3 Additional metrics and sources to measure the Internet of Things

This chapter reports on additional metrics and sources to monitor the growth and diffusion of the Internet of Things (IoT): patenting activity in IoT-related technologies, venture capital, mergers and acquisitions of IoT firms as well market developments in specific segments in the IoT value chain. These metrics help capture innovation opportunities and emerging commercial applications in the IoT field.

This chapter reports on additional metrics and sources to monitor the growth and diffusion of the Internet of Things (IoT). Patenting activity in IoT-related technologies provides a measure of innovation in the field. The dynamic of firm creation and venture capital (VC) investment helps capture emerging commercial IoT applications. Trends in specific segments in the IoT value chain, e.g. sensors and actuators, bring further insights into the evolution of IoT. Finally, mergers and acquisitions (M&A) of companies active in the IoT domain signal the expectations of key players regarding market potential.

IoT-related patents

Progress in the IoT can be measured by looking at global patenting activity in related technologies. Unfortunately, the International Patent Classification, which is used to allocate patents to specific technology fields, introduced a patent sub-class of the IoT only recently (WIPO, 2021[1]) and IoT patent data will only become available in forthcoming years. Therefore, evidence on IoT-related patents has so far been based on the occurrence of some set of IoT-related keywords in the abstract, i.e. the description of the patent applications.

Early work by the United Kingdom Intellectual Property Office (IPO, 2014[2]) estimated that there were almost 22 000 patent applications related to the IoT worldwide over the period 2004-13, with the annual increase in patenting activity in this field being up to 8 times higher than for patents in all other technologies.

Based on a simple search of the expressions “IoT” and “Internet of Things” in the patent abstracts, the United Nations Conference on Trade and Development (UNCTAD, 2021[3]) estimated that there were 22 180 IoT-related patent applications over the period 1996-2018. The leading countries, based on the location of the assignees, i.e. the patent owners, were the People's Republic of China (hereafter "China") (9 515), Korea (5 106) and the United States (4 275). The 3 leading companies for the number of IoT applications were the Samsung Group (2 508), Qualcomm (1 213) and Intel (667). However, these figures may underestimate the actual number of IoT-related patents. For instance, a recent report (IoTsens, 2021[4]) estimated that 129 710 IoT-related patent applications were filed over the period 2011-21, although the methodology used for such estimation is not explained. Contrary to UNCTAD (2021[3]) findings reported above, LG and Huawei are respectively fourth and fifth worldwide for the number of IoT patent applications, just above Intel.

According to the European Patent Office (EPO, 2020[5]), patent applications related to smart connected objects accounted for over 11% of all patenting activity worldwide in 2018. The report also points to the acceleration during the period 2000-18, with an average annual growth rate in patenting related to smart connected objects close to 20%, compared to 12.8% from 2000 to 2009. The annual increase in patent filings for Industry 4.0 technologies (4.2%) has been nearly five times greater than the growth of patenting in all fields since 2010.

IoT firm creation and VC investment

The creation of firms engaged in the production of IoT goods and services (labelled as “IoT firms” hereafter) provides a complementary measure of the diffusion of IoT technologies and their commercial applications. IoT diffusion is also reflected in the amount of VC investment accruing to these firms.

VC is a form of private equity financing, i.e. equity capital provided to enterprises not quoted on a stock market, particularly relevant for young companies with innovation and growth potential but untested business models and no track record.

Typically, VC investment is made to support a business's pre-launch, launch and early-stage development phases. VC firms or funds invest in these early-stage companies in exchange for equity or an ownership stake. Venture capitalists take on the risk of financing new or growing businesses with perceived long-term growth potential with the expectation that some of the firms they support will become successful.

Data on IoT firms and VC are drawn from Crunchbase (https://www.crunchbase.com/), a commercial database on innovative companies started in 2007 and that has become an international reference in the field (Dalle, den Besten and Menon, 2017[6]).

Crunchbase data are sourced through two main channels: a large investor network and community contributors. Data are then processed via artificial intelligence (AI) and machine learning (ML) algorithms in order to ensure accuracy. In addition, algorithms search the web for further information about the companies' profiles. As potential investors increasingly use Crunchbase, there seems to be an incentive for entrepreneurs to register with the website and to keep their information up-to-date.

As of May 2021, there were 10 384 IoT firms in the database, based on the Crunchbase classification of activities. Further IoT firms have been identified by searching the description of their activities based on a list of keywords (see Annex 3.A for details). This search identified 2 913 additional IoT firms, bringing their total number to 13 296.

Among the information about firms, Crunchbase reports the year of creation, the amount of VC received and the investment stage (Box 3.1). Newly established firms are usually included in Crunchbase with a three- to four-year lag. By contrast, once the firm is in the database, VC investment is documented in a timelier manner.

Box 3.1. VC investment stages

Crunchbase classifies VC investments according to three stages:

- **Early stage**: This stage encompasses all investments from the birth to the market launch of the firm. It ends when the firm starts generating revenues.
- **Expansion stage**: In this stage, the firm is seeing fast growth and seeks additional investment to keep up with demand. VC investment is mainly used to finance market expansion and product diversification.
- **Bridge stage**: In this stage, the firm has reached maturity. VC investments are typically made to support activities like M&A or raise equity capital.

