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Please cite this paper as:

OECD (2019-12-12), “Measuring distortions in international markets: The semiconductor value chain”, *OECD Trade Policy Papers*, No. 234, OECD Publishing, Paris.
http://dx.doi.org/10.1787/8fe4491d-en

OECD Trade Policy Papers No. 234

Measuring distortions in international markets: The semiconductor value chain

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OECD TRADE POLICY PAPER

This document has been declassified on the responsibility of the Trade Committee under the OECD reference number TAD/TC(2019)9/FINAL.

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MEASURING DISTORTIONS IN INTERNATIONAL MARKETS: THE SEMICONDUCTOR VALUE CHAIN

This report builds on the OECD's longstanding work measuring government support in agriculture, fossil fuels, fisheries, and more recently in the aluminium value chain in order to estimate producer support and related market distortions in the semiconductor value chain. Results for 21 large firms operating across the semiconductor value chain indicate that total government support has exceeded USD 50 billion over the period 2014-18. Government support provided in the form of below-market debt and equity appears to be particularly large in the context of the semiconductor industry and concentrated in one jurisdiction. Other types of support identified include support for R&D and investment incentives, which benefitted all firms studied in this report. The report also discusses the implications that these findings have for trade rules, and in particular for subsidy disciplines in a context of growing government involvement in semiconductor production and poor transparency of support measures.

Keywords Trade, market distortions, government support, subsidies, R&D policy, semiconductors

JEL Codes F23; G32; H25; H81; L33; L63

Acknowledgements

The preparation of this report has involved contributions from the following OECD staff members working under the supervision of Julia Nielson: Andrea Andrenelli, Julien Gourdon, Yuki Matsumoto, Taku Nemoto, Jehan Sauvage, and Christian Steidl. In addition, the report benefitted from the helpful comments and suggestions of (OECD unless specified otherwise): Ken Ash, David Drysdale, Assia Elgouacem, Javier Lopez Gonzalez, Deborah Lucas (Director, MIT Golub Center for Finance and Policy), Sébastien Miroudot, Evdokia Moïsé, Joon-Hyung Park, Caroline Paunov, Dirk Pilat, and Silvia Sorescu. The authors would like to thank Jacqueline Maher for preparing this document for publication. The OECD Secretariat is also grateful for the helpful comments and feedback that delegations and government officials provided throughout the preparation of this report.

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Abbreviations

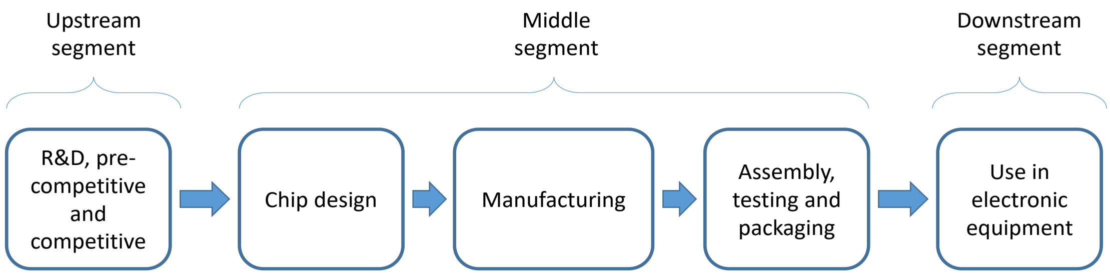
AI	Artificial intelligence
ASIC	Application-specific integrated circuit
CPU	Central processing unit
DRAM	Dynamic random access memory
EDA	Electronic design automation
EUV	Extreme ultra-violet
FPGA	Field-programmable gate array
GPU	Graphics processing unit
HS	Harmonized System
ICT	Information, technology and communication
IDM	Integrated device manufacturer
IoT	Internet of Things
IP	Intellectual property
IPRs	Intellectual property rights
ISIC	International Standard Industrial Classification
ITA	Information Technology Agreement
ITT	International transfer of technology
LED	Light-emitting diode
M&As	Mergers and acquisitions
MFN	Most favoured nation
NTM	Non-tariff measure
OSAT	Outsourced semiconductor assembly and testing
OSD	Optoelectronics, sensors, and discrete semiconductors
SIM	Subscriber identification module
SoC	System-on-a-chip
SOE	State-owned enterprise
TPU	Tensor processing unit
VAT	Value-added tax
VHSIC	Very high speed integrated circuit
VLSI	Very large-scale integrated circuit

