the high adoption of edge devices, ranging from Internet of Things (IoT) machines, such as mobile point-of-sale kiosks, smart cameras, industrial PCs, and medical sensors, to gateways and computing infrastructure ([37]). The EU is, instead, lagging behind all benchmark countries in terms of VC financing received by firms active in edge computing. In this case, narrowing the gap with respect to the leading economies in this type of investment – the US and China - would have required between €3.7 bn and €2.2 bn of extra investments over the period 2009-2021.

3.5 Quantum computing

Table 8 provides an overview of the investment landscape in the field of quantum technology, specifically focusing on assets growth and venture capital investments. The table includes data for each benchmark country, allowing us to examine the investment gap indicators in this domain. The EU has reported a negative assets growth (€-196 m), indicating a decrease in quantum-related fixed assets over the 2009-2021 period. Similarly,

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[34] https://equalocean.com/analysis/2023022019475

[35] https://finance.yahoo.com/news/36-3-cagr-edge-computing-092500362.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAACjyFOts2ZCbXf2AN7KPjRaWfbdeaompQgZadHDZlB_jOm67LXmtk5YPQ_m2GdDZGLJyLpdGOOXCh5NKFg3ZMi4WxZ06DDgCdh7iQy_lCSpFi6YLdtrNS0PmIQgAcvpQkE_KPekXy235FpYonUe1xy0xkSMhTyCMmDLnB8oFw8wY

[36] International Data Corporation (2022). Available at: https://www.idc.com/getdoc.jsp?containerId=prEUR148783922

[37] https://www.mordorintelligence.com/industry-reports/edge-computing-market

the US exhibits a negative assets growth (-€133 m). Negative growth in assets can be attributed to various factors, including assets depreciation, assets amortization, or a reduction in assets' purchases. Negative investment figures may also suggest a reallocation of resources or a transition phase in the development and deployment of quantum technologies. It is important to note that quantum technologies are still emerging and evolving. The first commercial quantum computer was presented in 2019, before that year there were few private firms investing in quantum research and it may be that firms active before 2019 related to quantum were doing a different activity in that moment. The US, in particular, has shown a recent strategic focus on quantum technologies. The National Quantum Initiative Act, signed into law in 2018, demonstrates the US government's commitment to advancing quantum research and development. This has likely contributed to the significant venture capital investment in the US quantum sector ([38]).

Table 8. Quantum - Investment indicators

Indicator	Country	Investment type	
		Assets growth	Venture capital
Amount (m €)	EU	-196	111
Amount (m €)	United States	-133	1,074
Amount (m €)	China	12,413	3
Amount (m €)	United Kingdom	25	79
Amount (m €)	South Korea	10	0
Amount (m €)	Japan	82	6
Amount as share of GDP	EU	-	0.0001%
Amount as share of GDP	United States	-	0.0006%
Amount as share of GDP	China	0.0085%	0.0000%
Amount as share of GDP	United Kingdom	0.0001%	0.0003%
Amount as share of GDP	South Korea	0.0001%	0.0000%
Amount as share of GDP	Japan	0.0001%	0.0000%
Ratio of amount as share of GDP	United States	-	7.29
Ratio of amount as share of GDP	China	-	0.03
Ratio of amount as share of GDP	United Kingdom	-	3.39
Ratio of amount as share of GDP	South Korea	-	0.00
Ratio of amount as share of GDP	Japan	-	0.18
Gap (m €)	United States	97	695
Gap (m €)	China	15,357	-107
Gap (m €)	United Kingdom	317	264
Gap (m €)	South Korea	292	0
Gap (m €)	Japan	452	-90

Note: This table does not report negative values in indicators *Amount as a share of GDP* and *Ratio of amount as share of GDP*.

In contrast, China demonstrates significant investments in assets growth, amounting to €12.4 bn. China's substantial investments in assets highlight its ambition to become a global leader in quantum technology. The country has launched various initiatives, such as the National Laboratory for Quantum Information Sciences and the Quantum Experiments at Space Scale program ([39]). The investment in assets growth in China is 0.0085% of their GDP, highlighting a notable investment intensity relative to its economy. The UK and Japan display relatively smaller investments in assets, with €25 m and €82 m, respectively.

Turning to venture capital investments, the US leads the way with €1.07 bn received by firms from venture capital, indicating a strong focus on supporting quantum technology startups and innovation. The VC funding as a share of GDP in the US is 0.0006%, demonstrating a relatively higher investment intensity in this area compared to the EU and the other competitors. When considering the ratio of investment as a share of GDP, we gain a comparative measure of each country's investment in quantum technology relative to the EU. The US exhibits a ratio of 7.29, indicating that US firms get 7.29 times more venture capital funding than EU firms (Figure 11). Similarly, the UK has a ratio of 3.39. Interestingly, the UK has also recognized the importance of quantum technologies and has taken steps to foster innovation in this domain. The UK Quantum Technologies