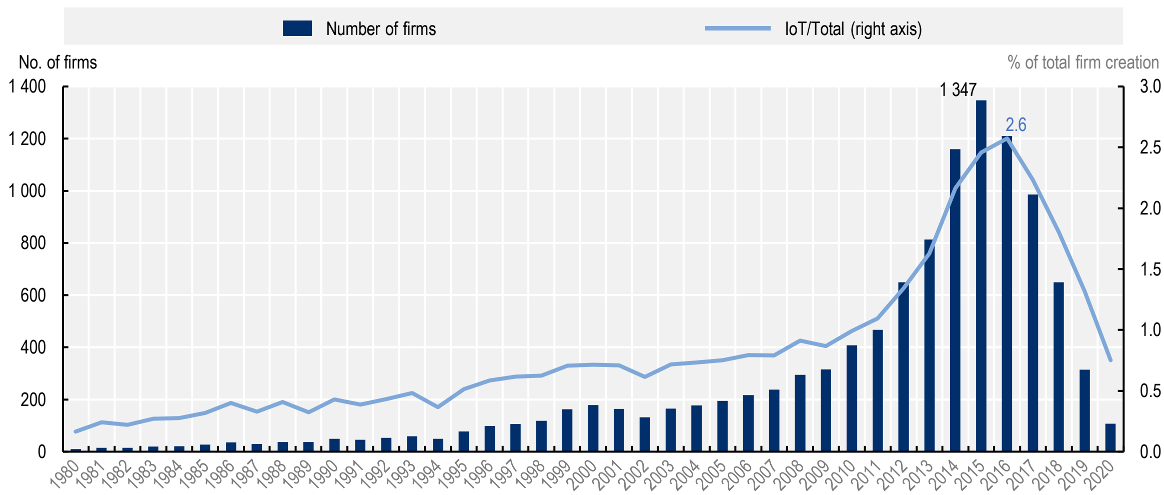
Source: Based on Crunchbase data.

Trends in IoT firm creation

The creation of IoT firms increased slowly between 1980 and 2009, from less than 100 to about 400 a year. It then accelerated in 2009, reaching a peak at 1 347 new firms in 2015 and then dropping to less than 200 new firms a year in 2020. IoT firm creation relative to total firm creation followed a similar trend, reaching a peak of 2.6% in 2016 (Figure 3.1).

The surprising decrease in IoT firm creation after 2015 may have several concurrent explanations. On the one hand, it may follow from the time lag with which Crunchbase registers newly created firms, although this would not explain the observed decrease in new IoT firms relative to all new firms. On the other, it may reflect a consolidation of the IoT market via M&A, as confirmed by the continued increase in VC investment in the IoT (see next section). The growing importance of security issues arising from IoT use, as well as the lack of interoperability between platforms and ecosystems (Nativi et al., 2020[7]), may also have contributed to slowing down firm creation in this field.

Figure 3.1. IoT firm creation, 1980-2020

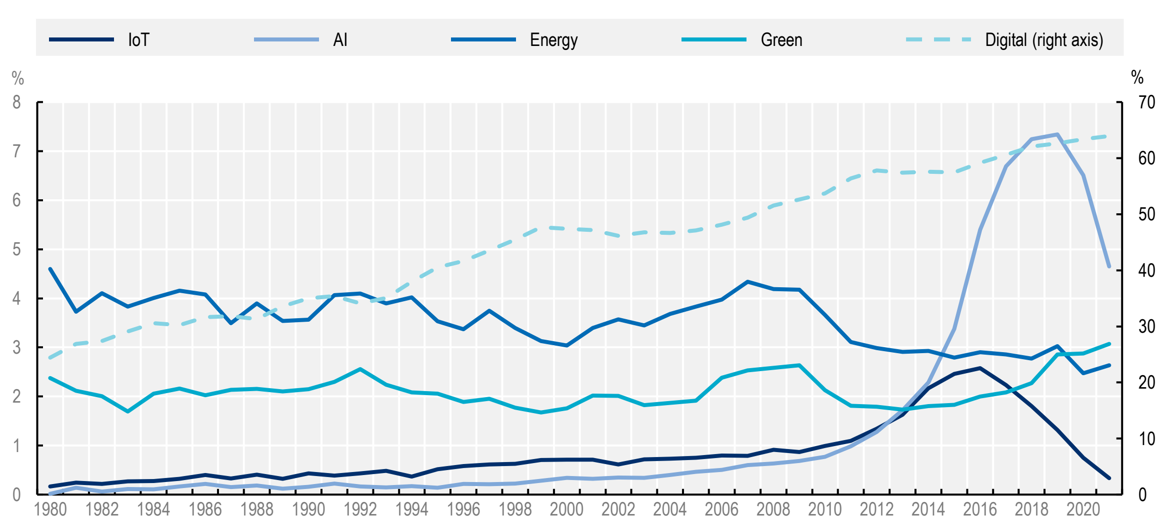


Source: Based on Crunchbase data.