Executive summary

The OECD has longstanding work identifying and measuring distortions in international markets. Much of that work has concerned the measurement of government support, focussing initially on support for agriculture and later expanding coverage to fisheries and fossil fuels. More recently, the OECD has begun looking into government support for key industrial sectors. Following the release of a report on market distortions in the aluminium value chain (OECD, 2019[1]), the present study aims to identify and measure market distortions in the semiconductor value chain.

The semiconductor value chain is complex and global in scope: not only is the production of semiconductors one of the most R&D-intensive activities, but it also spans a significant number of specialised tasks performed by different companies around the world (Figure 1). The largest semiconductor vendors are predominantly based in the United States, Korea, Europe, and Japan, but many outsource capital-intensive manufacturing and assembly & testing activities to specialised firms located in Chinese Taipei, the People's Republic of China (hereafter "China"), and Singapore. Although the industry is generally characterised by large economies of scale and significant market concentration, smaller companies are nonetheless able to specialise upstream in the computer-assisted design of semiconductors.

Figure 1. The semiconductor value chain spans a great number of specialised tasks



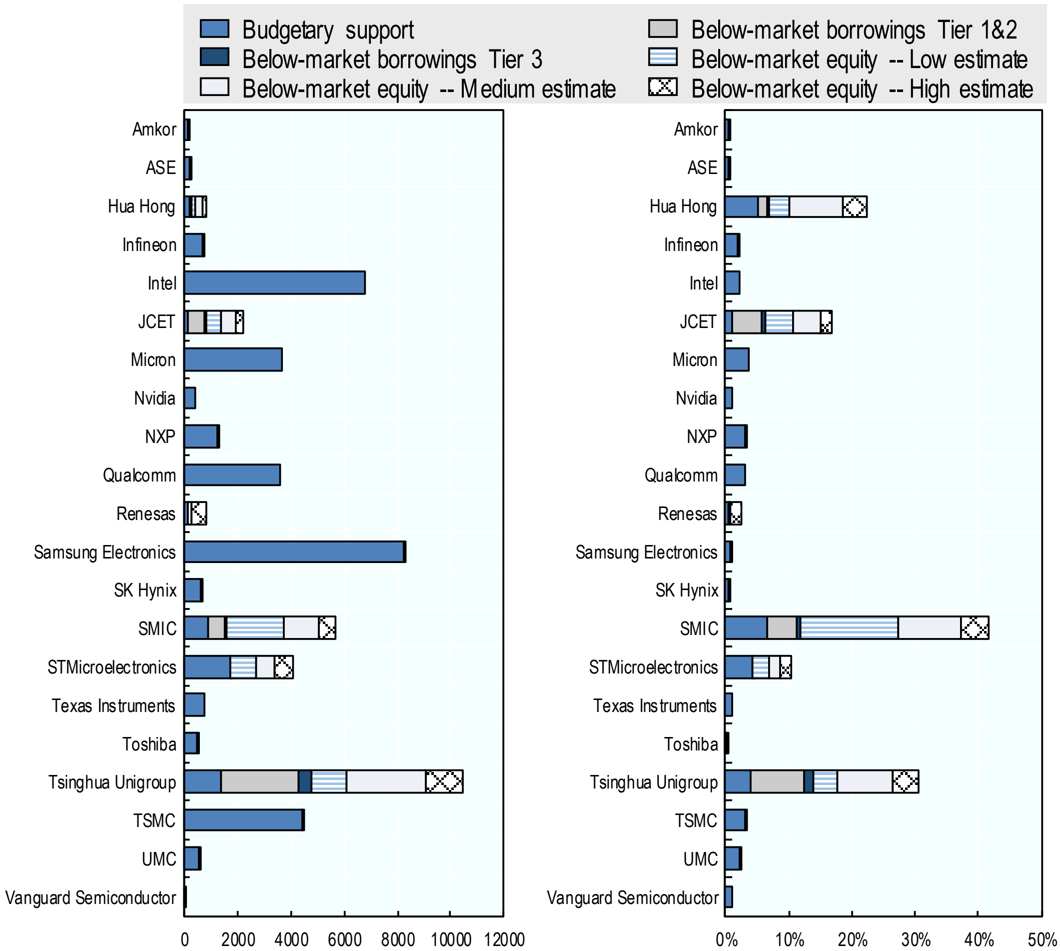
Looking at a sample of 21 large semiconductor firms operating at different stages of the value chain, this study highlights interesting characteristics of government support as it benefits technology-intensive companies. Based on both the extent of current support and recent changes in the ownership structure of semiconductor firms, the results show government involvement (ownership or investment by the state in semiconductor firms) to be especially large in one jurisdiction. Government investments in semiconductor firms may in turn create an important channel for facilitating the provision of a range of support, from below-market equity to assistance with technology acquisition through cross-border mergers and acquisitions. Cross-border acquisitions appear in particular to have gathered pace following the creation in 2014 of China's state-backed national semiconductor fund and related sister funds at local level. Overall, this suggests non-market forces to be considerably stronger in China than in the other economies studied.