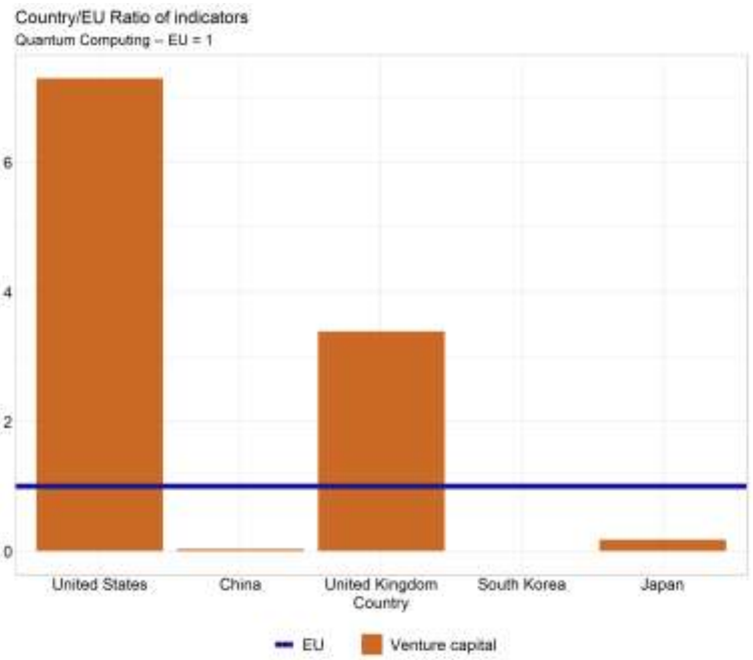
[38] https://thequantuminsider.com/2023/04/13/a-brief-overview-of-quantum-computing-in-the-us/

[39] https://english.ckgsb.edu.cn/knowledges/quantum-wars/

Programme, launched in 2014, aims to accelerate the development and commercialization of quantum technologies. The program has supported numerous research projects and collaborations, attracting both public and private investments in the UK quantum sector ([40]). According to the same source, the UK has invested £2.5 bn in quantum computing, aiming to be competitive in one of the world's fastest- moving fields of technology. The very low levels of venture capital raised by firms in China, Japan and South Korea (as shown by Table 8) may be reflecting a low coverage of Asian firms by Crunchbase (as mentioned in section 2.1), aggravated by the fact that quantum technology is a very recent technology, which may also cause delays in the detection of active firms.

In a similar vein, the EU is expected to invest €2.4 bn on quantum computing from public funding instruments (mostly RRF and Horizon Europe), in order to reach the DD target (Papazoglou et al., 2023). Moreover, to achieve the same level of growth assets as a share of GDP witnessed by China during the period from 2009 to 2021, the EU would have needed to increase its assets growth by €15.3 bn. Finally, in terms of venture capital funding, the EU would have required an additional €695 m to reach the level of investment seen in the US.

Figure 11. Quantum: Ratio of venture capital as share of GDP



3.6 Adoption of technologies: cloud

As seen in Table 9, Chinese and US growth in fixed assets of cloud firms are about 3-4 times higher than that of EU firms with respect to their GDP. Regarding revenues, which may be interpreted as a proxy of adoption by firms[41], US firms have more than twice (ratio of 2.07) the level of revenues with respect to GDP than the EU, and China and the UK present similar ratios (2.11 and 2.06 respectively). These results are consistent with the fact that the cloud market is dominated by US and Chinese companies (AWS, Google, Azure, Alibaba, VMware), which hold about 66% of the market share ([42]). According to the portal European-alternative.eu, there are only a handful of cloud providers based in the EU, all of them of small size, such as French OVH Cloud, German gridscale or Italian Aruba Cloud. However, this does not necessarily imply that European firms are adopting cloud technologies at a lower rate, as these services may be adopted with a non-EU provider. Additionally, US large providers, such as Google or Amazon Web Services, may have subsidiaries in Europe (whose revenues

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40 https://www.ft.com/content/900ba4ee-6c60-4406-963a-810771c2ad7c?accessToken=zwAGAL9gHXJAkdOQC6TubGBEBtOWOoEHccKtfA.MEUCIQDYDAMf4qEqBxBSNYOolSWTRI5JB6e2YbVAaU0os89ijQIgDtRdloRh5fiD7x2sqDbt1zVQ-RkNFejemkDny3g8_6E&sharetype=gift&token=19de4705-0f00-4eaf-83ec-a65c2b49c389

41 We consider that the level of revenues of firms supplying cloud computing, big data or AI technologies and related services reflects the adoption of these technologies by their clients, and therefore, the level of investment of technology adopters. See section 2.1 for more details on the assumptions made and main associated drawbacks.

