Joop Adema, Yvonne Giesing, Julia Gorochovskij and Tanja Stitteneder[1]

Innovation – Global Trends and Regulation

In view of an increasingly interconnected world, countries have been competing for innovative ideas, a skilled workforce, and the development of ever newer technologies. To keep up, economies need policies that enable and promote innovation. Such policies focus in particular on establishing an ecosystem where new ideas can flourish and enter the market and where sources of funding are available to enable R&D activities, and ultimately innovation.

In recent years, the EU has spent less on research and development (R&D) than other major economies such as Japan and the US; therefore the concept of an *Innovation Union* has been developed, aiming at "creating better jobs, building a greener society, and improving our quality of life, but also to maintaining EU competitiveness in the global market" (European Parliament 2019). In this context, indicators have been introduced to measure and monitor innovation across different European countries. Furthermore, the research initiative *Horizon 2020* was launched as the EU's flagship initiative to allocate funding to R&D and other scientific and social projects, with a total budget of around EUR 75 billion. Some EU countries have also taken note of the issue and developed their own measures to foster innovation. Germany, for example, initiated its *High-Tech Strategy – Innovation for Germany* to promote research, technology, and innovation (BMWi 2019). The strategy constitutes programs to promote innovation and bring research to the market, in particular for small and medium-sized enterprises (SMEs). Even though firms often rely on internal financial sources to fund innovation, it seems as if other means of funding, e.g., government and private sector funding, have become increasingly important (Spielkamp and Rammer 2009).

Generally, government or public funding can be either direct (through the allocation of funds to specific R&D projects) or indirect (through subsidies or tax incentives). Within direct project funding, the government keeps a good overview on where the funds go. Since direct public funding allows the government to select very specific projects, sectors, etc., it actually gives the authorities a certain degree of influence over the direction in which research is carried out. However, project-based funding is often associated with a long and complex application process, which comes with high workloads and potential bureaucratic hurdles.

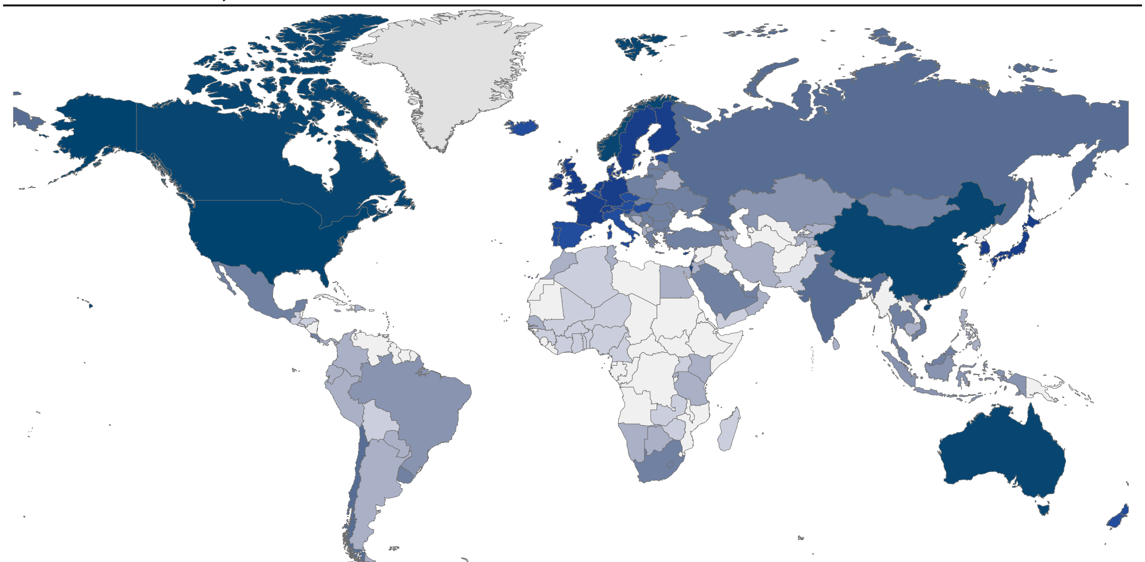
Indirect public funding, on the other hand, grants support automatically and thus saves companies and public authorities a lengthy application procedure. In addition, SMEs with possibly less experience in grant application can receive the same financial support as bigger, more experienced enterprises. On the downside, the government may lose control over what and whom exactly it finances.

Private sector investments, such as bank loans or venture capital investments, constitute another source of funding for R&D. Although potentially high-risk businesses may not always receive funding from the private sector, more resources may eventually be allocated if the application turns out to be successful. At the same time, companies that receive private sector financing

[1] ifo Institute (all authors).

Figure 1

Global Innovation Index, 2018



Note: Dark shades indicate higher scores and thus a higher degree of innovation.
Source: Cornell, INSEAD, and WIPO (2018).

must maintain high financial discipline. In addition, they may have to exchange shares in return, thereby accepting a loss in control over the company (Spielkamp and Rammer 2009).