For the sample of 21 large semiconductor firms considered in this study – and using conservative assumptions –, the analysis finds total government support to have exceeded USD 50 billion over the period 2014-18 (Figure 2). This comprises support provided through government budgets (e.g.

grants and tax concessions), but also that provided by state enterprises through the financial system in the form of below-market borrowings and below-market equity. Government support through below-market equity appears to be particularly large in the context of the semiconductor industry and concentrated in one jurisdiction. Such support amounted to USD 5-15 billion for just six government-invested firms in the sample, four of which are from China. For two of these firms (SMIC and Tsinghua Unigroup), total government support exceeded 30% of their annual consolidated revenue. Underpinning these results is the finding that the four Chinese companies in the sample all had sustained below-market equity returns throughout the period that this report covers (2014-18).

Figure 2. Total government support for all semiconductor firms studied amounted to more than USD 50 billion over the period 2014-18

Left: Total government support, 2014-18, USDmn, current
Right: Total government support, 2014-18, % of firm revenue



Note: Data for Toshiba are for 2013-17 instead of 2014-18.
Source: OECD calculations.

As the semiconductor industry counts among the most R&D-intensive industries, the majority of all *budgetary support* identified in this study targets the R&D activities of semiconductor firms. That support is usually conferred through either research grants or measures related to the tax treatment of R&D spending. While there are good economic arguments for supporting R&D – such as correcting market failures – care should be taken to design R&D measures in a manner that maximises societal benefits (i.e. innovation efforts that can increase productivity and well-being) while minimising costs (i.e. competitive distortions). Emphasis should preferably be placed on transparent and non-discriminatory policies that benefit either young firms that face financing constraints, or pre-competitive research collaborations that undertake basic, fundamental R&D, which might otherwise be undersupplied by the private sector.

Beyond support for R&D, much of the budgetary support that this study has identified falls into the broad category of investment incentives. Most are tax concessions that are relatively widespread: they can be found in China, Ireland, Israel, Italy, Korea, Malaysia, the Philippines, Singapore, Chinese Taipei, and the United States to name a few. Although certain investment incentives benefit both domestic and foreign firms, they still distort markets by encouraging more investment in semiconductor fabs[1] than market conditions would normally warrant, as well as diverting scarce public resources away from other policy priorities.