42 https://www.statista.com/statistics/1252617/europe-cloud-market-size-revenues/

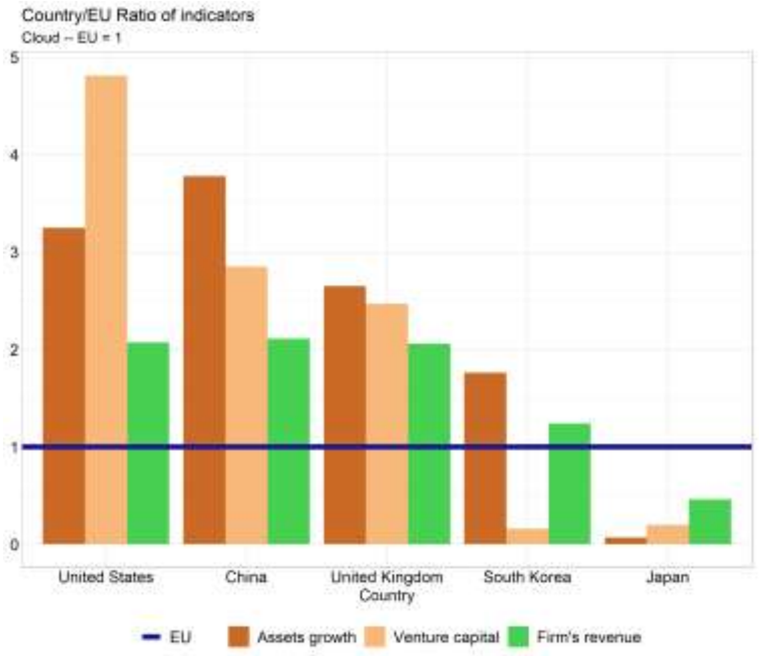
would be accounted as European in the study, since the data reflect country of location of the firm), which suggests that the gap in revenues are likely a lower bound of the real gap.

Table 9. Cloud computing adoption: Investment and revenues indicators

Indicator	Country	Investment type		Firm's revenue (*)
		Assets growth	Venture capital	
Amount (m €)	EU	61,082	9,343	1,077,114
Amount (m €)	United States	263,652	59,883	2,359,182
Amount (m €)	China	188,828	22,094	2,245,785
Amount (m €)	United Kingdom	34,165	4,881	353,899
Amount (m €)	South Korea	11,471	159	146,583
Amount (m €)	Japan	1,338	602	139,009
Amount as share of GDP	EU	0.0344%	0.0064%	0.5637%
Amount as share of GDP	United States	0.1117%	0.0309%	1.1692%
Amount as share of GDP	China	0.1299%	0.0183%	1.1898%
Amount as share of GDP	United Kingdom	0.0911%	0.0159%	1.1607%
Amount as share of GDP	South Korea	0.0604%	0.0010%	0.6975%
Amount as share of GDP	Japan	0.0023%	0.0013%	0.2605%
Ratio of amount as share of GDP	United States	3.25	4.81	2.07
Ratio of amount as share of GDP	China	3.78	2.85	2.11
Ratio of amount as share of GDP	United Kingdom	2.65	2.47	2.06
Ratio of amount as share of GDP	South Korea	1.76	0.16	1.24
Ratio of amount as share of GDP	Japan	0.07	0.20	0.46
Gap (m €)	United States	137,194	35,609	1,156,952
Gap (m €)	China	169,543	17,290	1,196,447
Gap (m €)	United Kingdom	100,686	13,745	1,140,780
Gap (m €)	South Korea	46,138	-7,862	255,611
Gap (m €)	Japan	-56,913	-7,465	-579,272

(*) Firms' revenues of companies providing the technology are used as a proxy of investment of firms adopting the technology.

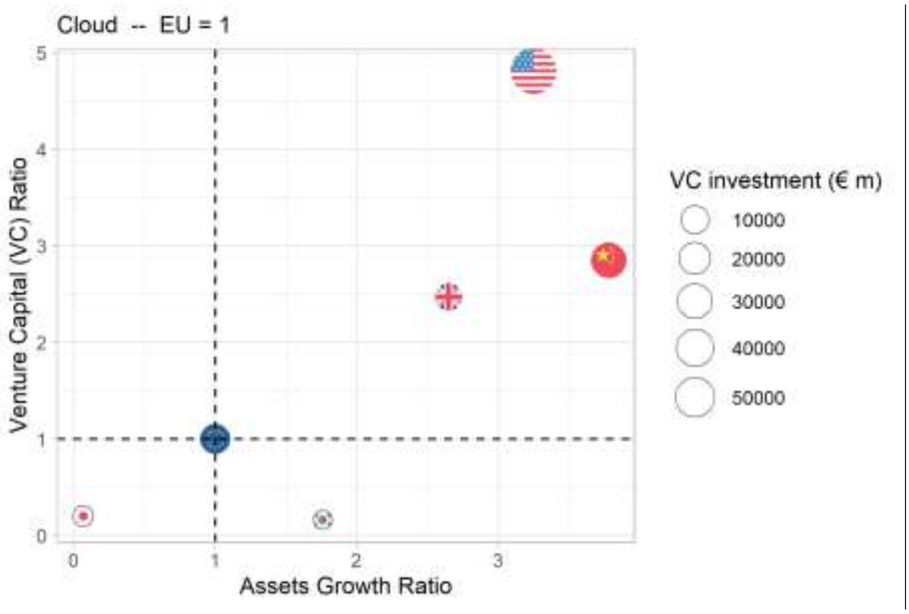
Figure 12. Cloud computing adoption: Ratio of investment and revenues as share of GDP



From Figure 12 and Figure 13, we observe higher VC investments directed towards US cloud firms than in the EU, receiving almost 5 times the money as a share of GDP than European firms, and Chinese firms getting almost 3 times the VC funding of the EU as a share of their GDP, similarly to what found when benchmarking with respect to the UK. Numbers are similar when focusing on fixed assets growth. This may suggest that the European cloud ecosystem is less dynamic than the one of its main competitors, excepting Japan.

