Europe's Technology Sovereignty and the Role of Knowledge Diffusion in Global Value Chains

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Contents

Abstract

The rise of China as the ‘workshop of the world’, combined with experiences with supply shortages during the COVID-19 pandemic, have led to a re-assessment in recent years of the dependencies of countries on foreign sources of technology. This study seeks to contribute to this discussion by analysing technology dependency in a global value-chain framework. We employ input-output and R&D investment data to assess how dependency on imported R&D inputs has developed over the last decade.

Our results indicate that there has been no general trend towards greater technological dependency on foreign R&D. In the last decade, the share of imported R&D in total R&D increased in around half of the countries in the analysis and remained unchanged in the United States and in the EU-27. Both the EU-27 and United States show comparable levels of dependency on foreign sources of technology. At industry level, low-tech sectors revealed the highest rates of dependency on foreign sources of technology. The data also confirm that dependency on China for imported R&D has at least doubled in most countries over the last decade. China, in contrast, was able to reduce its own dependence on foreign sources of technology in the past decade dependency due to fast-growing domestic R&D investments. In addition, regional integration in technology flows between Asian countries is much greater today than it was 10 years ago.

Executive summary

We investigate the dependency of the EU and other countries on foreign sources of technology in a global value-chain framework. We employ input-output and R&D-investments data to assess how dependency on imported R&D inputs has developed over the last decade.

Policy context

The question of the EU's technological dependency has come into focus for policymakers in part due to shortages of critical supplies during the COVID-19 pandemic. Moreover, both the rise of the People's Republic of China as the 'workshop of the world' and autocratic tendencies in the country have prompted a re-assessment of the relations between the EU and its Member States and China. This study seeks to contribute to discussions in this area.

Main findings

R&D investments by companies nearly doubled over the last decade globally. However, R&D investments grew more slowly in the EU than in China, Korea, and the US. This means that the EU lost share in global R&D output in the last decade.

We found no general trend for rising dependencies by countries worldwide on foreign technology in the past decade. The share of imported R&D in combined domestic and imported R&D increased in around half of the countries in the analysis, while it decreased in the other half of the sample and remained unchanged in the United States and in the EU-27. At sectoral level, the highest degrees of dependence on foreign technology in the EU-27 are found among the main sectors in telecommunications, computers, and electronics.

China has been able to reduce its own dependence on foreign technology in the past decade due to its fast-growing domestic R&D expenditures. A similar development can also be observed in some Central and Eastern European Member States. The data also confirm that dependency on China for imported R&D has at least doubled in most countries over the last decade. In addition, regional integration in technology flows between Asian countries is much higher today than 10 years ago.

Key conclusions

EU policy seeks to address concerns about Europe's growing dependency on foreign sources of technology. The analysis in this report shows that the EU's dependency on foreign technology has not changed during the last decade. One notable exception is its dependency on China, which has indeed grown in recent years. However, the EU is still less dependent on China for technology than the US or Japan are. Nevertheless, there are notable differences in levels of dependency on China between EU Member States. Concerns about the EU's technological dependencies on other countries may therefore be exaggerated. Instead of worrying about external dependencies, EU Member States should instead develop their domestic technological capabilities and close the gap in R&D expenditure with the United States, China, and Korea. This gap has widened in the last decade.

1 Introduction

In recent years, technology has become a geopolitical issue. Both the rise of the People's Republic of China (referred to as 'China' throughout the rest of this text) as an economic power and the experience of the COVID-19 pandemic have led to a re-assessment of Europe's dependencies on foreign sources of technology, and of the role of technology in international relations more generally. The question of technology dependency and sovereignty has also entered policy discussions (Leonard and Shapiro, 2019; Edler et al., 2020; Crespi et al., 2021). Hitt et al. (2021) and Luo (2022) use the term 'techno-nationalism' to describe a view of the world where technology is a source of national superiority and where the gains of one country are inevitably the losses of another. Recent policy documents by the EU stress the need to look closely at Europe's strategic dependencies and capacities (European Commission, 2021b) and the need to strengthen the EU's strategic autonomy and sovereignty (European Commission, 2021c).

However, these policy discussions are sometimes built on weak empirical foundations. The study of international dependencies and global value chains (GVCs) is relatively new, and there is still limited evidence on important questions such as the extent to which different countries depend dependency on foreign technology. This study seeks to contribute to this literature by analysing technology dependency using a GVC framework. According to Antràs (2020), a GVC includes 'a series of stages involved in producing products and services that are sold to consumers, with each stage adding value'. In a GVC perspective, technology dependency boils down to the question of how much foreign R&D is embodied in imports of intermediate products needed for domestic production. The basic idea of our study is simple: each stage of a value chain creates inputs which become part of the final product. We create a proxy of the R&D content of each stage of a value chain by weighting the intermediate goods supplied to downstream stages by the R&D efforts of this stage. Thus, we can consider the R&D content of a certain good as the sum of the producing sector's own R&D efforts plus the R&D efforts in upstream sectors (some of these upstream sectors may be foreign but some may be domestic). Such a decomposition of a value chain into its domestic and foreign upstream components weighted by their R&D content makes it possible to measure R&D embodied in GVCs. We implement this approach with: (i) input-output tables that trace the flows of goods throughout an economy; and (ii) data on R&D expenditures at the sectoral level.

This paper will focus on two interrelated questions:

1. Firstly, we look at the total and imported R&D content of GVCs. Which countries are highly dependent on imported R&D inputs? Is there a clear trend in the R&D content of GVCs which may point to a general increase in the degree of technology dependency across countries?

2. Secondly, we are interested in the role of Chinese R&D in GVCs. How has the dependency of the EU-27 and the US on Chinese R&D developed over time in comparison with dependency on the other main trade partners of these two blocs? What sectors are the most dependent on foreign R&D? Do China's increasing R&D investments go into GVCs, or do they serve domestic demand?

The paper proceeds as follows. After presenting the research background and the research questions in sections 2 and 3, we present the analytical framework and the data in sections 4 and 5. Sections 6 and 7 discuss levels of dependency across countries by looking at source countries with a special focus on China. The paper closes with conclusions in section 8.

2 Background

Nowadays, products and services are to a high degree the result of separated tasks that are located in different parts of the world. These tasks are organised in GVCs managed by large multinational firms. Simply speaking, a GVC is the 'recipe' for everything that is needed, directly or indirectly, to produce a particular final product. In a GVC perspective, the output of a sector can be seen as the sum of its own value added plus all the tangible and intangible inputs received from its upstream sectors. The producer of an electronic product, for example, needs components such as printed circuit boards, a screen, a microphone, and speakers. But they also need electricity, water, and a variety of services such as transport, accounting, R&D, and advertising.

GVCs as we know them today emerged in the 1970s and 1980s, fuelled by new information and communication technologies, air transport, and the integration of former communist countries into the world economy (Baldwin, 2006). The integration of China into the world economy was one of the main drivers of the expansion of GVCs in the 1990s and 2000s. The country considerably increased its share as a supplier of intermediate products to companies in the EU-27 and the US (Dachs et al., 2022). Despite their description as 'global', GVCs also reveal a strong regional component, with GVCs often focused on a particular region of the world (Mudambi and Puck, 2016; Baldwin and Freeman, 2021). The scholars Baldwin and Freeman (2021) speak of 'Factory Europe', 'Factory Asia' and 'Factory North America' to describe this regional integration.

Following the global financial crisis of 2008/2009, GVCs grew more slowly. This slowdown in growth is often referred to as 'slowbalisation' (The Economist, 2019). According to the International Monetary Fund (Aiyar et al., 2023), slowbalisation is characterised by rising geopolitical tensions, a weakening of the political institutions that support open trade, and a slowdown in the pace of trade reforms. Some commentators have even talked of the beginning of de-globalisation. However, measured by the contributions a particular sector provides for other sectors forward linkages) as well as by the contributions a sector receives from its suppliers (backward linkages), most countries are more integrated in GVCs today than they were around the year 2000 (Alvarez et al., 2021).