More importantly, analysis in this report also shows that *support provided through the financial system* – particularly through the equity channel – is a significant contributor to total government support in the semiconductor value chain. Government support provided through the equity channel (“*below-market equity”*) overwhelmingly benefitted Chinese firms in the sample, which together received 86% of all such support as measured by this study. This reflects the large investments that Chinese government funds, at both central and local levels, have made in domestic semiconductor firms, and which have profoundly reshaped China’s semiconductor industry by giving the state a stronger influence over corporate decisions. There notably appears to be a direct connection between equity injections by China’s government funds and the construction of new semiconductor fabs in the country. In that sense, below-market equity in China took the form of large government equity injections for investing in new production facilities. Not only was below-market equity considerably lower elsewhere, but it did not involve equity injections over the period considered (2014-18) and instead arose from government shareholders supporting companies with weaker financials. Likewise, Chinese firms in the sample obtained nearly all (98%) of the support conferred through the debt channel (‘*below-market borrowings*’) that this study has identified.

While government equity injections in the semiconductor value chain have implications for trade, what they mean for trade rules, and subsidy disciplines more specifically, warrants closer investigation. By its very nature, below-market equity is probably among the hardest forms of support to identify and quantify. This report chooses to assess the benefit to firms of this support *ex post*, by comparing over time the observed financial returns of government-invested firms against the returns that market participants might reasonably expect semiconductor firms to achieve. The approach used here, however, is only one possible way of identifying and quantifying government support provided through the equity channel. Other approaches are generally *ex ante*, focussing instead on whether the decision by the government authorities to invest in a firm was consistent at the time with market principles.

Methodological challenges and the complexities surrounding below-market equity together suggest that there will be challenges in disciplining such support via subsidy rules alone. This is especially the case given: the lack of an internationally accepted definition of below-market equity; the focus of current rules on contemporary equity injections, which ignores the continued benefits that can

1 “Fabs” refers to semiconductor manufacturing plants, i.e. “manufacturing” in the value-chain diagram (Figure 1).

come from past equity injections in the form of below-market returns[2]; and the opacity of firms' ownership structures. Other instruments may therefore be necessary beyond a sole focus on improving current subsidy rules, including trade disciplines in relation to state enterprises. A first critical step would be strengthened transparency mechanisms.

Enhanced transparency should focus, in particular, on (i) the extent to which governments own shares in semiconductor companies and their financial backers, as well as on (ii) the support policies that are in place in different countries. Unlike for some other industrial sectors, it is not always evident which semiconductor firms are state enterprises or government-invested. The considerable opacity in the ownership structures of many semiconductor firms in China in particular complicates efforts to discipline the provision of government support to and by state enterprises through trade rules. It also hampers efforts to understand the exact role played by state actors in transfers of technology through cross-border acquisitions. Finally yet importantly, information about the policies that confer support to semiconductor producers remains alarmingly scarce and inadequate.

Resolving some of these issues may therefore necessitate that policy efforts focus not only on improving current subsidy rules (including notification mechanisms), but also on devising specific disciplines on state enterprises and government-invested firms (with attention to the nature of the government involvement and the behaviour of the firm). This in turn could help address the problems posed by below-market equity and other forms of support that government-invested firms themselves provide (e.g. below-market borrowings). Reform efforts could build on existing rules and guidelines on state enterprises at the national and international levels.

One important implication of global value chains (GVCs) is that they make it difficult to determine the trade harm that might result from government support at any one point of the supply chain. With semiconductor firms interconnected through complex production networks, the impacts of any one measure may trickle down the value chain or instead affect companies upstream that provide crucial parts and components. This complicates efforts to determine the winners and losers from government support and suggests that the benefits from government support in a value-chain world may not necessarily accrue entirely to those receiving the measures in the first place.