Overall, these results indicate that the European Cloud ecosystem is small compared to the US, China, the UK and South Korea, and that European firms that want to adopt cloud computing services may be forced to do it through foreign providers.

Figure 13. Cloud computing adoption: EU relative position compared with benchmarking countries: Country/EU ratio of venture capital (as share of GDP) vs Country/EU ratio of assets growth (as share of GDP)



Note: The figure presents the relative position of the EU compared with the benchmarking countries considering both fixed assets growth ratio (x-axis) and venture capital (VC) ratio (y-axis). The EU is located at the intersection of the vertical and horizontal dashed line in point (1,1). The size of the points represents the total VC investments.

3.7 Adoption of technologies: big data

It is visible from Table 10, Figure 14 and Figure 15 that there is an overall large investment gap with respect to China and the US. While assets growth from EU firms is similar to that of US firms, there is a huge difference when compared to Chinese firms that amount up to 9 times the investment made by EU firms as a share of GDP. This gap is also positive when compared to the UK. Japanese and South Korean firms present very small investments, which is not what we would expect from the first and third more complex economies in the world, according to the Atlas of Economic Complexity ([43]). This hints to a coverage issue in this thematic area, although not seconded by revenues data (same source as assets growth), which are quite high for South Korea with respect to the EU.

When looking at VC investments, EU firms rank among the last of the benchmarking, only above South Korea and Japan. Even in absolute terms, UK firms alone receive larger investments than EU big data firms. The gap in VC is especially high compared to the US, whose firms receive 9 times more VC funding than European firms as a share of their GDP, as shown in . Chinese firms present 2 times larger VC funding as a share of their GDP than EU firms.

All in all, EU firms seem to be lagging with respect to China, the US, the UK and South Korea, and only perform better than Japan in all of them. Additionally, EU firms receive less VC investments and their assets grow slower

[43] https://atlas.cid.harvard.edu/rankings

than their British, Chinese and US counterparts. This may suggest that these sectors are less developed in the EU than in the benchmarked countries and, hence, we may expect a lower adoption. However, it is also important to recall, again, that firms do not necessarily, and indeed this is not the usual case, need to purchase cloud, big data or AI services from own country or region firms. EU firms could adopt cloud through Alibaba, or analyse their internal data hiring a US firm. Therefore, these numbers should be interpreted with caution.

Table 10. Big data adoption: Investment and revenues indicators

Indicator	Country	Investment type		Firm's revenue
		Assets growth	Venture capital	
Amount (m €)	EU	85,260	2,486	1,825,417
Amount (m €)	United States	124,222	28,835	1,506,179
Amount (m €)	China	628,206	4,538	3,910,926
Amount (m €)	United Kingdom	39,062	2,728	430,185
Amount (m €)	South Korea	3,766	53	473,294
Amount (m €)	Japan	1,955	67	249,982
Amount as share of GDP	EU	0.0480%	0.0017%	0.9553%
Amount as share of GDP	United States	0.0526%	0.0149%	0.7464%
Amount as share of GDP	China	0.4323%	0.0038%	2.0721%
Amount as share of GDP	United Kingdom	0.1042%	0.0089%	1.4109%
Amount as share of GDP	South Korea	0.0198%	0.0003%	2.2520%
Amount as share of GDP	Japan	0.0034%	0.0001%	0.4685%
Ratio of amount as share of GDP	United States	1.10	8.71	0.78
Ratio of amount as share of GDP	China	9.00	2.20	2.17
Ratio of amount as share of GDP	United Kingdom	2.17	5.19	1.48
Ratio of amount as share of GDP	South Korea	0.41	0.20	2.36
Ratio of amount as share of GDP	Japan	0.07	0.08	0.49
Gap (m €)	United States	8,159	19,160	-399,116
Gap (m €)	China	682,000	2,985	2,133,881
Gap (m €)	United Kingdom	99,697	10,419	870,562
Gap (m €)	South Korea	-50,061	-1,992	2,477,743
Gap (m €)	Japan	-79,168	-2,276	-930,136

(*) Firms' revenues of companies providing the technology are used as a proxy of investment of firms adopting the technology.