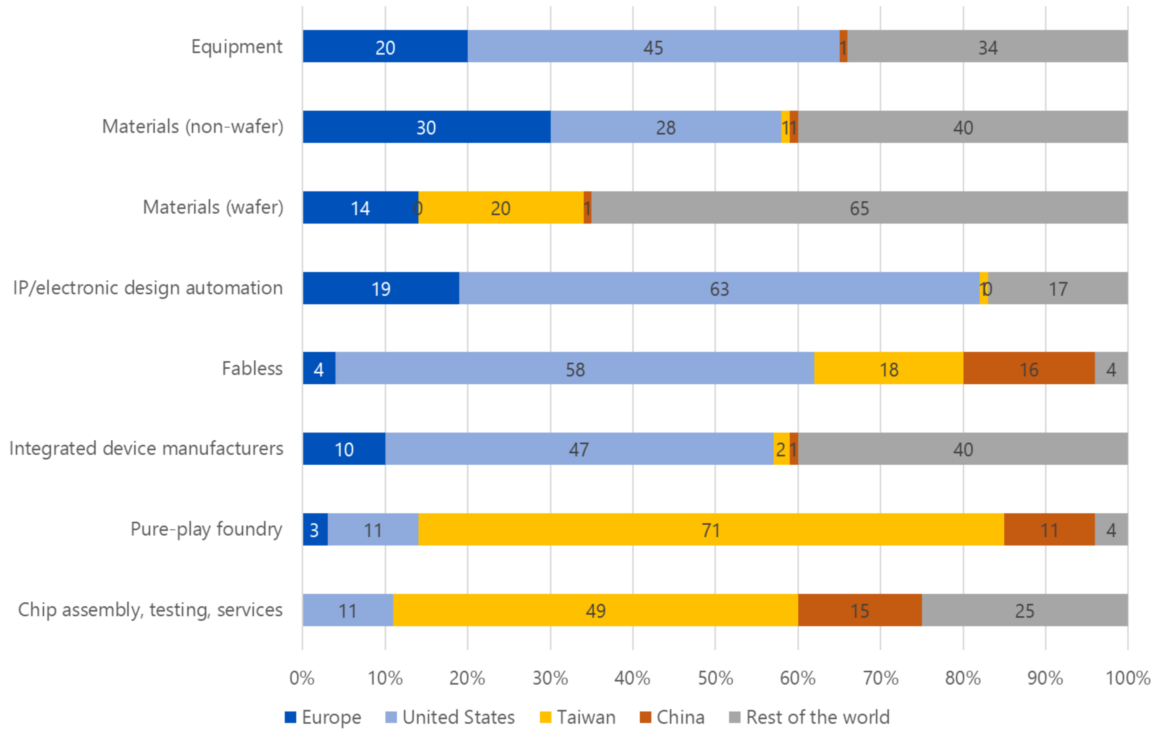
Slowbalisation was also accompanied by a change in the narratives. At present, the very idea of globalisation is met with suspicion in some political and policymaking circles (Rodrik, 2022; James, 2023). Witt (2019) has written of the liberal narrative that dominated in the 1990s and 2000s. In a nutshell, the liberal narrative stresses that specialisation in GVCs makes enterprises and countries more competitive in certain stages of the GVC. This helps countries that host these firms to gain larger shares of value added in the GVC and reach a higher level of welfare (Baldwin, 2016). The realist narrative, in contrast, points out that technology is a source of national superiority and that the gains of one country are inevitably the losses of another, a view which has been labelled as 'techno-nationalism' (Hitt et al., 2021; Luo, 2022). Integration in GVCs therefore brings with it the risk of greater dependence dependency on foreign technology and less resilience in GVCs, which may in turn make domestic production more vulnerable. In the long run, integration in GVCs may even result in a loss of strategic industries and domestic skills bases.

The realist narrative was bolstered in the EU by supply shortages during the COVID-19 pandemic, which brought into focus the possible negative consequences of GVC integration. In particular, the EU's dependence on foreign supplies of drugs, medical supplies, rare materials, and advanced technologies became apparent. As a result of this greater consciousness of the EU's dependence on foreign supplies of certain products, 'technological sovereignty' and greater independency from the US and China in key technologies emerged as new priorities for EU policy (Leonard and Shapiro, 2019; Edler et al., 2020; European Commission, 2021b; Fabry and Veskoukis, 2021). These authors suggested that the EU should aim to gain the capacity to act by: (i) reducing its dependencies on certain foreign technology; and (ii) improving its resilience to external shocks. However, the authors also stressed that these two goals should be achieved while maintaining the benefits of free trade. The authors also stressed that sovereignty does not mean autarky or protectionism. Recently, President von der Leyen spoke of economic 'de-risking' as being part of the EU's future China strategy. This de-risking includes: (i) making the EU economy more competitive and resilient; (ii) a more active role for trade policy; (iii) developing new defensive tools for critical industries; and (iv) aligning Europe's de-risking strategy with other partners (European Commission, 2023).

A few recent papers (European Commission, 2021b; Reiter and Stehrer, 2021) have also identified and quantified Europe's dependencies. However, it is not easy to measure dependencies in complex GVCs when R&D and technology come into play. R&D intensities and the resulting dependencies may differ in various stages of the value chain, so focusing on the final product alone may lead to the wrong conclusions. The value chain for microchips (Figure 1) provides an example of these multiple dependencies (Kleinhans and Baisakova, 2020; European Commission, 2022a). It is true that Taiwan holds a very high share of the final stages of the value chain for microchips (pure-play foundries and chip assembly in Figure 1). However, there is no single company or country that controls all stages of the microchip value chain or that is self-sufficient in microchips.

Several critical bottlenecks exist in the value chain in which the number of suppliers falls to only a handful of firms. An example of this is the Dutch company ASML, which is by far the largest provider of cutting-edge equipment to produce microchips. A lot of R&D by European firms also enters the microchip production chain via chemicals, wafers, and other intermediate products. This R&D is then re-imported to Europe to be embedded in the final product. A view that just looks at the final product does not consider these dependencies. Hence, a more sophisticated approach is needed to measure Europe's technological dependencies that captures all stages of a value chain.

Figure 1. Share of sales of different regions in different stages of the microchip value chain based on location of company's headquarters, 2018



Source: McKinsey & Company (2022)

One important task in GVCs is research, development (R&D), and innovation which are often one of the tasks that generate the highest value added in a GVC (Mudambi, 2008; Shin et al., 2012) However, the literature so far took only little notice of the relationship between R&D by MNEs and GVCs; according to Ambos et al. (2021) research on the impact of GVCs on innovations and on the effect of innovations on GVC activities "has been sporadic, inconclusive, and fragmented" (Ambos et al., 2021).

Ambos et al. (2021) see three streams in the academic literature which look at innovation and R&D in a GVC context. Firstly, there is the literature on global knowledge sourcing, which looks at geographically dispersed R&D activities in multinational enterprises (Papanastassiou et al., 2020; Dachs and Zahradnik, 2022). Multinational enterprises are responsible for a large share of trade within GVCs (Cadestin et al., 2019) and also for a large share of global business R&D expenditures (Grassano et al., 2021) so this linkage seems natural. Secondly, there is the literature on GVC governance, which looks at the contributions of upstream suppliers to the technological capacities of downstream firms via vertical supply chain linkages. Here, we may also add the literature on international knowledge 'spill overs' (Blomström and Kokko, 1998; Keller, 2002, 2010), which points out that global linkages are an important source of upgrading and productivity growth. Thirdly, there is the literature on the co-location of production and R&D. There are of course also studies that try to build bridges between these three main bodies of research. For example, Ramirez (2018) provides a conceptualisation of: (i) global innovation networks (GINs) within firms; (ii) knowledge-seeking inter-firm GINs;

(iii) contract-based inter-firm GINs; and (iv) GVCs on the production side. Subsequent research by the JRC collaborations (Dosso and Ramirez, 2020) linked GVCs and global knowledge sourcing by looking at knowledge-creating activities in multinational enterprises at different technology-readiness levels from basic research to development, prototyping and the start of the implementation. This paper is in the tradition of the second body of literature – the literature on GVC governance – but it follows a quantitative approach while most of the contributions made in the literature on GVC governance are qualitative.

The last decade saw increasing business expenditures on R&D (BERD) in almost all countries where data are available. Between 2010 and 2020, BERD at constant prices decreased only in Australia and Finland (OECD, 2022). Some countries saw considerable increases in BERD over this period. The most notable increase was in China where BERD more than doubled in this period, from USD 152.9 bn to USD 431.8 bn in purchasing power parity (constant prices). China surpassed the EU-27 during this period (EU BERD in 2020 was 252.2 bn USD PPP, constant prices). The rise of BERD in China challenges the observation that high-value activities such as R&D are largely located in advanced economies, while low-value activities in the middle of the 'smile curve' have moved to emerging economies (Mudambi, 2008).