The present article begins by describing some important innovation measures in terms of effort and output across various OECD countries and China. Next, two global trends – venture capital financing and artificial intelligence as a key technology – will be discussed in more detail, with each section providing a broad overview as well as discussing regulatory opportunities and challenges. The section will also argue that innovation does not just require policies to promote innovate thinking and working, but also clear rules on possible consequences that can arise as innovation progresses. Finally, a summary concludes the article.

COUNTRY COMPARISON

In order to assess the extent to which countries are innovative, we turn to the Global Innovation Index (GII). The GII is a single summarizing statistic for innovation on the country level, ranging from 0 to 100. It represents a weighted average of indicators for both the effort to be innovative and the outcome that is achieved. In general, the GII strongly correlates with GDP per capita (Figure 1): industrialized countries score better than African, most Asian, and South American countries. China, however, scores better than some Western European countries such as Italy and Austria.

We turn to several useful indicators to consider differences in approach and success of fostering and financing innovative enterprises. Table 1 shows indicators for the public and private effort put into innovation for a selected group of OECD countries and China.

Although lacking a thorough separation between R&D and innovation, R&D is considered to represent the underlying inventions that foster innovation (Rogers 1998). Gross expenditures into whole R&D as a percentage of GDP (GERD, which can be subdivided into business enterprise, higher education, and non-profit) are several percent of GDP for the countries in scope. South Korea devotes the largest share to R&D (4.5 percent), more than three times as much as Italy (1.35 percent). Compared to this total expenditure, venture capital (VC) investments in seed-phase and start-up companies contribute approximately only 1 percent to total R&D investments. Sweden's figure of 0.14 percent of GDP sharply contrasts with that of Germany, which has only 0.005 percent. To consider the government role in business innovation, we turn to both indirect (through tax advantages) and direct government funding of the business enterprise part of R&D (BERD) expenditures as a percentage of GDP. In 2016, tax advantages for R&D expenditures amounted to 0.25 percent of GDP in Italy, whereas they were non-existent in Germany and Switzerland. For most countries, direct government funding is smaller than indirect government funding.

To assess the effort in R&D in terms of workforce, we consider the number of researchers per 1,000 people employed. Around 1 percent of the total workforce of the countries in scope is considered a researcher, ranging from 2.2 (China) to 15.5 (Denmark) per 1,000 employees.

To consider the extent to which knowledge is spread by training the future workforce, we resort to the public and private expenditures towards tertiary education. Together this amounts to a share of between 0.9 percent (Italy) and 2.8 percent (Canada) of GDP. However, there are large differences between who

Table 1
Measures of Innovation Effort in Selected Countries

	Gross Exp on R&D expenditures (% of GDP, 2018)	VC Investments in seed phase (% of GDP, 2016)	Number of researchers employed (per 1000 employed, 2017)	Indirect (tax advantages) government funding of BERD (% of GDP, 2016)	Direct government funding of BERD (% of GDP, 2016)	Public financing of tertiary education (% of GDP, 2016)	Private financing of tertiary education (% of GDP, 2016)	Ease of doing business: starting a company (Score, 2018)
Austria	3.16	0.009		0.15	0.12 (2015)	1.615	0.09	83.21
Canada	1.59	0.087		0.13	0.05	1.21	1.28	98.23
China	2.13		2.2	0.06	0.06			93.52
Denmark	3.06	0.025	15.5	0.02	0.05 (2015)	1.56	0.09	92.52
EU-28	1.96		8.3					
Finland	2.76	0.039	14.5		0.06	1.71	0.06	92.43
France	2.19	0.018	10.3	0.28 (2015)	0.13 (2015)	1.14	0.31	93.27
Germany	3.022	0.015	9.3	0	0.07	1.03	0.17	83.58
Italy	1.35	0.005	5.4	0.25	0.03	0.61	0.32	89.50
Japan	3.20	0.019	10	0.11	0.02	0.5	0.96	86.1
Netherlands	1.99	0.014	9.4	0.17	0.02	1.17	0.5	94.31
South Korea	4.55		14.4	0.14	0.14	0.775	1.48	95.83
Spain		0.018	6.8	0.03	0.06	0.85	0.39	86.91
Sweden	3.33	0.021	15.0			1.442	0.18	94.69
Switzerland		0.029		0 (2015)	0.03 (2015)	1.28		88.41
UK	1.66	0.019	9.0	0.15 (2015)	0.08	0.47	1.22	94.58
US	2.79	0.140			0.13	0.92	1.73	91.23

Source: Authors' compilation of various sources (2019).

Table 2

Measures of Public and Private Outcome Concerning Innovation

	Share of innovative enterprises (%, 2016)	Innovation intensity[3] (% of firms turnover, 2016)	Triadic patent family (number, 2018)	Growth of patent applications (R&D intensive techno-logies (2006-2016))	Foundation rates[2] (% of firms, 2016)
Austria	62	2.2	424.7		6.6
Canada			535.9	-21	
China			3890.3	671	
Denmark	52	3.3	298.4		12
EU-28	51		13660.3	2	
Finland	65	2.5	309.1	-21	6.9
France	58		2450	5	9.7
Germany	64	3.1	4520.3	-3	6.7
Italy	54	1.4	845.6	-11	7.7
Japan			17390.9	29	
Netherlands	60	1.6	1364.3	-2	9.6
South Korea			2598.6	67	
Spain	37	1.2	253.1		10.0
Sweden	54	3.8	678.9	26	7.0
Switzerland			1211.4	7	7.0
UK	59		1694.2	-6	15.0
US			14220.8	-1	

Notes: [2] Foundation rate: Number of company foundations in relation to the number of companies. [3] Innovation intensity: Innovation expenditure of enterprises in relation to total turnover.