Figure 14. Big data adoption: Ratio of investment and revenues as share of GDP

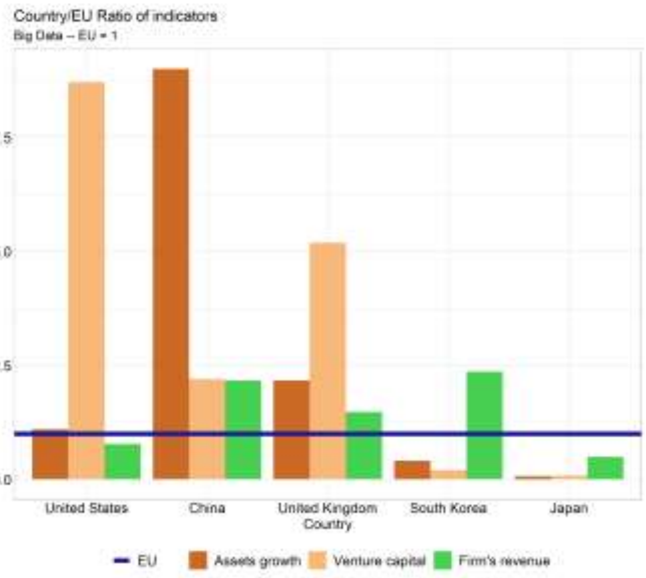
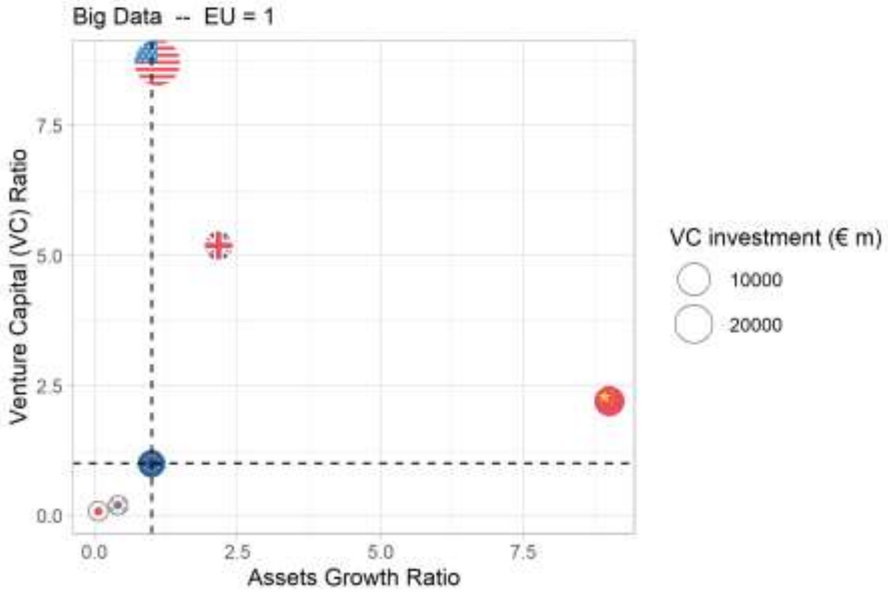


Figure 15. Big data adoption: EU relative position compared with benchmarking countries: Country/EU ratio of venture capital (as share of GDP) vs Country/EU ratio of assets growth (as share of GDP)



Note: The figure presents the relative position of the EU compared with the benchmarking countries considering both fixed assets growth ratio (x-axis) and venture capital (VC) ratio (y-axis). The EU is located at the intersection of the vertical and horizontal dashed line in point (1,1). The size of the points represents the total VC investments.

3.8 Adoption of technologies: artificial intelligence

Table 11, Figure 16 and Figure 17 show that fixed assets growth and VC investments as a share of its GDP are lower in the EU than in both China and the US. Fixed assets growth of Chinese firms related to AI, with respect to their GDP, are of a magnitude of 3 times larger than that of the EU. Indeed, the EU would have needed to invest additional €867 bn in order to match Chinese AI firms' investments over the 2009-2021 period, which would result in additional €67 bn per year (that is, 140% above what has been actually invested). The numbers are similar to those of the US, hinting the large efforts of Beijing in becoming a technological leader in AI, as suggested by Forbes ([44]) or the NIST ranking of AI companies producing facial recognition algorithms, where all top 5 firms are Chinese ([45]). Considering venture capital funding, we see that EU AI firms received less VC investments as a share of its GDP than all benchmarking countries, excepting Japan. The gap is especially high compared to US companies, that present VC almost 9 times higher with respect to their GDP than the EU, and leverages an investment gap of almost €50 bn. A smaller gap can be found with respect to China, of €35 bn and almost 7 times larger amounts than the EU. The gap is also positive when we benchmark with the UK, with British firms receiving 4 times more investments than EU firms.

Revenue data shows that EU firms and Chinese firms receive a similar amount of revenues, a number that is equivalent to 4.4% and 4.7% respectively of their GDP, above the figures shown by the US, South Korea and Japan. These results could be reflecting EU firms buying services from subsidiaries of foreign firms located in Europe, hence inflating the revenues of the EU (since the firm's country corresponds to its location).