3 Research Questions

Against this background, this paper investigates the R&D content of GVCs over the period 2010-2019. Our paper aims at improving the empirical foundation of current discussions on technological dependency. In particular we are interested in three interlinked topics, set out in the three paragraphs below.

Firstly, we ask how the total R&D content of GVCs has evolved over time. Which countries are highly dependent on imported R&D inputs? How has the ratio of R&D from GVCs to R&D from domestic sources changed over time? Is there any indication that dependency on foreign R&D has increased in most countries?

Secondly, we are interested in the countries that contribute to R&D in GVCs. Which countries provide the greatest R&D input into GVCs? Are there significant differences between countries/sectors in their role as knowledge sources?

Finally, a couple of questions arise around the role of Chinese R&D in GVCs. How has the dependency of the EU-27 on Chinese BERD developed over time in comparison with the dependency of the EU-27's other main trade partners on Chinese BERD? Does China's increasing BERD go into GVCs, or does it serve domestic demand?

4 Approach

We model dependency on R&D in GVCs based on the embodied R&D content of intermediate goods. The basic idea is simple: each stage of a value chain creates inputs which then become part of the final product. At the same time, production activities at each stage require R&D, which enters downstream stages of production embedded in the output of this stage.

Our paper is not the first one which applies this concept to knowledge. Previous contributions in this vein include Papaconstantinou et al. (1996), Hauknes and Knell (2009), or Fusillo et al. (2021). The idea that knowledge may diffuse via GVCs has also been used in models of direct and indirect greenhouse-gas emissions in international trade (see Yamano and Guilhoto, 2020 for a recent iteration of this literature). However, this paper is the first to apply the methodology to the question of technological dependencies.

We distinguish between the country that imports intermediate goods (receiving country), and the source country which exports these goods The total R&D use in the business sector of a receiving country consists of the business sector's own R&D efforts, plus the R&D efforts of domestic upstream sectors, plus R&D imported via GVCs. We create a proxy of the R&D content of each stage in a value chain by weighting the intermediate goods supplied to downstream stages by the R&D efforts of this stage. Thus, we can consider the R&D content of a certain good as the sum of the R&D efforts in upstream sectors and the producing sector's own R&D efforts. The decomposition of a value chain into its domestic and foreign upstream components weighted by their R&D content makes it possible to measure the direct and indirect R&D content in GVCs.

We base our analysis on input-output tables that trace the flows of goods for intermediate or final use throughout an economy. The analysis will use annual inter-country input-output tables from FIGARO (Full International and Global Accounts for Research in input-Output analysis) provided by Eurostat (see next section). An important feature of FIGARO is that the input-output tables of individual countries are linked by imports and exports of intermediate and final goods. This makes it possible to analyse GVCs across countries. R&D data includes expenditures on research and development by the 2 500 companies with the largest R&D expenditures worldwide. We aggregate both FIGARO and R&D expenditures data to the NACE 2-digit industry level and country level.

There are two ways to look at embodied R&D content in GVCs. Firstly, it can be looked at from the perspective of the 'receiving' country that uses R&D for its own production. Secondly, it can be looked at from the perspective of the 'source' country which contributes R&D to production activities in other countries.

We start with the perspective of the receiving country. In a first step, we calculate an R&D input coefficient vector $\mathbf{r}$ by dividing R&D expenditures by gross output. The total R&D content of final goods production consists of domestic and GVC (imported) R&D content and is calculated as:

$$\mathbf{RDc}_{\mathrm{f}}^{\mathrm{total}} = \left(\mathbf{r}' \cdot \mathbf{L} \cdot \hat{\mathbf{f}}\right)'$$

where $\mathbf{L}$ is the global Leontief inverse and $\mathbf{f}$ the final demand vector. ^ denotes the diagonalised final demand vector. We relate R&D content to final goods production and not to gross output because this avoids double counting.

We can now separate the total R&D content into purely domestic R&D and imported R&D embodied in GVCs. The purely domestic R&D content includes R&D by the sector itself as well R&D in domestic upstream sectors and is calculated as:

$$\mathbf{RDc}_{\mathrm{f}}^{\mathrm{dom}} = \left(\mathbf{r}' \cdot \bar{\mathbf{L}} \cdot \hat{\mathbf{f}}\right)'$$

where $\bar{\mathbf{L}}$ denotes the (block-diagonal) Leontief inverse. The results are aggregated over industries to the country level. The difference between the global and the domestic R&D content can be interpreted as 'imported' (i.e. not purely domestic) R&D content. Imported R&D thus also includes domestic R&D which was supplied into GVC activities and then re-imported.

However, absolute values for R&D content are difficult to compare across countries. This is why we calculate indicators based on the share of imported R&D in total R&D for each country as:

$$\mathbf{shRDc_f} = \frac{\mathbf{RDc_f^{c,dom}}}{\mathbf{RDc_f^{c,total}}}$$

An economic interpretation of this indicator is that it shows the degree to which goods production in a particular country is dependent on foreign technology relative to domestic R&D efforts. However, this interpretation has to be taken with a grain of salt because of the non-rival character of R&D (Foray, 2004): R&D embodied in imported intermediate goods do not exclude that the same R&D activities also benefit the enterprise in the source country.

A second perspective is that of the 'source' country that contributes R&D to the production processes of all other countries. This perspective shows how much R&D from a particular country is embodied in the final demand or export output of all other countries or, in other words, how much a particular country's R&D contributes to production in other countries in terms of R&D. In practice, all countries are at the same time always both source and receiving countries.

Domestic and GVC R&D source figures are calculated as:

$$\mathbf{RDs}_{\mathrm{f}}^{\mathrm{total}} = (\hat{\mathbf{r}} \cdot \mathbf{L} \cdot \mathbf{f}) \qquad \text{and } \mathbf{RDs}_{\mathrm{f}}^{\mathrm{dom}} = (\hat{\mathbf{r}} \cdot \bar{\mathbf{L}} \cdot \mathbf{f})$$

where $\mathbf{L}$ and $\bar{\mathbf{L}}$ denote the global and purely domestic Leontief inverses, and f is the global final demand vector. These are aggregated over industries to the country level.

We calculate the share of a country's R&D in global final goods production as:

$$\mathbf{shRDs_f^{c,total}} = \frac{\mathbf{RDs_f^{c,total}}}{\sum_c \mathbf{f}^c} \quad \textbf{and} \quad \mathbf{shRDs_f^{c,dom}} = \frac{\mathbf{RDs_f^{c,dom}}}{\sum_c \mathbf{f}^c}$$

This measure can, for example, be compared with country c's share in global R&D expenditures. The difference between $\mathrm{shRDs_f^{c,total}}$ and $\mathrm{shRDs_f^{c,dom}}$ indicates how much a country contributes to R&D in global final demand via GVC integration (irrespective of whether consumption takes place in the same country or in other countries).

The analysis utilizes annual inter-country input-output tables at sectoral level from FIGARO (Full International and Global Accounts for Research in input-Output analysis) provided by EUROSTAT. FIGARO edition covers the years 2010 to 2020 and includes data for EU Member States, the United Kingdom, the United States, China, and the main trade partners of the EU.

Data on business R&D expenditures (BERD) at the sectoral level have been proxied by the 2021 EU Industrial R&D Investment Scoreboard. This data set includes R&D figures for the 2 500 companies with the largest R&D expenditures worldwide based on their latest published accounts and covers 90% of the global R&D by the business sector (Grassano et al., 2021). These data were converted to EUR using nominal exchange rates and aggregated at NACE two-digit level.

Like in most research, there are also some limits to the conclusions which can be drawn with this methodology. For example, firms not only benefit from R&D embodied in intermediate products, but also from R&D embodied in investment goods which are not part of intermediate goods. One example of this is the use of robots, which embody considerable amounts of R&D and help user industries to become more efficient (Koch et al., 2021). Thus, the result is more likely to underestimate than overestimate the amount of R&D embodied in imports. However, any error due to this embodiment of R&D in, given that imports of investment goods have at least the same R&D content as intermediate goods. The error should not be too large. A previous study (Hauknes and Knell, 2009) which included investment goods found that their contribution to overall embodied R&D is much smaller than their contribution to intermediate goods.