Source: Authors' compilation of various sources (2019).

bears the cost. For example, Austria, Denmark, and Finland rely almost completely on public funding, whereas in South Korea, the UK, and the US the majority of education spending is privately borne.

Not only the financial but also the regulatory environment is important in fostering innovation. The World Bank's *Ease of Doing Business* database aims to give a score to several experience-based indicators per country, based on surveys conducted among experts. One of those is *Starting a Business*, which is particularly interesting in the context of innovations. Among the countries considered, Germany performed worst with a score of 83 out of 100. Compared to other OECD countries, the German procedure is more complicated and costly and requires a relatively high level of minimum capital (World Bank Group 2019). Canada scored highest with 98 out of 100 points, as it has no minimum capital requirement, the cost is only 0.3 percent of income per capita, and it takes on average only 1.5 days to start a business.

Table 2 shows several indicators considering the outcomes of innovation in the respective countries. One might argue that the amounts invested in innovation displayed in Table 1 already reflect the level of innovation: if investors or executives decide to finance R&D projects, they want to generate a return and would not invest if their investment did not lead to profitable innovation; instead they would invest it elsewhere.

Similarly, R&D expenditures can be seen as investments returning the technologies necessary for innovation. However, without other innovation-related measures it is impossible to determine with any certainty how fruitful the returns will be (Smith 2006). One could consider changes in products (materials, technical attributes, design, or performance) to observe the extent of the impact of innovation. Although it is hard to objectively quantify this on the product level, one could consider the firm level. This can be investigated through surveys, although this would not be a measure of the total size of innovative outcome. The Communication Innovation Survey of the European Commission (2019b) reports the share of companies that innovated their products in the period 2014–2016. The figure varies between 37 percent for Spain and 65 percent for Finland. For a more absolute indicator of how innovative companies are, we turn to expenditures on innovation. Although it is difficult to derive expenditures on innovation from the annual accounts of enterprises, EFI (2019) computes the share of innovative expenditures in the total turnover of private companies for a few countries on the basis of survey data (European Commission 2019b). Considerable differences have been found between Northern and Southern European countries: Italian and Spanish firms spend only 1.4 percent and 1.2 percent on innovation, whereas the figures are 3.3 percent and 3.8 percent in Denmark and Sweden, respectively.

To consider the fruits of research, we turn to the number of patent applications of the triadic patent family. The triadic patent family is a set of patents filed at either the US, European, or Japanese patent office. The count per country is a fractional count based on the country of residence of the applicants. The largest concentration of patent applicants is in Japan and the US, followed by the European Union, which has substantially more inhabitants. Despite the rapid growth of China's patent applications, the total number of patent applications is still dwarfed by the three large economic blocks: Europe, the US, and Japan. Within Europe, there are also considerable differences: Spain has fewer patent applications than many significantly smaller countries. To consider recent developments in patent applications, we turn to the growth of patents in R&D-intensive technologies. In many countries, the number of patent applications declined or grew slowly between 2006 and 2016. The big exception is China, where the number of patent applications has grown almost sevenfold.

To examine the extent to which new companies, which usually enter the markets with innovative products, are founded, we turn to the number of firms founded in 2016 as a percentage of the total number of firms. Around 10 percent of firms were newly founded in 2016, ranging from only 6.6 percent in Austria to 15 percent in the UK.

GLOBAL TRENDS: START-UPS AND VENTURE CAPITAL

Microsoft, Amazon, Apple, Google, Facebook – The five companies with the largest market capitalization globally[2] have several things in common. In addition to all of them operating in high-technology industries and likely being very familiar names to the average reader, all of them were founded out of a US garage or a dorm room and subsequently provided with funding to scale their business. While Apple and Microsoft revolutionized the computer software and hardware market from the 1970s onwards, Amazon, Google, and Facebook brought about disruptive innovations on the internet after its commercialization in the 1990s, revolutionizing online markets, online searches, and online networking, respectively. The "creative destruction" of industries has been a concept since the 1940s as coined by Schumpeter (1942) and, arguably, the companies mentioned above are examples of it. However, what may differentiate them from previous cases is their use of the digitalization of our economy. The advent and increasing affordability of both computers and the internet led to companies disrupting industries at higher rates. In the latest trends, the development of the sharing economy based on *"the peer-to-peer based activity of obtaining, giving, or sharing the access to goods and services, coordinated through community-based online services"* (Hamari et al. 2016) gave rise to a new generation of companies such as AirBnB and Uber. Using online platforms, these companies innovated the hotel and transportation industry, respectively, having been small start-up companies back in 2010.