All in all, European firms are lagging with respect to many of their competitors in terms of venture capital and asset growth. This does not necessarily imply that EU firms are adopting AI technologies at a slower pace than Chinese or US firms. Indeed, adoption of AI is still low in all countries and concentrated in determined economic sectors (Calvino and Fontanelli, 2023). KOSTAT, the South Korean national statistics office, finds an adoption rate of 2.7% in 2017-2018; the US Census Bureau, an AI adoption rate of 6.6% in the United States for that same year, and only 4% of job listings of S&P500 companies mention AI, according to The Economist ([46])

[44] https://www.forbes.com/sites/craigsmith/2023/01/14/chinas-ai-implementation-is-edging-ahead-of-the-us/

[45] https://pages.nist.gov/frvt/html/frvt11.html#_Status_

[46] https://www.economist.com/leaders/2023/06/29/the-widespread-adoption-of-ai-by-companies-will-take-a-while

(DeStefano et al. 2021, Zolas et al. 2021). Generally, China seems to be the country investing more heavily in AI technology and anecdotal evidence presented here suggests that it has a leading position in the field.

Table 11. AI adoption: Investment and revenues indicators

Indicator	Country	Investment type		Firm's revenue
		Assets growth	Venture capital	
Amount (m €)	EU	431,372	6,280	8,364,301
Amount (m €)	United States	616,529	73,986	5,473,526
Amount (m €)	China	1,063,081	34,447	8,902,931
Amount (m €)	United Kingdom	49,805	5,190	1,483,459
Amount (m €)	South Korea	19,252	682	459,907
Amount (m €)	Japan	-11,781	1,417	1,754,440
Amount as share of GDP	EU	0.2431%	0.0043%	4.3774%
Amount as share of GDP	United States	0.2612%	0.0382%	2.7126%
Amount as share of GDP	China	0.7316%	0.0285%	4.7169%
Amount as share of GDP	United Kingdom	0.1329%	0.0169%	4.8654%
Amount as share of GDP	South Korea	0.1014%	0.0044%	2.1883%
Amount as share of GDP	Japan	-0.0207%	0.0030%	3.2883%
Ratio of amount as share of GDP	United States	1.07	8.84	0.62
Ratio of amount as share of GDP	China	3.01	6.61	1.08
Ratio of amount as share of GDP	United Kingdom	0.55	3.91	1.11
Ratio of amount as share of GDP	South Korea	0.42	1.01	0.50
Ratio of amount as share of GDP	Japan	-0.09	0.70	0.75
Gap (m €)	United States	32,280	49,258	-3,181,058
Gap (m €)	China	867,023	35,243	648,744
Gap (m €)	United Kingdom	-195,553	18,271	932,571
Gap (m €)	South Korea	-251,416	66	-4,182,848
Gap (m €)	Japan	-468,077	-1,862	-2,080,983

(*) Firms' revenues of companies providing the technology are used as a proxy of investment of firms adopting the technology.

Figure 16. AI adoption: Ratio of investment and revenues as share of GDP

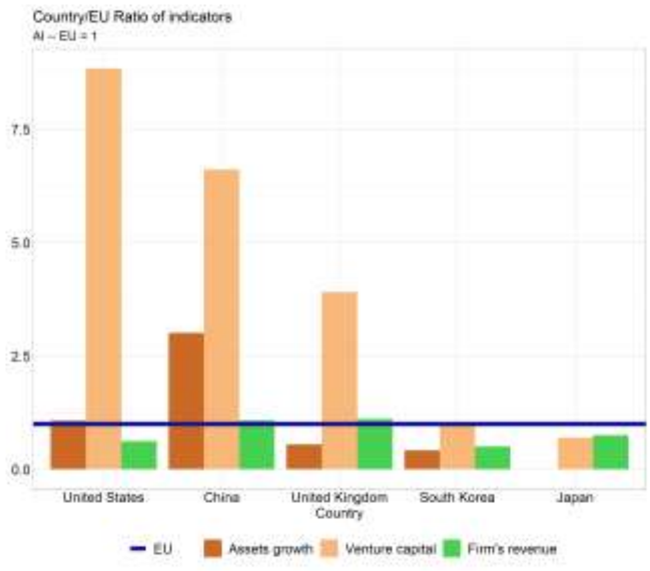
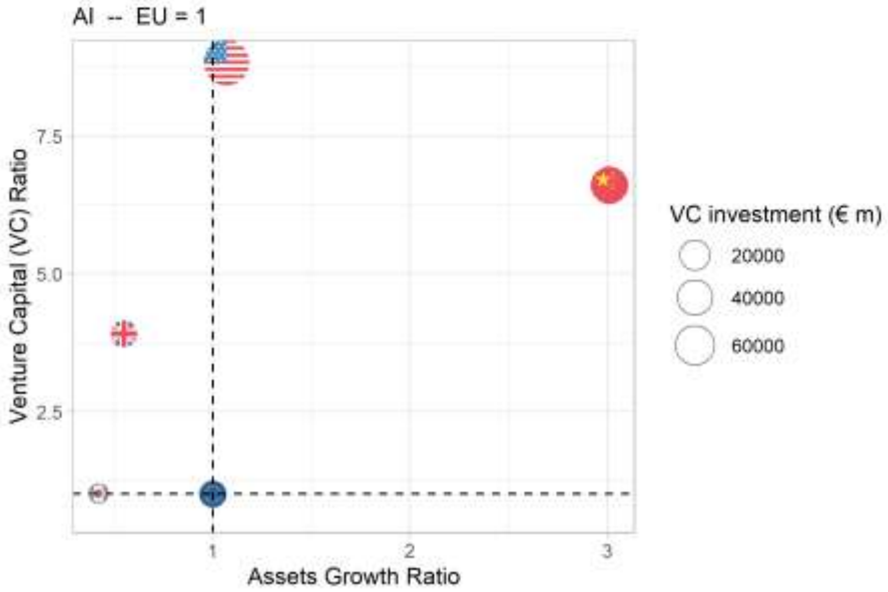