Figure 3.2 shows trends in firm creation in selected activities related to the IoT: AI, energy and green. Firm creation in the IoT and AI followed a similar trend from 1980 to 2014 when the AI share started to grow exponentially from about 2% to above 7% in 2018. The share of newly created firms in energy was higher than in the IoT over the whole period considered. The same holds for newly created firms in green activities, except for 2013-17.

Figure 3.2. Firm creation in selected activities

As a percentage of total firm creation

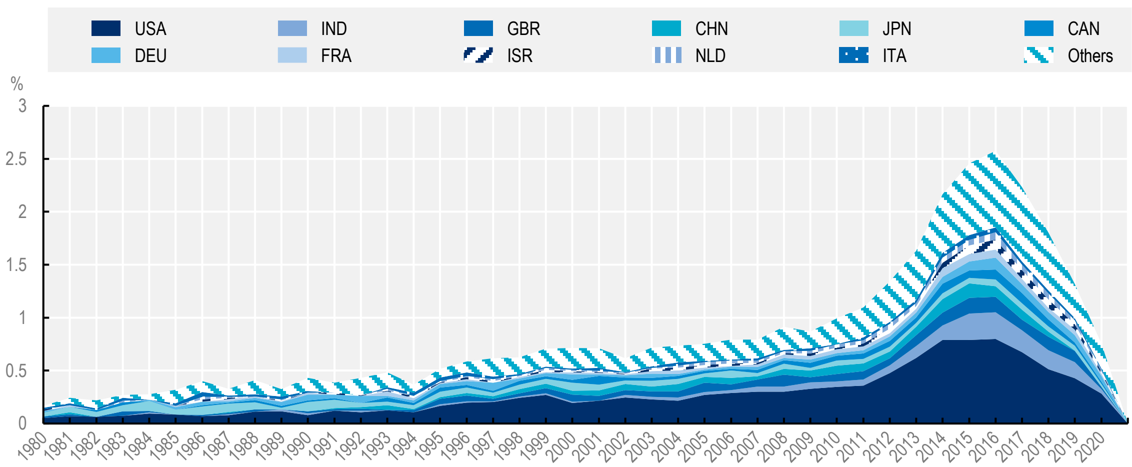


Note: For the definition of IoT firms, see Annex 3.A. The AI activity is defined by Crunchbase. Energy, Green and Digital activities have been developed by the International Energy Agency, building on the Crunchbase classification. Firms may belong to more than one activity.
Source: Based on Crunchbase data.

Over 1980-2020, about 75% of IoT firm creation worldwide occurred in 10 countries, 56% in Group of Seven (G7) countries, and one-third in the United States alone. India and China accounted for 7% and 5% of newly created IoT firms worldwide respectively (Figure 3.3).

Figure 3.3. IoT firm creation by country

As a percentage of IoT firm creation worldwide

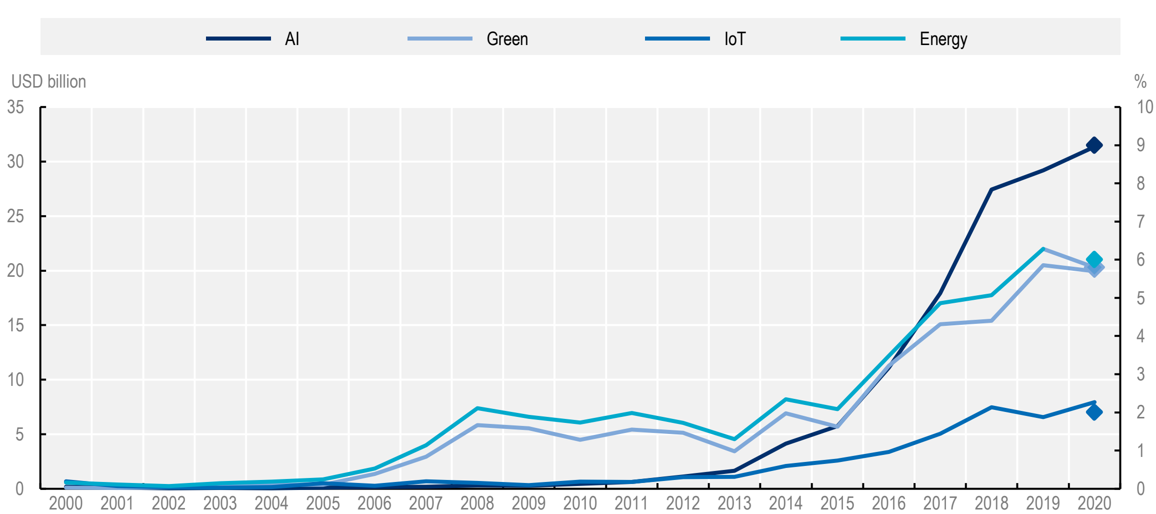


Source: Based on Crunchbase data.