All previously mentioned examples of innovative companies were considered start-up companies at the beginning of their company history. Start-up companies are ventures initiated by entrepreneurial individuals or a group of entrepreneurs, with a business model that can typically be repeated and scaled up to a high-growth business without the need for large fixed costs and physical capital investments, thus mostly defined by their ability to grow (Robehmed 2013). Mostly, however, start-ups are associated with innovative new business ideas, and thus have been shown to be connected to innovation rates especially in developed countries (Anokhin and Wincent 2012). This association is stronger than for large existing corporations; while they do innovate, they do so at slower rates and less disruptively, as they have smaller incentives to erode their own competitive advantage in an established market (Granstrand and Alänge 1995). In addition to innovation, or perhaps as a consequence of it, higher start-up rates have also been shown to increase economic growth (Acs et al. 2009), the productivity of an economy (Bygrave et al. 2003), and the productivity of its workers (Audretsch and Keilbach 2004).

Policymakers have started to take note of this, and thus public innovation policy is increasingly connected to the encouragement of the formation of new start-up ventures by fostering a policy environment where these typically highly innovative companies are able to thrive.

An Overview of The Start-up Ecosystem

These environments where young companies can thrive are typically referred to as "start-up ecosystems" and are "formed by a set of interdependent actors and factors coordinated in such a way that they enable productive entrepreneurship within a particular territory" (Stam and Spigel 2016). Stemming from the idea that entrepreneurship may be the result of a social process rather than the sole achievement of any one individual entrepreneur, these ecosystems can support the ability and intention to start a business, help to provide entrepreneurs with sources of funding, and ultimately may encourage a successful exit from a firm. As seen previously in Table 1, multiple components of start-up ecosystems and the quality of their development are often considered indicators of public and private efforts for innovation. Components of such systems may include accessible markets, a favorable regulatory framework for starting businesses, a strong tertiary education system, a support system in the form of mentors, professional services, and incubators, a highly skilled workforce attracted by the location and services, as well as cultural support (World Economic Forum 2013).

While Silicon Valley remains the best-known start-up ecosystem, having produced a multitude of successful technology companies and continuing to do so, new such systems are beginning to develop in other areas of the world. Outside of the United States, Startup Genome (2019) identified ecosystems in London, Beijing, Tel Aviv, Shanghai, Paris, and Berlin as being among the top ten ecosystems globally. However, what we find most often is that public debate on start-up companies is focused on the potential lack of funding and, thus, on the investors. They provide funding and finance to young companies and thus typically allow for

[2] As of July 26, 2019.

further research and development as well as a scaling of the business, which allows companies to realize their growth potential. Due to the often early stages of development and lack of a credit record of young companies, entrepreneurs rarely have access to traditional bank funding (World Economic Forum 2013). Their main sources of funding are thus their or their families' personal savings, contributions from wealthy experienced individuals, often referred to as angel investors, or crowdfunding. Most prominently and with roles across all funding rounds, venture capitalists may typically take an equity position in the emerging venture in exchange for entrepreneurial support in the higher-risk growth phase.

While information asymmetries for these investors are a significant source of uncertainty, venture capitalists typically mitigate these through screening and monitoring of portfolio firms using instruments such as board memberships, employment of industry specialists, and a staged funding process. To justify the high risk of start-up projects, venture capitalists furthermore tend to invest in high-technology businesses with significant growth potential, especially in information and communication technology (ICT) and biotechnology (Harroch 2018); as a result, they arguably have a special importance for innovation policy and thus often attract the attention of public policymakers.

The Venture Capital Industry

Unlimited liability of shareholders and limited information systems initially discouraged equity investments in favor of less risky bank lending. However, changes in the US regulatory framework gradually led to an increase in investments in small businesses. From then onwards, the US venture capital industry progressively grew until reaching its peak during the dotcom bubble in 2000, with its particular focus on high-growth technology firms. Since then it has returned to growth as presented in Figure 2, with investment amounts once again reaching pre-dotcom levels in 2018.