At a broader level, this report also raises questions about the role and effectiveness of government support in R&D-intensive industries characterised by short product cycles. Where market failures provide valid reasons for government intervention, support policies need to be designed in a way that maximises innovation and access to capital markets while minimising distortions to trade and competition. Besides R&D support and investment incentives (discussed above), there are also questions as to whether below-market finance is conducive to productivity gains and competitiveness in the long term. This discussion has a particular resonance for China, which is trailing in semiconductor foundry technology despite relatively large government support, and which has long had policies that explicitly seek to support the development of the domestic integrated-circuit industry, and more recently to support the creation of national semiconductor champions. It is an open question at this stage whether the provision of government equity on a large scale marks a fundamental shift in the effectiveness of government support in semiconductors. Yet however effective it is, the provision of large amounts of support by one country – including where it stems from government equity injections that help increase companies' semiconductor assets – can nevertheless cause significant trade distortions that are a serious concern for all others.

2 As explained in this report, these benefits take the form of financing costs that are below the cost of capital wherever government-invested firms fail to generate a fair return on equity for taxpayers in addition to covering their interest costs.

1. How semiconductors are made: A description of the value chain

Semiconductors, otherwise known as 'integrated circuits' or 'computer chips'[3], are the brains of modern electronic equipment, storing information and performing the logic operations that enable devices such as smartphones, computers, and servers to operate. Their name comes from their electrical properties that combine features of both insulators and conductors, allowing control of the flow of electric current. There are usually multiple semiconductors implanted on the circuit board of any electronic device, each fulfilling a precise function, be it a central processing unit (CPU) or chips specifically designed for memory, graphics, audio, or power management.

The industry[4] generally describes semiconductors as falling into two broad categories, namely (i) 'integrated circuits' proper and (ii) so-called 'optoelectronics, sensors, and discrete semiconductors' (OSD). OSD represent less than 20% of the total market for semiconductors, much of it for light-related applications such as LED lamps, solar photovoltaic panels, or cameras. Demand for such devices typically obeys a different pattern than that for other semiconductors, with other considerations such as energy policy taking centre stage. This study therefore chooses to concentrate primarily on integrated circuits since they make up the most technologically advanced and economically significant segment of the semiconductor market.

Integrated circuits themselves usually take the form of either logic, memory, or analog devices, in decreasing order of economic importance.[5] While they vary in nature and complexity, products in all three groups exhibit short life cycles that may last just a few months as producers try to keep pace with innovation and consumer demands for faster and more reliable electronics (McKinsey and Co., 2011[2]; Ernst, 2015[3]; Aizcorbe, 2005[4]). Moore's Law[6] has come to epitomise these short cycles, noting famously that the number of transistors on a chip – an indicator of chip performance – has tended historically to double every two years, to the point where some semiconductors possess today more than two billion transistors. Industry-wide cyclicality is also a feature of semiconductors, with business activity going through periodic booms and busts, spurred by the ebb and flow of product innovations and market imbalances.

The semiconductor value chain is complex and global in scope, as producers have come to rely on vast networks of suppliers and contractors to perform specialised tasks at different stages of the chain. By one estimate, a large US-based semiconductor firm may have as many as 16 000 suppliers worldwide (Semiconductor Industry Association and Nathan Associates, 2016[5]). This makes the semiconductor industry highly reliant on the free cross-border flow of parts, machines, services, knowledge, and talent, thereby heightening its sensitivity to supply-chain disruptions.

3 In what follows, this report uses all three terms interchangeably, even though integrated circuits are technically a subset of all semiconductors.

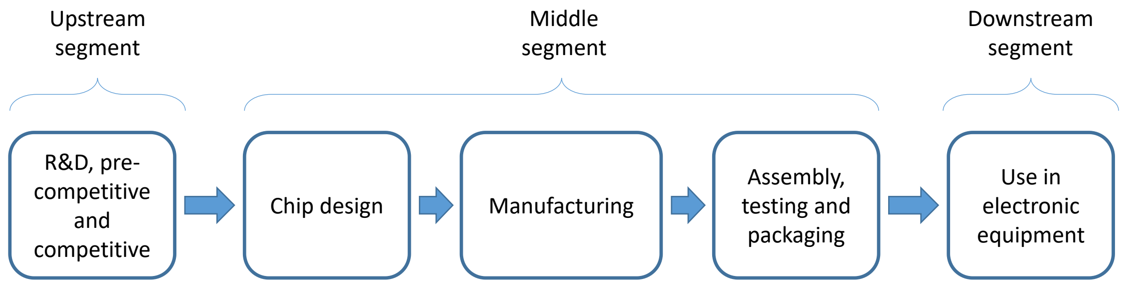
4 See, for example, Semiconductor Industry Association and Nathan Associates (2016[5]) and PwC (2017[109]).