VC investment in IoT firms

VC investment in IoT firms was fairly low until 2011 but increased dramatically afterwards, reaching USD 8 billion in 2020. Yet, VC investment in IoT firms has been much lower than in AI, energy and green firms, with the gap increasing dramatically in most recent years. In 2020, investment in energy and green, on the one hand, and AI, on the other, were respectively 3 and 4.5 times greater than in the IoT (Figure 3.4).

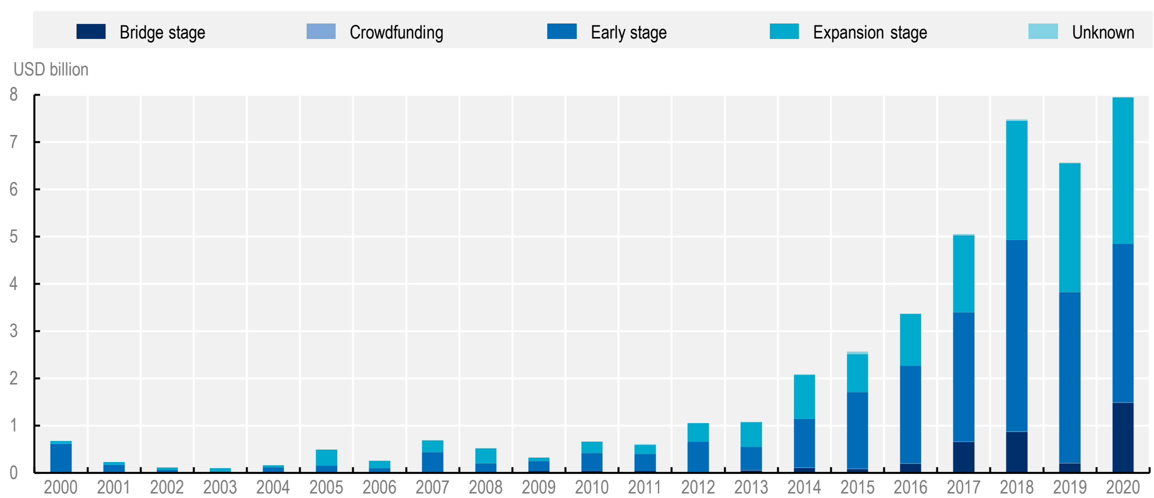
Figure 3.4 VC investment in selected fields of activity



Note: The markers (right axis) represent the 2020 percentage of total funding in start-ups.
Source: Based on Crunchbase data.

Since 2019, VC investment in IoT firms has focused on expansion and bridge stages, which correspond to firms' growth and maturity phases. This shift seems to confirm the hypothesis of consolidation of the IoT sector discussed above (Figure 3.5).

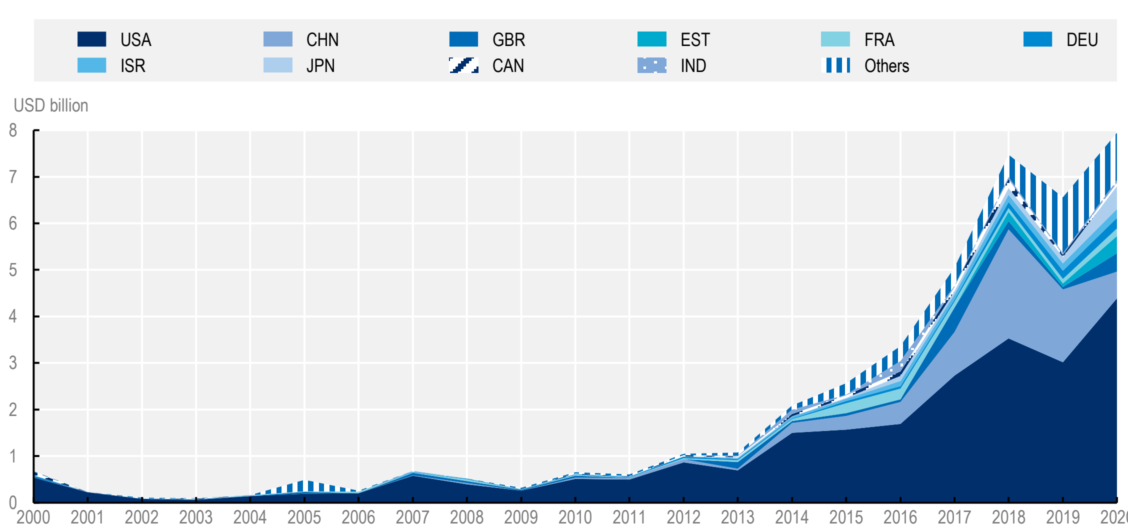
Figure 3.5. VC investment in IoT firms by stage, 2000-20



Note: VC investment stages are defined in Box 3.1.
Source: Based on Crunchbase data.

Over 2000-21, VC investment in IoT firms was concentrated in a few countries, with 10 countries accounting for over 90% of total VC investment worldwide. The main recipients were the United States (60%) and China (15%). In 2020, VC investment in United States IoT firms reached USD 4.5 billion, up from USD 1.6 billion in 2015 (Figure 3.6).