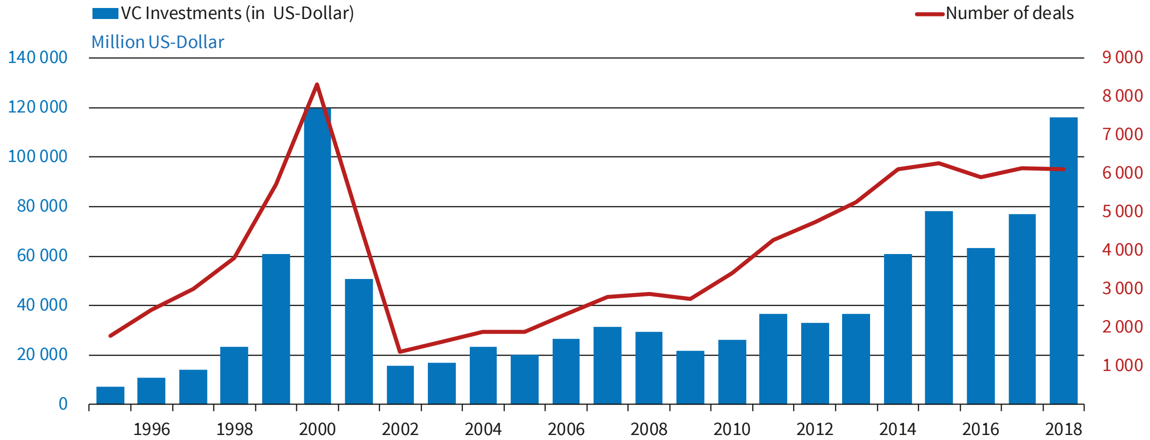
The US remains the largest venture capital market today (see Figure 3), with 86 percent of total venture capital investments in the OECD stemming from the US in 2016. Global venture capital investments have followed a similar growth trend over the past decade and have thus seen growth in investments since 2010, with a peak in 2018 (KPMG 2019). However, it has also been pointed out that the gap between US and European venture capital in particular is widening quite consistently across sectors (OECD 2018a), with European venture capital funds found to have lower returns than those based in the US (European Private Equity and Venture Capital Association 2014).

The Importance of Venture Capital Financing for Innovation

The difference in size and success of the venture capital industry could be tracked potentially both to the lower maturity of the European market as well as a difference in regulatory frameworks. However, the fact remains that the presence and availability of venture capital funding increases start-up company growth (Davila et al. 2003) and performance (Rosenbusch et al. 2013) and, in turn, increases innovation rates, productivity, and economic growth as desired by public policy (Kolmakov Vladimirovich et al. 2015; Sun et al. 2019; Lerner 2010; Brander et al. 2015). Indeed, VC funding has been shown to have a larger positive effect on patenting and innovation than corporate investments into research and development (Kortum and Lerner 2000). As well as providing funding, venture capitalists thus serve a number of other functions in the start-up ecosystem, among them teaching and embedding companies into the start-up ecosystem (Ferrary and Granovetter 2009). The fact that European venture capital lags significantly behind the US market, with Silicon Valley remaining the most successful and never replicated start-up ecosystem, poses an ongoing challenge to European policymakers. Thus, governments have begun to put significant effort into encouraging the development of

Figure 2

US Venture Capital Investments
1995–2018



Source: PwC (2019).

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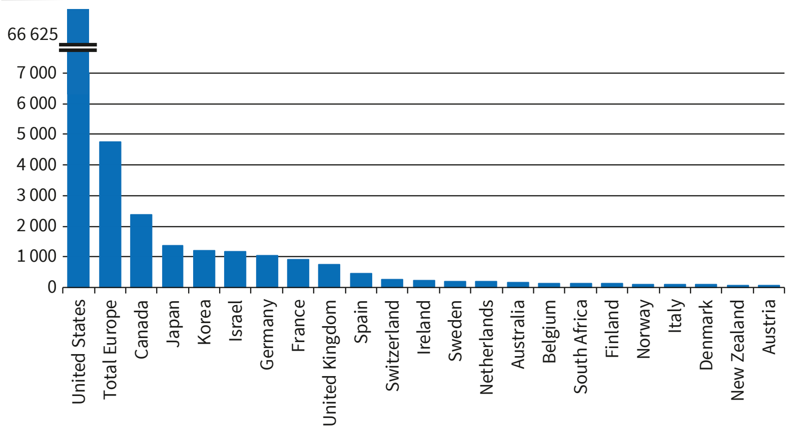
Figure 3

Venture Capital Investments by Country (in Million US Dollar)
2016



Note: 2014 data is shown for Israel (latest available).
Source: OECD (2018a).

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the venture capital industry outside of the United States.

The Role of Government

Most public policy focused on encouraging the development of a national venture capital market centers around creating a tax environment favorable to investors, as well as creating government-funded venture capital programs (Da Rin et al. 2006; Bradley et al. 2019).

Tax policy may include capital gains taxation reductions (Da Rin et al. 2006; OECD 2018b) or tax credits for investment or company research and development (Bradley et al. 2019), which have been shown to encourage early-stage and high-tech investments in particular, thus supporting innovation rates. The reduction of capital gains taxation is notably directed mainly at increasing returns to investment into start-up companies and will thus influence decision-making and risk appetite (European Commission 2015). In general, such tax incentives most often take the form of tax credits in the amount invested, as well as tax exemptions on the investment returns.

Such policies pose an incentive to venture capitalists to increase investments despite the risky nature of the venture capital market. According to the European Commission (2015), which analyzed tax incentive schemes in the EU-28 and eight additional OECD countries, 19 out of the 36 countries operated tax incentives targeted at venture capital investors, with France and the UK implementing the highest number of tax incentive schemes. Furthermore, compared to the member states from the 2004 and 2007 accessions, a larger share of EU-15 members operate such schemes. Table 1 provides an overview of tax advantages as a percentage of GDP in a country-by-country comparison, showing the intensity of indirect government funding.