The analysis uses annual inter-country input-output tables at sectoral level from FIGARO (Full International and Global Accounts for Research in input-Output analysis) provided by Eurostat. The 2022Various authors, starting with Griliches (1979), have suggested to measure the contribution of R&D not by annual R&D investments, but by the flows of knowledge from a stock of R&D investments accumulated over time. However, due to some problems with this approach including the calculation of this R&D stock and of an annual depreciation rate for the R&D stock, the majority of studies in the past has used annual R&D investments. We will also measure embodied R&D by annual R&D investments in the source country and sector.

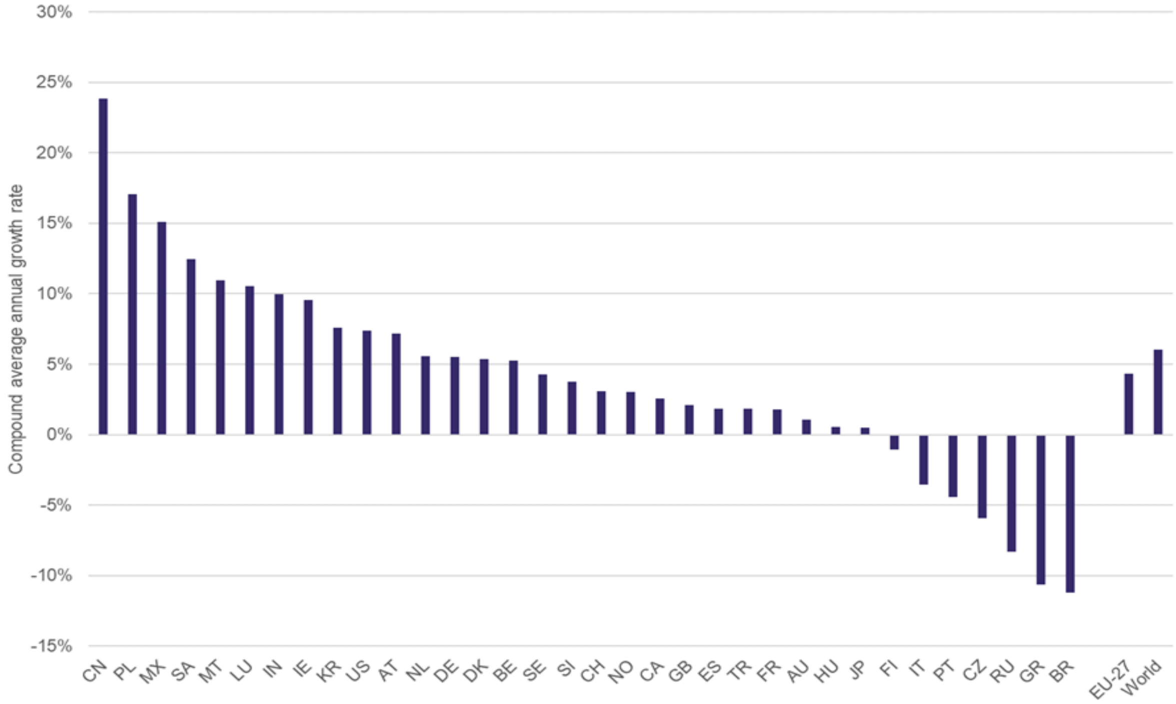
Nominal exchange rates may be another limitation to the study. Nominal exchange rates may underestimate R&D activities in China or India because their currencies are undervalued compared with purchasing power parities. However, applying purchasing power parities would considerably change the relationships in FIGARO because this data is also in nominal, not real terms. Moreover, there is no price deflator available for R&D services across countries, and a general deflator might bring additional bias into the data.

When interpreting the results, it is also important to consider that all R&D expenditures are counted by the home country of the company. Thus, if a country has a high share of R&D by companies that are not in the top 2 500, or a large share of foreign-owned firms on business R&D expenditures, their aggregate R&D expenditures according to the Scoreboard are lower than according to OECD and Eurostat data on R&D. This is the case for some smaller countries such as Austria, Belgium, Slovakia, or Slovenia. Here, we have to consider that the indicators will reveal greater dependence dependency on imported R&D than indicators based on OECD and Eurostat data on R&D. On the other hand, if a country hosts large multinational companies with global R&D activities, the significance of that country's domestic R&D may be overestimated. Some countries do not have any companies in the top 2 500. These countries have been removed and only included where no comparison with domestic R&D expenditures is made.

The data indicate that global business R&D expenditures of the firms in the EU Industrial R&D Investment Scoreboard nearly doubled between 2010 and 2020, from EUR 480 bn to EUR 939 bn in 2020. This is a dramatic increase if we assume that this means a doubling of global capacities to solve the world's most pressing challenges. Half of this increase in absolute terms originates from the United States, where R&D expenditures grew by EUR 193 bn. This was followed by China with an increase in BERD of around EUR 132 bn.

Figure 2 below provides more information on the growth of R&D business R&D expenditures in the companies analysed in this paper by the main location in which the company is based. While business R&D expenditures over the period 2010-2020 climbed to reach an annual compound growth rate of 7.8% in the United States and 23.9% in China, the corresponding value for the European Union was only 4.3%. This was mainly due to slow growth in large Member States (including France, Germany, and Spain) compared with the US and the world average. But some small countries such as Finland, Denmark or Sweden also grew more slowly than the world average.

Figure 2. Compound annual growth rate of business R&D expenditures in different countries, 2010-2020



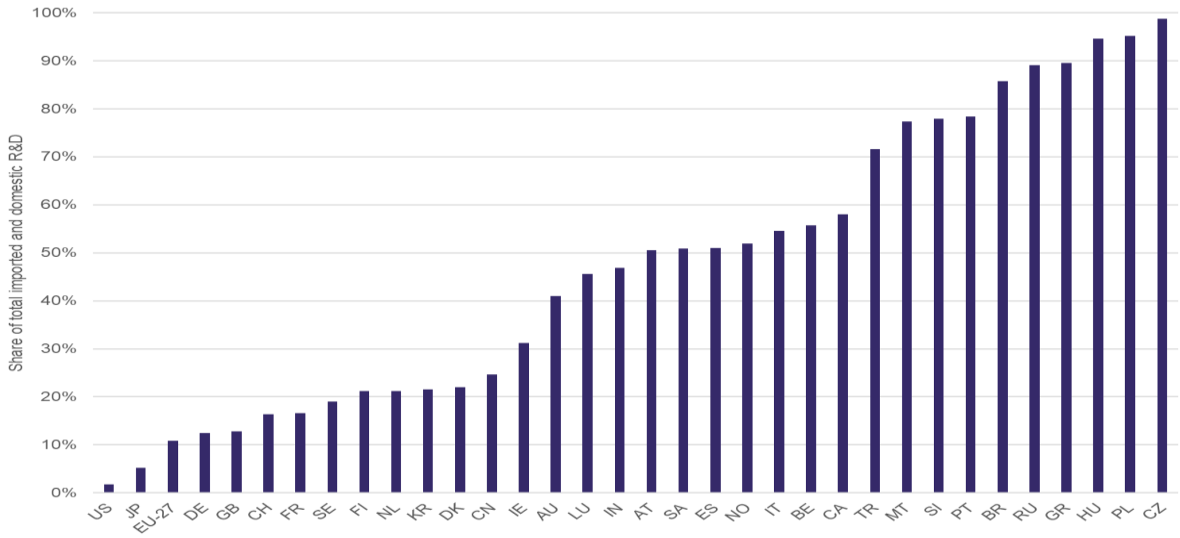
Source: EU Industrial R&D Investment Scoreboard; own calculations

In contrast to Western Europe, recent years have seen a period of rapid catching-up in some central and eastern European EU Member States, in particular Poland, where BERD is now growing more quickly than in the US.

5 Dependency on R&D in GVC over time

In a next step, we calculate domestic and imported business R&D via GVCs at country level that are used directly and indirectly in the production of final goods. We create an indicator of dependency by relating imported R&D use to total (domestic and imported) R&D use (see Figure 3 below). Dependence on imported R&D is lowest in Japan, the United States, and Germany, where this share is below 20%. The EU-27 has a slightly higher value in the dependency indicator compared with the US and Japan. China is also one of the countries with a lower level of dependency on imported R&D. On the other side of the distribution there are several countries where the indicator is more than 50%, which indicates that most R&D used in products from these countries originates from abroad.