Figure 3.6. VC investment in IoT firms by recipient country, 2000-20



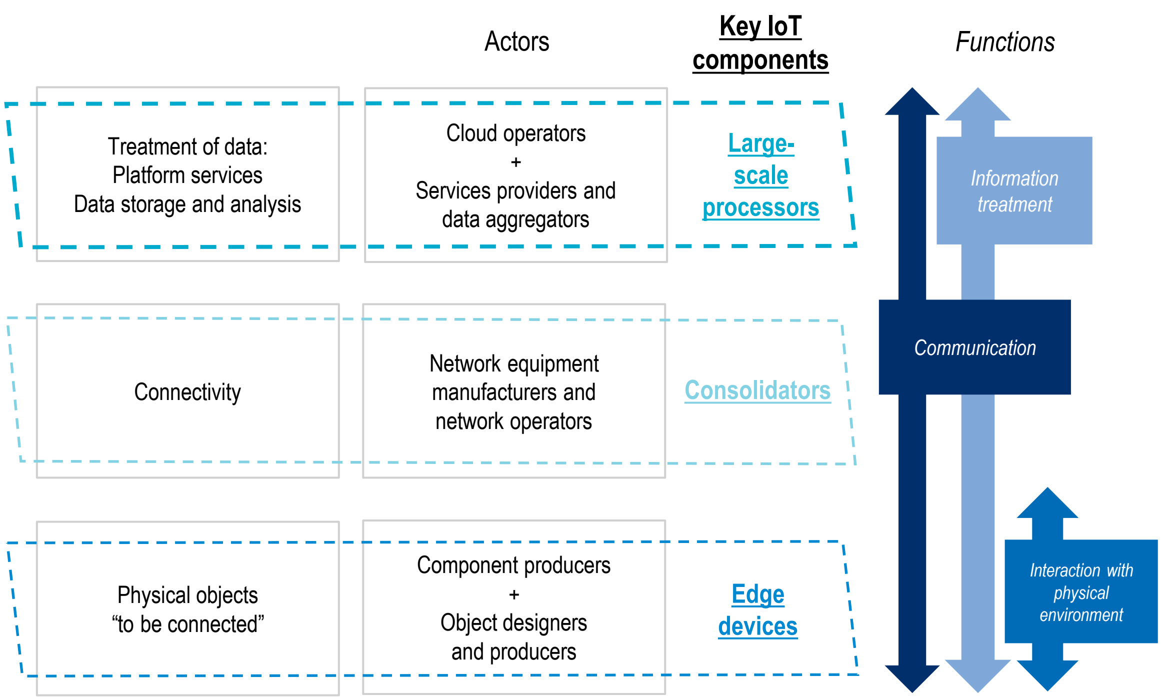
Source: Based on Crunchbase data.

Semiconductor industry trends relevant to the IoT

The importance of semiconductors for the IoT

Semiconductors are one of the key components and foundational layer of the IoT ecosystem, as the three key components of any IoT system – edge devices, consolidators and large-scale processors – rely on them (Figure 3.7). Semiconductors in the IoT are essential to ensure the sensing and actuating functions ("interaction with the physical environment" at the level of the devices), the connectivity function ("communication" across all layers) and the data processing function ("information treatment" at the level of the device and/or at the data centre). The type of semiconductors used varies among IoT components due to the variety of their applications. For example, smart vehicles require more processing power and data collection than sensors in smartwatches or clothing.

Figure 3.7. IoT enabling environment and key IoT components



Note: Functions refer to binding characteristics to be associated with semiconductors. Edge devices, e.g. watches, meters, typically gather, to varying degrees, the following abilities: i) capture some characteristics of the environment and translate them into information or physical action through one or more sensors and actuators; ii) treat and process this information through a processor; iii) transmit this information to a network using various means of communication. Consolidators are hubs or access points. As the means of communication in edge devices are likely to have a limited range, they need to be connected to something that acts as an access point for a wide-area network. Large-scale processors, often hosted in the cloud, make use of the data being generated from the edge devices.
Source: Adapted from OECD (2018[8]), "IoT measurement and applications", https://doi.org/10.1787/35209dbf-en.

The large scope of applications for semiconductors within the same family does not make it possible to identify those that are specific to IoT components. For instance, while virtually all IoT use communication integrated circuits (ICs), semiconductors in this family are used for a much wider set of applications, e.g. home Wi-Fi wireless network protocols, mobile telecommunications. In addition, the product classification currently used by the semiconductor producers is too broad to single out semiconductors that are used predominantly, if not exclusively, in IoT components. IC Insights cited in an OECD paper (2019[9]) estimated the value of semiconductors for Internet connection ("communication") used by the IoT at

USD 21 billion in 2017, or one-third of the total communication ICs in 2017, i.e. 5% of the total market of semiconductors in that year. However, the methodology supporting these estimates is not disclosed and IC Insights discontinued this analysis; therefore, it is impossible to outline the share of the IoT within communication ICs in more recent years.

At the same time, many connectivity functions in IoT devices are now embedded in the system-on-chip IC instead of application-specific ICs. Therefore, unlike the effect discussed above, trends in wired and wireless semiconductors may understate the actual growth in IoT devices.