Figure 17. AI adoption: EU relative position compared with benchmarking countries: Country/EU ratio of venture capital (as share of GDP) vs Country/EU ratio of assets growth (as share of GDP)



Note: The figure presents the relative position of the EU compared with the benchmarking countries considering both fixed assets growth ratio (x-axis) and venture capital (VC) ratio (y-axis). The EU is located at the intersection of the vertical and horizontal dashed line in point (1,1). The size of the points represents the total VC investments.

4 Conclusions

Acceleration of digitalisation and development of cutting-edge technologies, as outlined in the Digital Decade Policy Programme, are critical for the European Union's technological sovereignty and defence. This report benchmarks EU private investments in some of the Digital Decade thematic areas with respect to other relevant advanced economies in order to assess its international position.

Comparing the performance of the EU on Digital Decade targets with respect to non-EU countries is complex, as the indicators defined and used within the EU are not necessarily measured in other countries. To obtain comparable investment figures, we exploit the DGTES dataset to identify firms in the digital ecosystem worldwide, and compare investment figures across countries using BvD Orbis dataset and Crunchbase venture capital data, among other sources. Our results show that, while China and the US are leading the way in investments in all the technologies analysed, the European Union occupies a medium-level position.

These results are closely related to other policy reports that point to the same observations for Europe in several critical technologies, finding that citations of scientific publications in most critical technologies are from Chinese or US institutions; or detecting a prominent role of Chinese and US startups receiving investments and a much more modest role of European firms.

Our findings regarding broadband coverage indicate that the EU should step up efforts to compare with the United States and China. Additional investments of up to €227 bn would be needed to achieve comparable investments in telecommunication equipment. In the realm of 5G, the EU faces a significant investment disparity with the US and China. Substantial increases in investments across assets growth and venture capital would be needed to align the EU more closely with the dedication observed in the US and China.

While the EU has a robust semiconductor industry, it lags behind major players such as the US, China, South Korea and Japan. Redirecting investments of approximately €60 bn and over €500 bn can help the EU approach the cumulative fixed assets growth seen in the US and China, respectively. Furthermore, there is a considerable investment difference in semiconductor equipment spending, exceeding €1.3 tn when compared to South Korea. In the domain of edge computing, EU firms have shown leadership in cumulative fixed assets growth, closely matched by China, but lag behind in venture capital. In the quantum technology thematic area China has surged ahead as a global leader. Finally, the adoption of technologies by businesses (cloud, big data and AI) faces significant challenges compared to the US and China. Overall, results seem to indicate an underinvestment of the European Union in many critical technologies, such as semiconductors, AI, edge computing or 5G, among others, vis-à-vis other large economies.

Insights from this report call for targeted investments and strategic initiatives. Strengthening research and development capabilities would be desirable, particularly in emerging areas like quantum computing and AI. Cross-border collaboration between Member States would be a positive step to promote a more cohesive Union where there are shared interests. Empowering digital skills is also crucial for the EU's digital transformation journey. These measures may help in the final goal of creating a Europe that, through digitalisation, can improve its productivity, change its economic structure, and create a more skilled, empowered and employable population.

References

Calvino, F., & Fontanelli, L. (2023). *A portrait of AI adopters across countries: Firm characteristics, assets' complementarities and productivity.* Available at: https://www.oecd-ilibrary.org/docserver/0fb79bb9-en.pdf?expires=1693393570&id=id&accname=guest&checksum=4910B35B7776954265B4AA7DCDB654D6

Calza, E., Dalla Benetta, A., Kostić, U., Mitton, I., Moraschini, M., Vázquez-Prada Baillet, M., Cardona, M., Papazoglou, M., Righi, R., Torrecillas Jódar, J., Lopez Cobo, M., Cira, P. & De Prato, G. (2023). *Analytical insights into the global digital ecosystem (DGTES)*. EUR 31538 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-68-04045-4, doi:10.2760/811932, JRC132991.

Calza, E., Dalla Benetta, A., Kostić, U., Mitton, I., Vazquez-Prada Baillet, M., Carenini, M., Cira, P., De Prato, G., Righi, R., Papazoglou, M., Lopez Cobo, M. & Cardona, M. (2022*). A policy oriented analytical approach to map the digital ecosystem (DGTES).* EUR 31319 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-59139-9, doi:10.2760/37629, JRC130799

DECISION (EU) 2022/2481, Decision of the European Parliament and of the Council of 14 December 2022 establishing the Digital Decade Policy Programme 2030.