Figure 3. Share of imported R&D on total R&D use in different countries, 2020



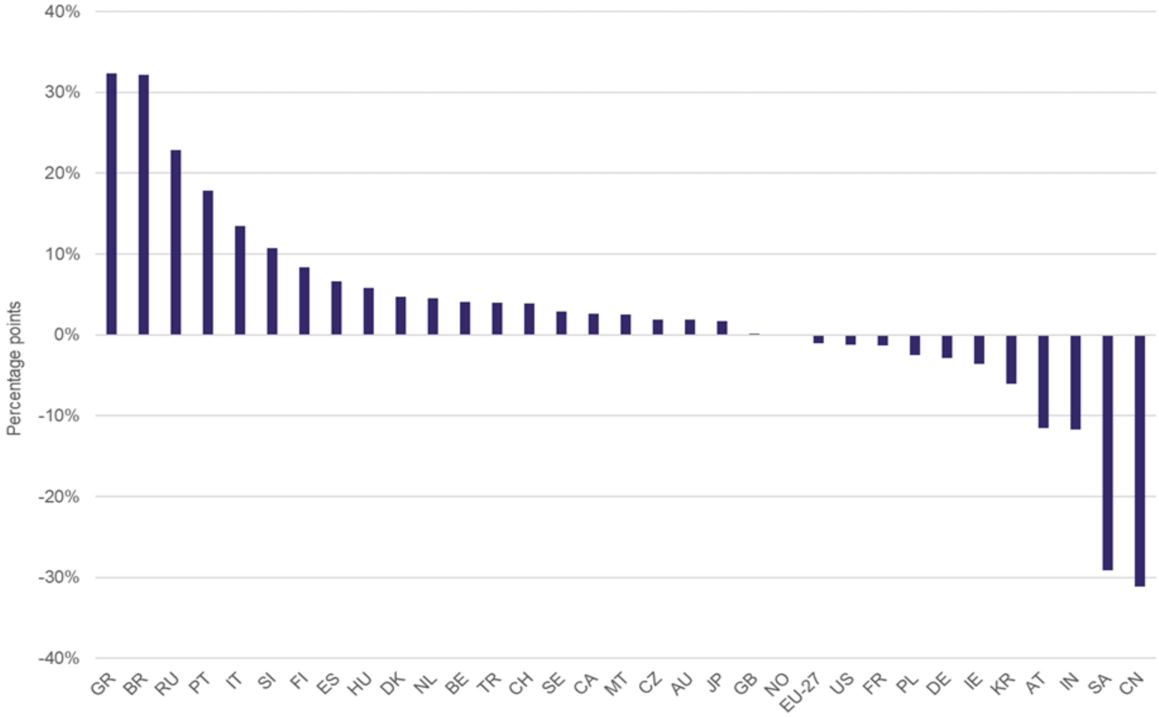
Source: Eurostat, EU Industrial R&D Investment Scoreboard; own calculations

The data indicate a negative relationship between the share of imported R&D in total R&D and the size of the country. The correlation coefficient between the indicator and GDP in absolute terms is -0.4. The highest levels of dependency are found in small countries. Sweden and Switzerland, as two smaller countries which weight above their size in terms of their share of global R&D investments are exceptions here. This can be explained by the higher degrees of trade openness in some smaller countries. Moreover, not all relevant knowledge may be available in smaller countries, which may also lead to higher reported shares of imported R&D. In contrast to country size, domestic R&D capabilities (measured by domestic R&D as a share of gross output) have a clearly negative relationship with the share of imported R&D. Thus, domestic capabilities are a substitute for imported R&D and for dependency on foreign sources of R&D. The idea of reducing dependencies by improving domestic R&D capacities is also found in some recent EU industrial policy documents (European Commission, 2021b, 2022b).

The next Figure 4 presents the change in the share of imported R&D in total R&D expenditures over time. In around half of the countries, imported R&D accounted for a higher share of total R&D in 2020 than it did in 2010m, which indicates that dependency on foreign R&D increased in these countries during that decade. Some examples of this greater dependency on foreign R&D in the EU are Greece, Italy, Slovenia, and Finland. However, in large countries such as Germany and the United States, dependency on foreign R&D remained unchanged over this period. This is also true for the EU-27 as a whole, where dependency on foreign R&D decreased by a mere 1.1 percentage points over the last decade. China, Saudi Arabia, and India reduced their dependency on imported R&D considerably in the last decade. However, data for these countries may suffer from limited comparability due to different price levels.

However, Figure 4 shows no clear trend towards higher dependency across countries. Dependency on foreign R&D changed only little for the large countries and the EU as a whole in particular. In some countries technological capacities in terms of domestic R&D increased faster than imported R&D despite increasing imports, leading to less, not more dependency. Current discussions on technological dependency therefore may rather reflect changing perceptions of dependency and an increased importance of autonomy than changes in the economic fundamentals.

Figure 4. Change in the share of imported R&D in total R&D use in different countries, percentage points, 2010-2020



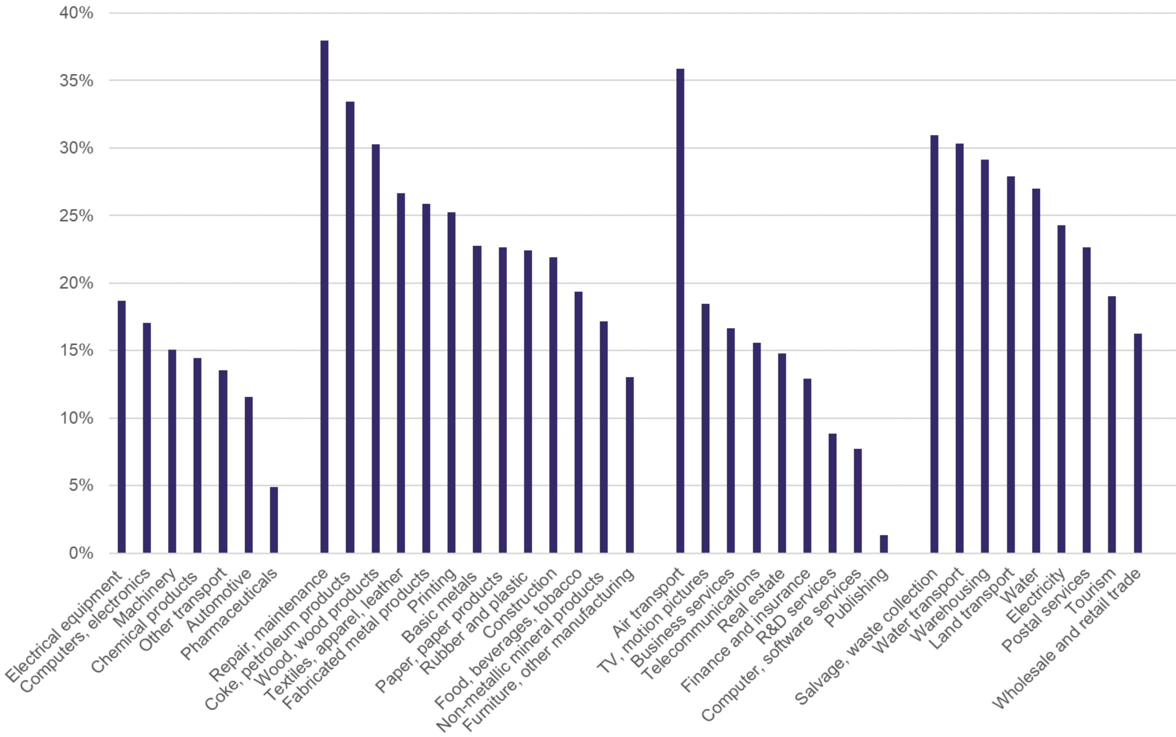
Source: Eurostat, EU Industrial R&D Investment Scoreboard; own calculations

Sectoral differences are a significant driver of technological dependency at country level. Countries which host a high share of industries that are dependent on imported technology will reveal higher overall dependency. Figure 5 below depicts the share of imported R&D in total R&D use for different manufacturing and service sectors at NACE two-digit level in the EU. The sectors are grouped into high-technology sectors (first group left), low-technology sectors (second group), knowledge-intensive services (third group), and less knowledge-intensive services (last group to the right). The classification has been provided by Eurostat (2014, 2016). We have excluded intra-EU trade to make the data for the European Union as a whole comparable with other countries.