To deal with the above issues, the approach taken in this section is to narrow the scope for measurement based on semiconductors along two axes. First, the measurement focuses on edge devices only, thus leaving aside the other two key IoT components, i.e. consolidators and large-scale processors. Second, the measurement focuses on semiconductors, which, while not exclusive to the IoT, are embodied in all IoT edge devices. This seems to be the case with sensors and actuators: while information processing and communication functions are widely diffused and not limited to IoT devices, the function provided by sensors and actuators can be considered as more specifically related to IoT devices (Figure 3.7). Although not all devices equipped with sensors and/or actuators are connected to a network, therefore meeting the definition of the IoT, it seems safe to assume that this is the case for a large majority of them.

Figures on sensors and actuators are likely to be lower band estimates, as IoT-relevant items can also be found within communication ICs – although they are probably a minority within this group – and in other semiconductor sub-families, such as processors, where they are also present but in relatively lower shares than other items such as computers. The section also provides some figures on “wireless” and “wired” subproducts intended for “communication” within the product group “application-specific ICs”. Figure 3.9 provides both the overall revenues for these sub-products and the revenues of subset products dedicated to short-range communication. However, as it is not possible to single out IoT applications within these sub-products, these figures are only shown for illustrative purposes.

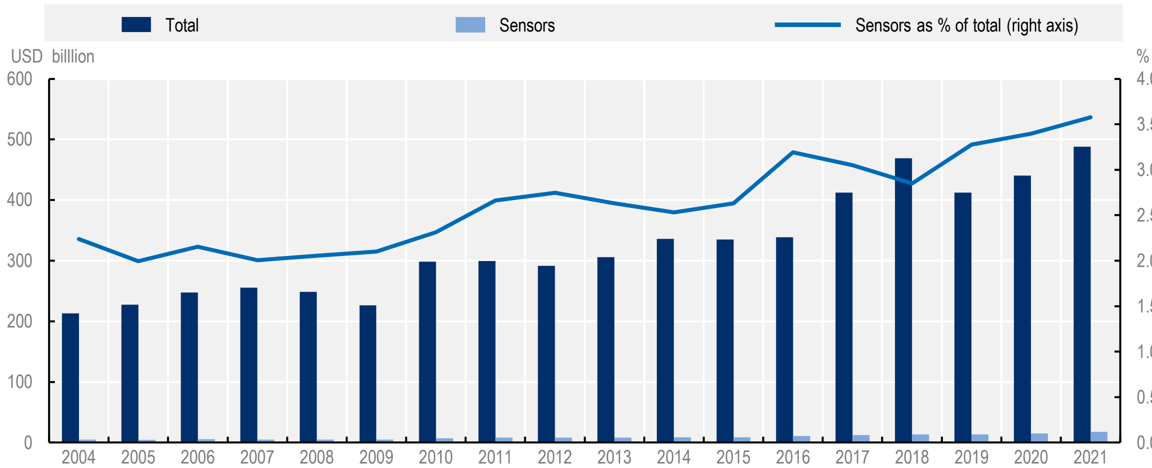
Sensors

In 2021, worldwide semiconductor revenues were estimated to reach USD 488 billion, up from USD 213 billion in 2004 (Figure 3.8). The share of sensors and actuators is expected to reach 3.6% of the market, up from 2.2% in 2004. Growth of this share was marked during the 2010-20 decade, while being relatively stable – at around 2% - between 2004 and 2009. Sensors are important components which benefitted from strong demand during the most recent decade and in many different sectors, such as advanced driver assistance systems in the automotive industry or within the increasing variety of smart home devices.

Communication ICs

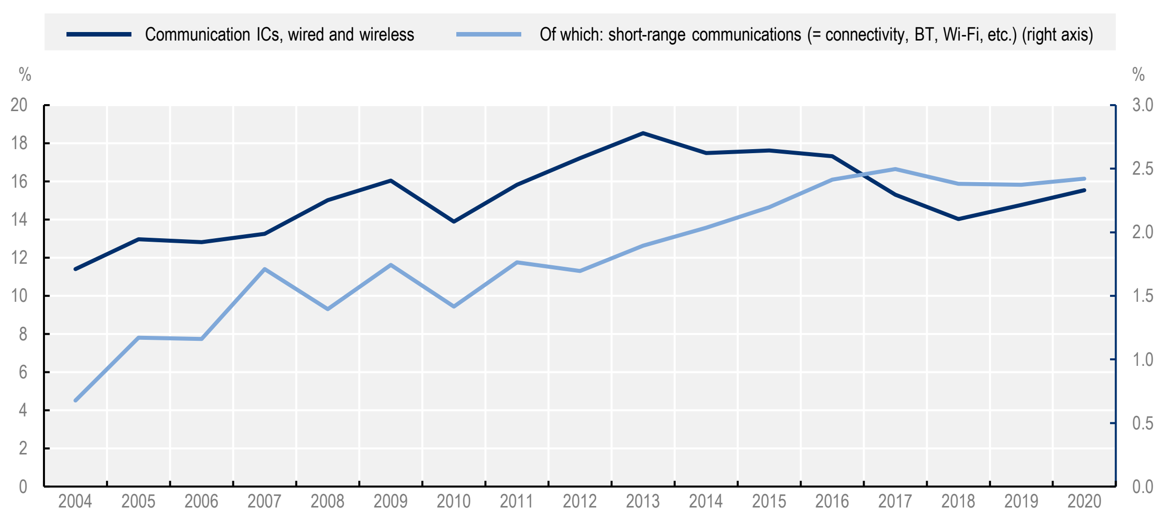
As shown in Figure 3.9, with a market of 68.4 USD billion, the share of communication ICs reached 15.5% of the worldwide semiconductor market in 2020, up from 11.4% in 2004 (USD 24.3 billion). However, this share slightly decreased between 2014 and 2020 (from 17.5% to 15.5%). The short-range communication components, while accounting for a small share of the worldwide market (below 3%), have been regularly growing over the 2004-20 period. This is clearly reflecting the progressive diffusion of portable wireless communications devices using short-range wireless transmission technologies such as Bluetooth, Wireless Local-Area Network, Ultra-Wideband (UWB) and Zigbee. According to World Semiconductor Trade Statistics, the volume of short-range semiconductors shipments multiplied by more than 7 times during the period, reaching 6.6 million units in 2020 worldwide.