Directly government-funded venture capital programs are becoming increasingly prominent, especially in Europe, supported by the hypothesis that channeling more funds into venture capital markets will aid their development, encourage more private participation in the long run, and thus close the funding gap for small companies especially in their growth phase (Fuerlinger et al. 2015). Examples in Europe include the venture capital division of the European Investment Fund (Signore and Torfs 2017), the pan-European venture capital funds-of-funds program VentureEU, the Enterprise Capital Funds by the British Business Bank (British Business Bank plc 2018), Bpifrance (Bradley et al. 2019), the KfW Bank Group, or, for international examples, the Canadian Venture Capital Action Plan and the Venture Capital Catalyst Initiative.

While empirical evidence on the effectiveness of these measures is still contradictory, citing a crowding out of private investment by public sources (Da Rin et al. 2006; Lerner 2010), the impact of government-funded venture capital investments have a similar positive impact on the economy to private investments (Signore and Torfs 2017). Furthermore, they seem to have a positive impact on enterprise performance if combined with substantial funds from private venture capitalists (Brander et al. 2015; Grilli and Murtinu 2014). Finally, they have been shown effective as certification devices to private investors, thus increasing the likelihood that funded companies will also receive private venture capital (Guerini and Quas 2016). Within the European Union, government agencies committed around 18 percent of total venture funding in 2018[3], which amounts to the lowest proportion in the past ten years (InvestEurope 2019).

In less direct strategies, simplifying the act of both founding a company as well as exiting the company investment has been shown to be an effective method to develop the industry, by reducing the complexity of the company formation process on the one hand and increasing the availability of stock markets targeted at entrepreneurial companies on the other (Da Rin et al. 2006). Furthermore, the attraction and retention of innovative talent has been emphasized as essential (Bradley et al. 2019). While the evidence on immigrants contributing the majority of companies to Silicon Valley (Meeker 2018) is anecdotal, logically it may be sensible for potential innovators to emigrate to a better start-up ecosystem if their funding needs are not met

[3] Note that a commitment of venture funds does not guarantee a perfect translation into invested funds and is thus not equivalent to the metrics used in previous figures.

in their home country. Hence, devising policies that attract and retain talent can foster more frequent start-up creation and thus attract more venture capital investors that see viable investment opportunities.

GLOBAL TRENDS: ARTIFICIAL INTELLIGENCE AND INNOVATION POLICY

When considering global trends in innovation policy, one must consider current innovative technologies. Artificial intelligence (AI) is a key technology that has shaped technological progress in recent years and will continue to do so in the future. In the following, we will look at AI in more detail, drawing on the opportunities and challenges it brings and taking a closer look at the role of government. Although the future of the technology and its impact on society are somewhat unclear, it is certainly the responsibility of government to implement policies for developing and using it. It should be in the utmost interest of both government and business to exploit the benefits of AI while protecting its users and the people who developed it.

Artificial Intelligence at a Glance

In the following, we will take a closer look at artificial intelligence (AI). We will refer mainly to the paper "Economic Policy for Artificial Intelligence" by Agrawal, Gans, and Goldfarb (2018), who discuss the expansion of AI and the associated regulatory needs due to the emerging challenges.

According to Agrawal et al. (2018), recent progress in AI stems from advances in computational statistics, particularly in *machine learning.* Machine learning describes the process of computers learning patterns from existing data, potentially enabling superior prediction (without causal inference). However, AI can take a more sophisticated form called *artificial general intelligence (AGI)*, which refers to machines that are capable of performing basic cognitive tasks (such as understanding, problem-solving, and reasoning) with the ultimate goal of achieving a human-like consciousness. AGI is in its infancy and no meaningful statements can be made about its impact on innovation and the need for regulation. When it comes to artificial intelligence, we will therefore focus entirely on machine learning in the following. A short discussion of the origin and abilities of machine learning, and specifically deep learning, can be found in Box 1.

Artificial intelligence is likely to affect many sectors, so Agrawal et al. (2018) regard it as a general-purpose technology (GPT). Being a relatively new technology, the full impact of AI on society cannot yet be properly measured in many cases. According to the authors, the pessimistic view of AI focuses on rapid change and the belief that machines will take over jobs. Others (e.g., Stevenson 2018) view AI more optimistically and expect a rise in productivity ultimately leading to a rise in income and more spare time for employees as they no longer have to spend so much time on unpleasant tasks in their jobs.

BOX 1

The Rise of Deep Learning

Recently, the field of machine learning has started growing tremendously. This is mostly sparked by successes in image recognition by artificial neural networks (ANNs). An ANN is a self-learning network organized in multiple layers of many parallel nodes, each containing a non-linear function $f(x,w)$ with inputs x from the previous layer (where the first layer contains the raw independent variables) and learnable parameters w. Based on a function after the last layer, which compares the prediction of the network to the actual dependent variable of interest, all those parameters are updated iteratively (called training or learning). Once the ANN is trained with sufficient data, we can supply a set of independent variables and obtain a prediction. These procedures are considered "deep" learning, because the best-performing networks are dozens of layers (of various kinds) deep. The field of deep learning engages in developing tools to ensure efficient learning and overcoming numerical issues in order to increase the accuracy of prediction and efficiency (e.g. Bottou et al. 2018).