The figure reveals that the EU as one single entity has high dependencies on foreign R&D of 30% or more for 4 sectors, 3 of which are low-tech sectors. For high-tech sectors and knowledge-intensive services, there are lower levels of dependency on foreign R&D than there are in low-tech sectors. Thus, the degree of dependency is correlated with the degree of R&D intensity of sectors. This may be related to the fact that low-tech, supplier-oriented industries receive technology not through their own efforts in R&D but embodied in products from upstream sectors. Results from a previous study (Hauknes and Knell, 2009, Table 1) also show there is a higher share of imported R&D inputs in total R&D content in supplier-oriented industries. The topic could also be further investigated with a decomposition analysis that separates structural from R&D intensity effects.

Some high-tech sectors such as pharmaceuticals, automotive, or other transport equipment (including aerospace) rank in the lower half of the distribution, with dependencies on foreign R&D of 15% or less, which indicates that their dependency is less than that of other industries. Low dependence on foreign R&D in motor vehicles and other transport equipment indicates the EU's global technological leadership in these sectors, which is also confirmed by the Scoreboard. In pharmaceuticals, the Scoreboard shows that US multinationals have widened the gap in R&D investments to their EU counterparts. Our data indicate that the EU has only low dependency on foreign embodied R&D. This means that, at the aggregate level, pharmaceuticals production in the EU is highly autonomous in terms of the knowledge it needs to create new products. The Scoreboard also indicates that imports of pharmaceuticals into the EU are much less R&D intensive than the goods produced in the EU. However, dependencies on foreign R&D may also emerge at the level of individual substances and products which this analysis is not able to capture.

Figure 5. Share of imported R&D in total R&D use in different EU industries, 2020

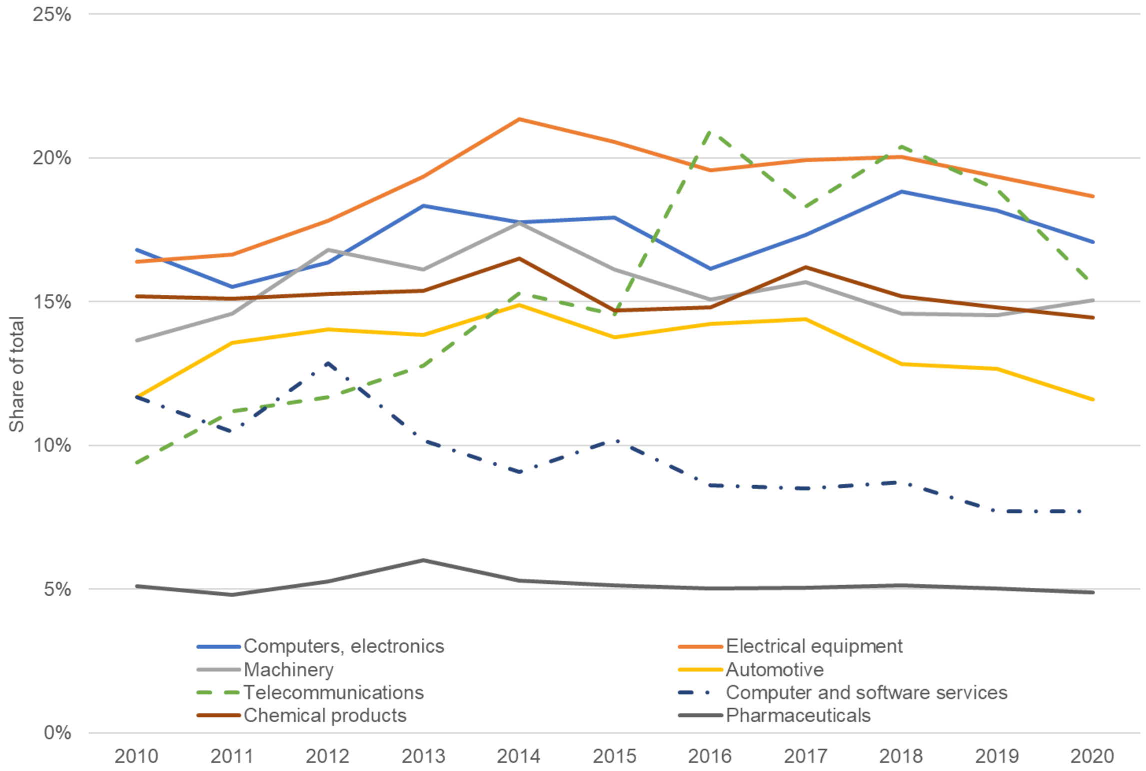


Source: Eurostat, EU Industrial R&D Investment Scoreboard; own calculations

It is difficult to compare dependencies on foreign R&D at sectoral level across countries, because much depends on how well-represented a particular country is in the Scoreboard. As mentioned above, there may be a bias towards larger countries. However, we can compare the dependencies of important sectors in the EU over time. This is done in Figure 6 below.

In general, dependencies change only slowly over time. This means that the current dependencies of the EU economy have not emerged overnight but are instead the result of decades-long processes. The largest shift in the industries included in the figure can be observed in the telecommunications industry, where EU dependency on foreign R&D in GVCs increased by 50% in the last decade. This reflects the rise of telecommunication equipment vendors from Asia. Software and internet services, in contrast, were able to decrease their dependency by a third.

Figure 6. Changes in the share of imported R&D in total R&D use in selected EU industries, 2010-2020

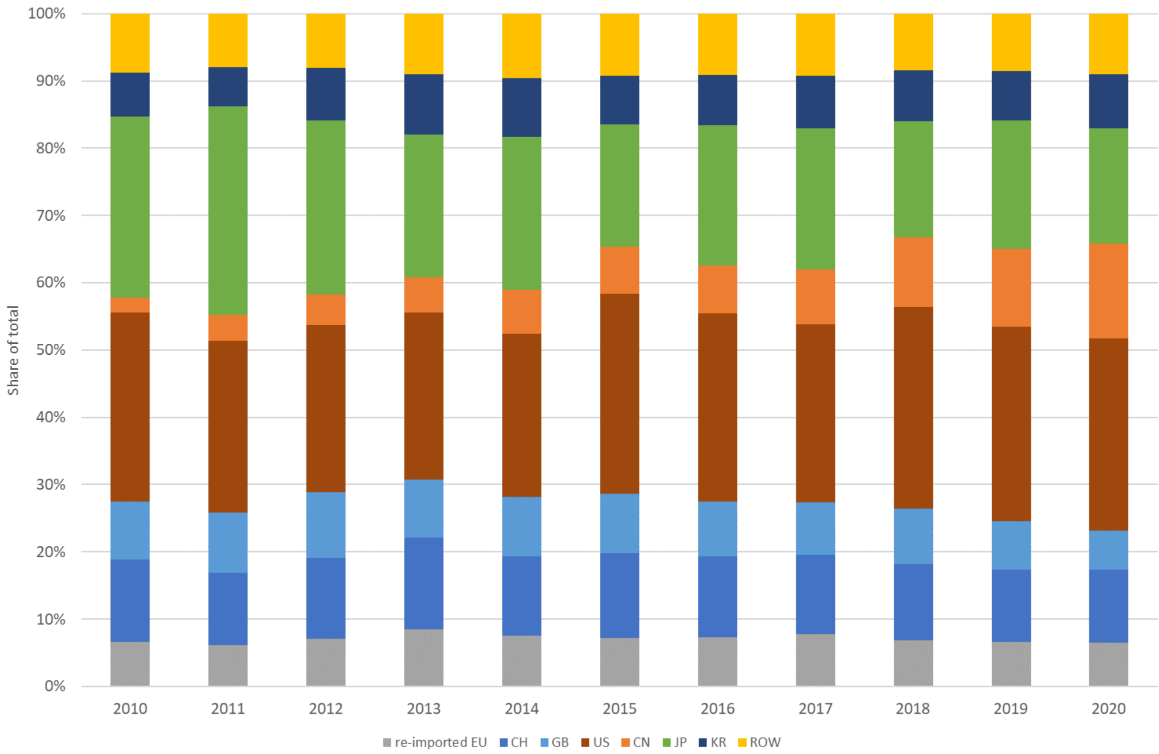


Source: Eurostat, EU Industrial R&D Investment Scoreboard; own calculations

We will have a closer look at the sources of GVC R&D in the automotive industry in the next figure. The many car manufacturers in the Scoreboard, and the fact that the automotive sector is one of four sectors which account for more than three quarters of total Scoreboard R&D, indicates that R&D is a key driver for the competitiveness of this industry. The EU automotive industry relies mostly on R&D carried out within the EU, as Figure 5 above indicates.