Figure 3.8. Worldwide semiconductor and sensors revenues, 2004-21



Note: Sensors include actuators. Estimates for 2021.
Source: WSTS (2021[10]), *Market Statistics (database)*, https://www.wsts.org (accessed on 15 January 2022).

Figure 3.9. Share of communication ICs (wired and wireless) in the worldwide semiconductor market, 2004-20



Note: Short-range communications include "Wireless Communication Short Range" and "Short-Range Wireless", corresponding respectively to the categories JDc and L7c of the WSTS Product Classification 2018.
Source: WSTS (2021[10]), *Market Statistics (database)*, courtesy from WSTS.

Overall, sensors account for 3.6% of the market (as per above, most of them are assumed to be relevant to IoT devices). Communication ICs account for 15.5% of the market: while most of this is not presumably associated with IoT devices, a tiny part probably is. Within those, short-range communication ICs account for nearly 2.5% of the market (a small part of this is associated with IoT devices). Those two groups display a regularly growing trend of their share in the worldwide semiconductor market. Taking into account the above figures and assumptions, it seems to consider that the share of semiconductors components related to the IoT is currently at least between 5% and 7% of the worldwide semiconductor market and certainly encounters a regularly growing trend.[1]

M&A in the semiconductor industry

Over the past two decades, a broad movement of industry consolidation has taken place in the global semiconductor industry, as can be observed in the value of M&A, particularly intense in 2015 (OECD, 2019[9]). One explanation for this trend toward industry consolidation may be found in accelerating increases in the costs of semiconductor R&D and capital equipment in the race to produce leading-edge chips (EC, 2021[11]), which have made it harder for smaller firms to compete (OECD, 2019[9]).

Addressing the technology requirements of a growing IoT market is likely to have contributed to consolidation in the semiconductor industry, as leading semiconductor firms acquire capabilities and talent to improve their offers, signalling where the market potential is expected to be the highest. IoT applications rely on the capability of the semiconductor industry to develop the technology necessary to meet the specific needs of this market: IoT application-specific microcontrollers, AI capabilities at the edge (Box 3.2), efficient power consumption and environmental resistance (IEEE, 2020[12]).

In an attempt to gain IoT market segments, the semiconductor industry is also shifting from the development of chips and hardware to the provision of security and software solutions, moving from component suppliers to solution providers. Particularly relevant in this regard is the specialisation in vertical applications, such as the automotive or smart home sectors (Deloitte, 2018[13]).

Intel and Qualcomm, two leading semiconductor companies, have created specific IoT segments in their businesses, also starting to disclose revenues for these segments separately. Intel IoT Group's net revenues amounted to USD 3.007 billion in 2020 or 4% of the company's total net revenues. In 2018 and 2019, this share was 5%. Qualcomm Ventures LLC, the investment arm of Qualcomm, together with Indicator and the Brazilian Development Bank (BNDES), has also recently announced the launch of the USD 45 million early-stage VC fund Indicator 2 for the IoT. This is the first investment vehicle dedicated exclusively to the IoT and connectivity in Latin America (BNDES, 2021[14]). Another trend pushed by the diffusion of the IoT – as well as by ML, he fifth-generation technology standard for broadband cellular networks (5G) and autonomous cars – is the entry of non-semiconductor technology groups such as Alphabet (Google), Amazon, Apple and Facebook in the semiconductor development market. In recent years, these companies have started developing their own application-specific ICs for use in their businesses, from data centres to smart speakers.

Box 3.2. Edge AI

In edge (as opposed to cloud-based) AI inference functions are embedded locally in the IoT endpoints that reside at the edge of the network. The IoT devices communicate wirelessly with an edge server that is located relatively close. This server decides what data will be sent to the cloud server (typically, data needed for less time-sensitive tasks, such as retraining) and what data get processed on the edge server.