Decision SARL (2020*). Study on the electronics ecosystem. Overview. Developments and Europe's position in the world (2020).* Available at: https://op.europa.eu/o/opportal-service/download-handler?identifier=272a2468-489d-11ea-b81b-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=

DeStefano, T. J., Teodorovicz, T., Cho, J., Kim, H., & Paik, J. (2022*). What Determines AI Adoption*?. In Academy of Management Proceedings (Vol. 2022, No. 1, p. 14791). Briarcliff Manor, NY 10510: Academy of Management.

European Bank for Reconstruction and Development (2015). *Transition Report 2015–16: Rebalancing Finance.* EBRD London, UK. Available at: https://www.ebrd.com/documents/oce/pdf-transition-report-201516-english.pdf

European Commission (2020), Commission Staff Working Document. *Identifying Europe's recovery needs*, Accompanying the Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. *Europe's moment: Repair and Prepare for the Next Generation,* COM(2020) 456 final (SWD(2020) 98 final).

European Commission (2021), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and The Committee of the Regions (2021). 2030 Digital Compass: the European way for the Digital Decade, COM(2021) 118 final.

European Commission (2022), Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2022). A Chips Act for Europe, COM(2022) 45 final.

European Commission (2023a), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Report on the state of the Digital Decade 2023 (COM(2023) 570)

European Commission (2023b), Communication from the Commission establishing the Union-level projected trajectories for the digital targets, C(2023) 7500

European Investment Bank (2016). *Restoring EU Competitiveness*. Available at: https://www.eib.org/attachments/efs/restoring_eu_competitiveness_en.pdf

Federal Communications Commission (2023). *Measuring Fixed Broadband - Twelfth Report*. Available at: https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-twelfth-report#_Toc43144651

Gaida, J., Wong-Leung, J., Robin, S., and Cave D. (2023), ASPI's Critical Technology Tracker. The global race for future power, ISSN 2209-9689 (online). ISSN 2209-9670 (print)

Hess J., Denkena W., Kleinhans, J-P., & Maham, P. (2023). *Who is funding the chips of the future*?. Available at: https://www.stiftung-nv.de/sites/default/files/snv_semiconductor_startup_funding_activities.pdf

Kalal, M., Efimova, K., Fouchereau, R., Roberti, G., Smulski, J., Venkatraman, A., Arend, C., Teyton, B., Veronesi, L., Cosso, S., Wells, D. (2020). *The technology impacts of edge computing in Europe.* IDC Market Perspective.

Kleinhans, J-P. (2021). *The lack of semiconductor manufacturing in Europe. Why the 2 nm fab is a bad investment.* Policy Brief March.

López-Cobo, M., Torrecillas Jódar, J., Cardona, M., De Prato, G., Righi, R., Vazquez-Prada Baillet, M., Papazoglou, M., Calza, E., Mas, M., Fernández de Guevara, J., Benages, E., Hernández, L., Mínguez, C., Pascual, F., Pérez, J., Robledo, J-C., Salamanca, J., Solaz, M. (2023*). 2023 PREDICT Twin transition Dataset*. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/2682f25a-3d4f-40c7-9938-e2d73a4ff3c1

McCahery, J., Lopez de Silanes, F., Schoenmaker, D., & Stanisic, D. (2015). *The European capital markets study: Estimating the financing gaps of SMEs.* (Duisenberg School of Finance; Vol. 1, No. 3). Duisenberg School of Finance.

Papazoglou, M., Torrecillas Jódar, J., Cardona, M., Calza, E., Vázquez Prada-Baillet, M., Righi, R. (2023). *Mapping EU level funding instruments to Digital Decade targets.* López Cobo, M. and De Prato, G. editors, Publications Office of the European Union, Luxembourg, 2023, doi: 10.2760/986930, JRC134647.

Poitiers, N., & Weil, P. (2021). *A new direction for the European Union's half-hearted semiconductor strategy.* (No. 17/2021). Bruegel Policy Contribution.

Tech4i2 (2020). International Digital Economy and Society Index 2020 SMART 2019/0087. Available at: https://digital-strategy.ec.europa.eu/en/library/i-desi-2020-how-digital-europe-compared-other-major-world-economies

TechNation (2023). *How to build a scale-up.* Available at: https://technation.io/tnr2023/#vc-investment

Tong, X., & Wan, X. (2023). *National industrial investment fund and China's integrated circuit industry technology innovation.* Journal of Innovation & Knowledge, 8(1), 100319.

Verbeek, A., & Lundqvist, M. (2021). *Artificial Intelligence, Blockchain and the Future of Europe: How Disruptive Technologies Create Opportunities for a Green and Digital Economy: Main Report*. European Investment Bank.

Zolas, N., Kroff, Z., Brynjolfsson, E., McElheran, K., Beede, D.N., Buffington, C., Goldschlag, N., Foster, L. and Dinlersoz, E. (2021). *Advanced Technologies Adoption and Use by US Firms: Evidence from the Annual Business Survey* (No. w28290). National Bureau of Economic Research.

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