Imported R&D in the EU automotive industry mainly originates from the United States and Japan, with smaller contributions also coming from China, Switzerland, and Korea. The position of Switzerland may be surprising in this context, but Switzerland has one large automotive supplier (TE Connectivity) and several other supplier industries outside the automotive sector, such as electrical equipment or chemical products. Overall, R&D imports to the EU from the rest of the world (ROW) and Asian countries have increased in the last decade, despite decreasing shares of imports to the EU from Japan. A considerable part of imported R&D is also re-imported R&D by EU firms, for example when a German firm supplies intermediate products to a UK company which are then re-imported to the EU.

Figure 7. Source countries of imported R&D in the automotive industry in the EU, 2010-2020



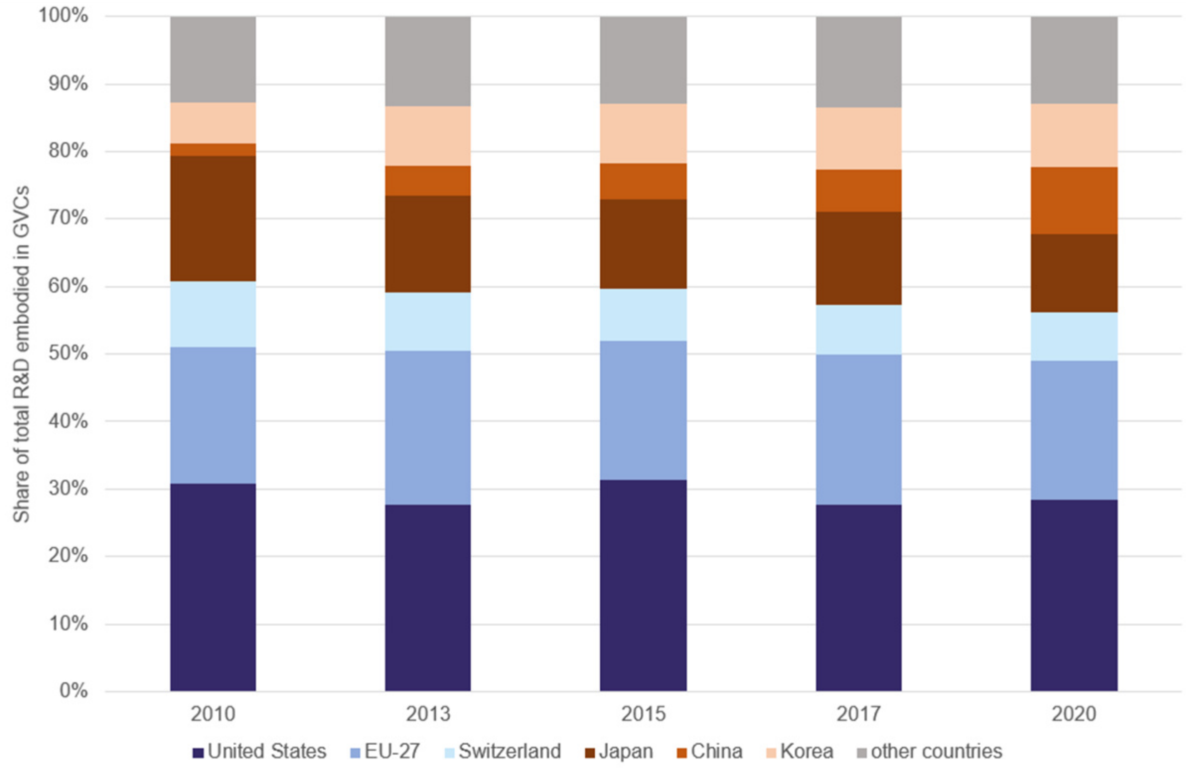
Source: Eurostat, EU Industrial R&D Investment Scoreboard; own calculations

6 Source countries for embodied R&D and the role of China

We now move to the perspective of source countries. Thirty years ago, most of the global R&D investments of firms – with the exception of firms in Japan – were concentrated in the United States and in Europe. The rise of emerging economies in Asia has brought new players and de-concentration (i.e. global R&D investment is no longer quite as concentrated in the United States and Europe). We relate the contributions of individual countries to R&D in GVCs to the total amount of R&D embodied in these GVCs. What remains of the total R&D expenditures of countries goes into domestic use. The result can be seen in Figure 6 below.

The United States and the EU still account for around half of all the R&D that diffuses into GVCs, followed by enterprises from Japan, China, Korea, and other countries not explicitly mentioned in Figure 6. The share of China is considerably smaller than the shares of the US and the Member States of the EU. Altogether, we see decreasing concentration in R&D supplied into GVCs, which also means that technological capabilities worldwide are more evenly distributed than they were 10 years ago. The combined share in embodied R&D of the United States and the Member States of the EU dropped by 2 percentage points from 51% in 2010 to 49% in 2019, while Japan's share also shrank. The biggest increase in embodied R&D was in Asian countries, some of which are also included under 'other countries'. Growth rates for R&D used domestically and for R&D that entered GVCs show that, in the EU-27, R&D that entered GVCs increased faster, while in the United States R&D used domestically grew faster. In China, both components grew at the same rate.

Figure 8. Share of different countries out of total R&D embodied in GVCs, 2010-2019



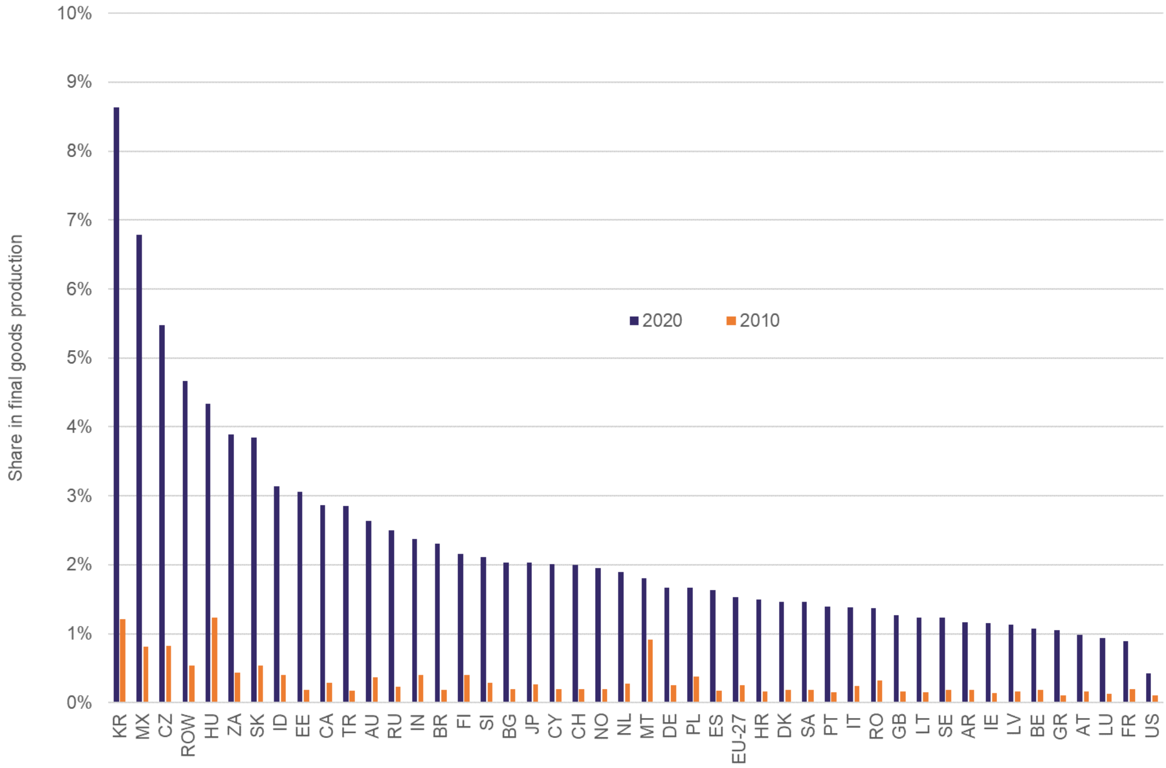
Source: Eurostat, EU Industrial R&D Investment Scoreboard; own calculations

Technological dependency has become an issue in economic policy discussions mainly because of China's growing weight in the world economy. It is therefore important to have a closer look at China's contributions to technological knowledge in other countries via GVCs. We did this by eliminating all R&D inputs from other countries into GVCs except for the R&D inputs of China.