Compared to cloud-based AI, in which data need to move back and forth from the endpoints to the cloud server, edge AI addresses privacy concerns more easily. It also offers the advantages of response speeds and reduced cloud server workloads. Due to the power constraints typically imposed by battery-powered IoT devices, the inference engines in these IoT devices also need to be very energy efficient.

Source: imec (2021[15]), "The future semiconductor landscape: Five trends", https://www.imec-int.com/en/articles/five-trends-will-shape-future-semiconductor-technology-landscape.

The IoT is considered to have fuelled USD 163 billion in M&A investments for 782 IoT-related M&A deals during the period 2014-20 (451 Research, 2021[16]). Looking at the semiconductor industry only, Intel, one of the leading semiconductor companies, concluded a number of deals in recent years, which can be considered as related to the IoT market. In 2015, the company acquired manufacturer of programmable logic devices Altera for USD 16.7 billion, with the objective to merge Altera's field-programmable gate array technology – processors which the customer can configure and customise to adapt the algorithms involved with various workloads – and Intel's processors so as to tailor them for IoT applications in automotive and manufacturing. Relevant for edge AI, Intel acquired Habana Labs, a start-up focusing on chips with training and inference processing, for USD 2 billion in 2019. To strengthen its value proposition to the automotive industry, in 2017, the company acquired Mobileye, an Israeli start-up specialised in computer vision for autonomous driving technology, for USD 15.3 billion in 2017 and Moovit, a mobility-as-a-service solutions company, for approximately USD 900 million in 2020.

Table 3.1 reports, for illustrative purposes, a selection of deals operated by some of the major semiconductor companies in the years 2014-20, based on information in the press.

Table 3.1. Select M&A deals by major semiconductor companies relevant to the IoT market, 2014-21

Company acquiring	Company acquired	Year	Value (USD)	Acquired company's specialisation	Relevant for:				
					Edge AI	Connected and autonomous vehicles	Wearables	Smart home	Manufacturing
Intel	Moovit	2020	900 million	Mobility-as-a-service		✓			
	SigOpt	2020	Not disclosed	AI software models	✓				
	Habana Labs	2019	2 billion	AI training and inference chips	✓				
	Nervana	2018	350 million	Deep learning	✓				
	Vertex AI	2018	Not disclosed	Deep learning	✓				
	Mobileye	2017	15.3 billion	Computer vision for autonomous driving		✓			
	Yogitech	2016	Not disclosed	Functional safety		✓			
	Altera	2015	16.7 billion	Field-programmable gate array processors and technology		✓			✓
	Recon Instruments	2015	175 million	Smart glasses			✓		
	Saffron AI	2015	Not disclosed	Cognitive computing platform					✓
	Lantiq	2015	Not disclosed	Broadband access and home networking technologies				✓	
	Basis	2014	100 million	Health tracker			✓		

Company acquiring	Company acquired	Year	Value (USD)	Acquired company's specialisation	Relevant for:				
					Edge AI	Connected and autonomous vehicles	Wearables	Smart home	Manufacturing
Samsung Electronics	Harman International Industries	2017	8 billion	Audio, visual and connectivity company	✓				
	Dacor	2016		Luxury home appliance				✓	
	Viv	2016	215 million	AI virtual personal assistant				✓	
	SmartThings	2014	200 million	Smart home and IoT applications				✓	
Micron Technology	FWDNXT	2019	Not disclosed	Deep learning	✓				
	Pico Computing	2015	Not disclosed	Deep learning	✓				
Qualcomm	CSR	2015	2.4 billion	End-to-end semiconductor and software solutions		✓			

Annex 3.A. Defining IoT firms in Crunchbase

As of May 2021, Crunchbase classified 10 384 firms as active in the IoT. However, as the IoT is a technology diffused to several sectors, complementary to other technologies and enabling diverse applications and use, the Crunchbase classification may leave out some IoT firms. To address this issue, a text search was carried out on the description of the firms' activities based on a set of keywords and their combinations (labelled IoT expressions) drawn from IoT-related patents.

The search returned 5 032 additional firms, of which 2 913 were retained as IoT firms after validation.

Annex Table 3.A.1. Top-20 IoT expressions used to identify IoT firms

IoT expressions	Number of start-ups
['iot']	1 493
['home automation']	316
['internet of things']	252
['smart city']	112
['smart grid']	99
['m2m']	83
['smart device']	61
['sensor technology']	59
['industry 4.0']	33
['industrial internet']	31
['iot', 'm2m']	30
['smart solution']	29
['iiot', 'iot']	28
['smart metering']	18
['industrial internet', 'industrial internet of things', 'internet of things']	17
['smart technology']	17
['smart lighting']	15
['internet of things', 'iot']	15
['smart home device']	11
Others	194
Total	**2 913**

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Note

[1] Following a different IoT semiconductor classification methodology, IoT Analytics estimates that the penetration of semiconductor components classified as IoT is expected to grow from 7% in 2019 to 25% by 2025 (2021[17]).

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