Since 2012, so-called convolutional neural networks (CNNs) have achieved impressive increases in accuracy when labeling pictures in the ImageNet database (a database containing millions of pictures, which are given a single label by hand, such as cat, dog, plane, frog, or car). Convolutional layers transform the data (with a mapping that also has learnable parameters) to extract meaningful structures, which heuristically work well for image recognition. Interestingly, these "convolutional" neural networks recognize those objects in a similar (but by no means identical) way to the animal brain: they recognize low-level features such as horizontal and vertical edges separately in different parts of the network, in a similar way to that found in cats by tilting a bar in their receptive field and measuring neural response (Hubel and Wiesel 1962). More applications of deep neural networks can be found in the fields of computer vision and natural language processing, which both deal with understanding sequences of data.

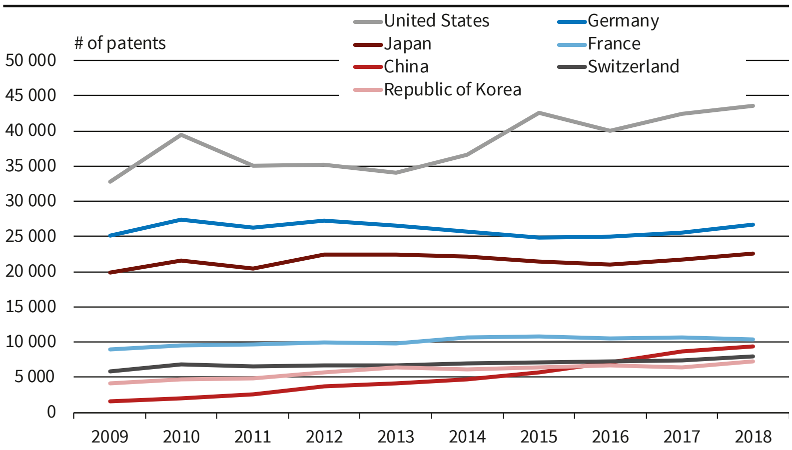
General Patents and Patents in AI

To assess to what extent AI research is being adopted around the world, we first look at the number of patents per country. Figure 3 illustrates that most patents originate from the US, followed by Germany and Japan. As mentioned before, countries like China, South Korea, and Switzerland also seem to have taken up the development in recent years and have seen an increasing number of patent applications. Next, we turn to the institutions and firms that apply for the most patents worldwide in the field of artificial intelligence, which all have applied for thousands of patents relating to AI. Figure 4 lists the top 30 firms, consisting of 26 compa-

Figure 4

Number of Patents by Country, 2009–2018

Countries with most patent applications in 2018



Source: European Patent Office (2019). © ifo Institute

nies and four public research institutions. Out of the top 20 companies, 12 have their headquarters in Japan, while many others are from the US. The main patent category among 19 of the top 20 applicants is *Computer Vision. Only IBM has most of its applications in the category Natural Language Processing* (WIPO 2019).

Not only large high-tech firms are developing AI applications, but also smaller firms. A 2018 survey among US executives showed that 62 percent of the respondents' firms apply *Natural Language Processing* (e.g., operating chatbots or to query datasets), 57 percent use *Computer Vision* (e.g., facial recognition and vision for autonomous vehicles), and 50 percent use some form of *Deep Learning* (Deloitte 2018). 70 percent report a rate of return of over 10 percent. AI-derived business value already encompasses trillions of USD per year and is expected to grow rapidly (Gartner 2018).

Artificial Intelligence and the Role of Government

The expansion of artificial intelligence will impact society in different ways. Policies that provide research support are likely to accelerate technological progress. Agrawal et al. (2018) define three policy categories around artificial intelligence that intensively require the attention of policymakers: liability, privacy, and trade. Not adequately addressing these issues could potentially hamper the development and diffusion of AI.

Artificial intelligence, like other technologies, relies heavily on data. Thus, privacy protection plays an important role: too little protection may prevent consumers from participating in the technology and thus from making their data available. Furthermore, a low level of privacy protection can induce a race to the bottom in privacy policy among countries in order to get ahead of each other in AI development. Too much data protection, on the other hand, may keep firms from innovating, as the potential costs from risks associated with privacy protection would be too high. The challenge for policymakers is therefore to find the right balance between the level of privacy regulation that is needed to ensure individual protection, while at the same time encouraging innovation.

In addition to privacy concerns, Agrawal et al. (2018) state that trade policies can impact the expansion of AI. Trade policies refer to behind-the-border policies often included in trade agreements. According to the authors, when international standards for data protection are included in trade agreements, such trade policies can mitigate the race to the bottom induced by lax privacy regulation.