Figure 9 below depicts R&D imported from China as a share of the value of total final goods production for 2020. A high share indicates strong technological dependency of these economies on China. We find high values in Korea and Mexico, but also in some central and eastern European countries such as Hungary or Czechia. The figure also reports increased regional integration between China and other Asia-Pacific countries such as Korea, Indonesia, or Australia, a trend that that has been labelled 'Factory Asia' (Baldwin and Freeman, 2021). Some Asian countries are also included in the ROW aggregate.

The EU are on the whole is less dependent on technology from China than Japan are. This can mainly be explained by the share of China in imported value-added content of final demand of the other Asian countries, which is lower in the EU but more dependent than it is in the United States. The figure below also shows the corresponding values for 2010, which give some indication of the dynamics of dependency on China. The share of China in R&D in total final goods production at least doubled in all countries, and growth was stronger in small countries on average than it was in larger countries. Despite this rapid growth, China still accounts for only a tiny fraction of total imported R&D. Overall, the patterns for 2010 and 2020 seem quite similar, so there are only a few countries that had little or no dependency on Chinese R&D in 2010 but high dependency in 2020. Thus, dependency grew at a roughly comparable rate in all countries.

Figure 9. Share of imported R&D from China in total final goods production, 2010 and 2020

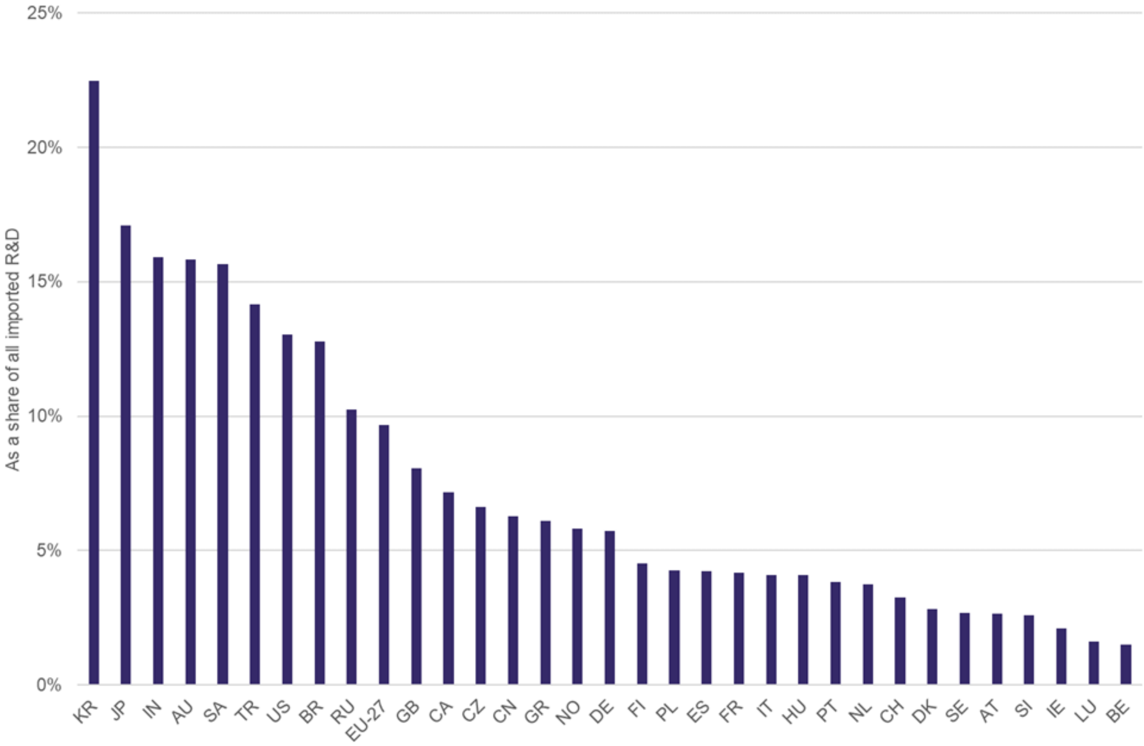


Source: Eurostat, EU Industrial R&D Investment Scoreboard; own calculations

Finally, we can also relate R&D imported from China to the total amount of R&D imported at country level to compare specialisations across countries. The results of this comparison are presented in Figure 10 below.

Here, the Member States of the European Union together are less dependent on technology from China than the United States or Japan. A lot of the results can be explained by simple arithmetic: China inevitably has a larger share in intermediate imports of large countries because small countries cannot supply the volumes needed to become a significant trade partner of the United States or Japan. Accordingly, the highest values are found in the United States, India, Japan, Korea, and the EU. Moreover, there is also an effect of geographical proximity visible in the Figure. Asian countries tend to have higher values than European countries.

Figure 10. Share of imported R&D from China in total imported R&D, 2020



Source: OECD, Eurostat, national statistical offices; own calculations

7 Conclusions

This paper contributes to the growing literature that links international relations to the technological capabilities of countries and GVCs. Governments increasingly consider these two issues as interrelated, so it is important to provide sound empirical evidence to inform discussions in this area. We investigated the dependency of countries on foreign technology proxied by R&D embodied in imported intermediate products. The study applied input-output analysis and combined this with sectoral R&D data for the period 2010 to 2020.

R&D expenditures have increased in almost all countries included in the analysis. However, R&D expenditures in the EU grew more slowly than they did in China, Korea, and the US, so the EU has lost share in global R&D output in the last decade.

We found no general trend for rising dependencies on foreign technology. The share of imported R&D in domestic and imported R&D increased in around half of the countries in our analysis, while it decreased in the other half of the sample and remained unchanged in the United States and in the EU-27. At sectoral level, the highest degrees of dependency in the EU-27 are found among the main sectors in telecommunications, computers and electronics.

China was able to reduce its own dependence on foreign R&D due to its fast-growing domestic R&D expenditures. A similar development can also be observed in some Central and Eastern European Member States. The data also confirm that dependency on China in terms of imported R&D has at least doubled in most countries over the last decade. In addition, regional integration in terms of technology flows between Asian countries is much higher today than it was 10 years ago.

EU policymakers worry about the EU's growing dependence on China. Dependency has indeed grown in recent years. However, the EU is still less dependent on China than the US or Japan are, although there are notable differences in the level of dependence between different EU Member States. Moreover, one of the reasons for growing dependency is also that R&D investments have increased more slowly in the EU than in China and the US. The question for EU policy should instead be how to improve R&D capabilities in the EU rather than how to reduce dependencies.

One strategy proposed by the European Commission is to build up domestic capacities in strategic fields (European Commission, 2021a). The EU Chips Act, which aims at doubling the share of the EU in the global production of microchips, is an example for this approach. The results of this paper provide some support for this strategy – we see that countries with strong domestic R&D capabilities have a lower share of imported R&D in total R&D. This is not necessarily a trivial conclusion, since countries with high shares of imported R&D often reveal low overall R&D intensities.

One example of a policy measure at the European level is the Important Projects of Common European Interest (IPCEI), pan-European consortia aimed at developing industrial pilot applications in fields that are considered strategic for Europe. IPCEIs already exist for batteries, microelectronics, or the production of hydrogen for industrial applications. A European approach should also be favoured in other fields where the EU wants to reduce dependencies on foreign R&D. Another answer to growing dependencies is diversification of sources. However, diversification is difficult for large countries, as potential trade partners need to have a certain size to be able to supply in sufficient quantities. This explains some of the rising dependency on China.

However, the goal of reducing dependencies should not be confused with the search for self-sufficiency. Knowledge is often cumulative and builds on the results of scientists and engineers from other countries. Innovation increasingly concentrates in a small number of places worldwide (Paunov et al., 2019), and it is not certain whether these innovation ecosystems can simply be replicated somewhere else. Moreover, Europe will need to cooperate with the United States, China, and other countries to tackle the challenges such as climate change. In this perspective, thinking in terms of dependencies may block the way for necessary solutions.

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