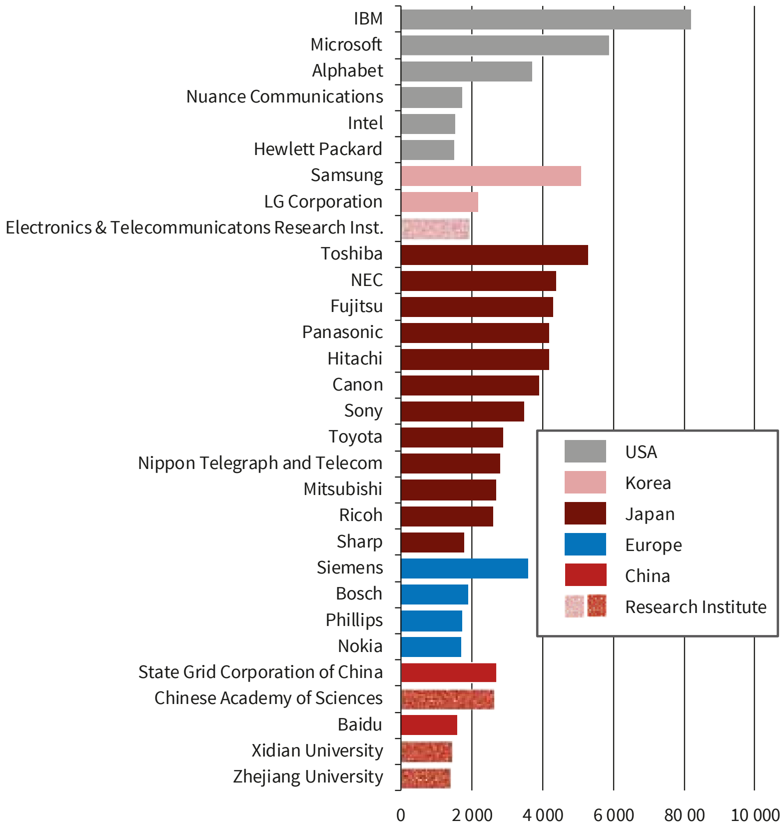
The authors address another concern relating to liability that can arise when people get injured and are consequently compensated by others. Unclear liability rules may increase the risk of unlawful actions with uncertain outcomes and potentially high payments. Therefore, firms may be reluctant to invest in AI for as long as the liability rules around AI are uncertain. In addition, algorithms used in AI might be biased, possibly leading to discrimination. Agrawal et al. (2018) refer to the example of a job advertisement for STEM occupations, which was more often advertised to men. The underlying bias was not that men are the better engineers but that women are underrepresented in STEM professions and therefore less often addressed by such advertisements. It is the task of policymakers to create clear liability rules and help dismantle potential preconceptions.

Other policies do not target advances in AI directly, but rather the consequences that may follow from its diffusion. AI is considered as a productivity enhancing technology; it will have an effect on jobs (and therefore income), inequality, and competition. Trajtenberg (2018) argues that with the expansion of AI, new skills will be needed. These are skills that machines cannot (yet) perform, like critical or creative thinking. Humans will probably need a combination of both technical and social skills in order to use the machines and tell them what to do (e.g., EC 2019a). Education policies can play a crucial role as humans may need to adapt their skill set to the new technology. According to Agrawal et al. (2018) education policy should therefore focus on "the skills taught and the structure of the delivery" (p. 15). However, it remains an open question what such an education policy may look like in detail.

Furthermore, leading AI companies are the ones collecting the most consumer data via their applications or on the internet. Since there is a growing market

Figure 5

Patent Applications in Artificial Intelligence by Enterprise and Country
2016



Source: WIPO (2019). © ifo Institute

for personal (consumer) data, a company could be put in a monopolistic position if it owns most or a majority of such data. Therefore, policies should increasingly take into account the enforcement of antitrust law in the future (Agrawal et al. 2018).

Finally, there is a lively public and academic debate on the increase or decrease of inequality as AI progresses towards artificial general intelligence. To address possible impacts on the overall economy, Gries and Naudé (2018) argue for the necessity of maintaining labor income as AI increases the capital intensity of production. In order to prevent stagnation of the world economy and to address concerns regarding inequality and large-scale unemployment, policy proposals focus on adjustments to the social safety net, in particular through the taxation of capital, the introduction of a universal basic income (Bruckner et al. 2017), or even taxing robots (Oberson 2017).

SUMMARY

The success of innovative enterprises depends on many factors: financing, a suitable start-up environment, and a trained workforce, among others. For innovative firms to flourish, government regulation and policy is needed. Although government policy is omnipresent in the form of direct project funding and tax advantages, large differences between countries remain in terms of innovative outcome. Many countries aim to make financing more attractive, some financing start-ups themselves and creating Silicon Valley-style start-up ecosystems. In order to finance young companies, venture capital financing in particular is proving to be important, as many large high-tech companies were financed through VC. Despite the efforts of other governments around the world, the world's VC industry is strongly concentrated in the US.

After academic breakthroughs in past decades, artificial intelligence has recently become a heavily patented, multi-billion dollar technology. Concerns regarding the privacy of individuals' data, the inclusion of rules in trade agreements, and liability for the implications of the technology all require adequate legislation. A failure to implement suitable laws imposes a risk both on the adaptation of useful technologies and on society as a whole.

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