5 *Ibid*. Logic semiconductor devices are sometimes broken down further into high-end microprocessors (e.g. CPUs) and the more standardised 'commodity chips' that are used for routine logic operations and produced in large volumes. Memory semiconductor devices include both volatile memory (e.g. DRAM) and non-volatile data storage (e.g. 3D NAND).

6 Named after Gordon Moore, co-founder of US firm Intel. See Box 1.1 and www.intel.com/content/www/us/en/silicon-innovations/moores-law-technology.html (accessed on 25 October 2019).

Its complexity notwithstanding, the semiconductor value chain is often broken down into three broad segments that each involves a number of discrete stages and tasks (Figure 1.1). In the upstream segment, researchers in the private sector, academia, and government undertake, often collaborative, research and development (R&D) in order to generate the basic knowledge upon which firms then build their own competitive innovation efforts. The production of semiconductors itself occurs in the middle segment of the chain, where it follows a sequence that begins with (i) the design of chips; followed by (ii) their fabrication in so-called ‘foundries’ or ‘fabs’; and ends with (iii) their assembly, testing, and packaging. In the downstream segment, firms then distribute packaged semiconductors for use in electronic devices such as smartphones and computer servers, the demand for which greatly affects derived demand for semiconductors.

Figure 1.1. The semiconductor value chain



Source: Adapted from Semiconductor Industry Association and Nathan Associates (2016[5]).

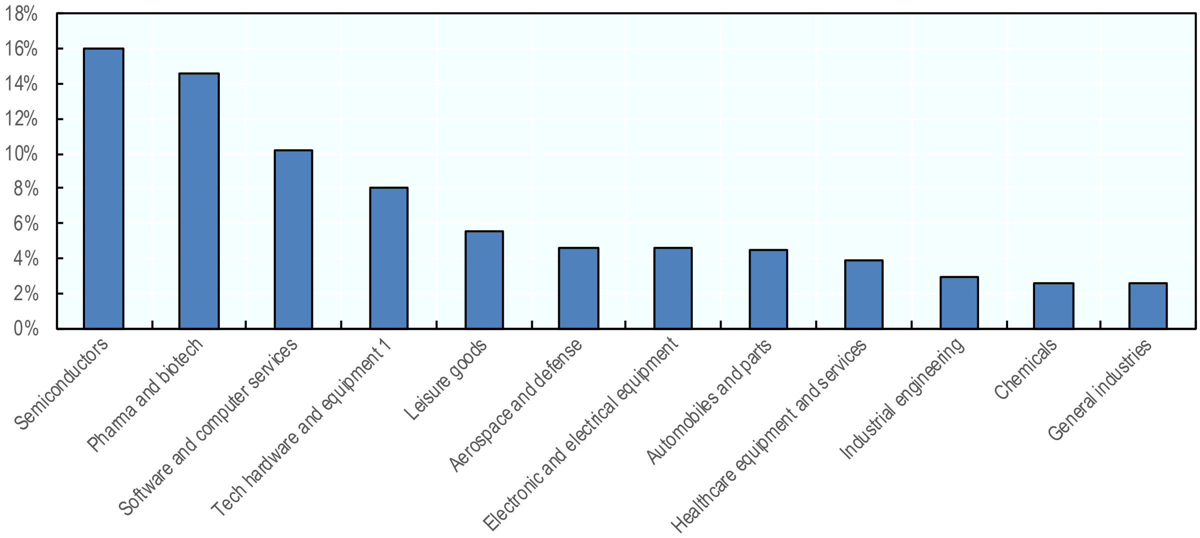
1.1. Upstream segment: The generation of knowledge and its central role in the semiconductor industry

The production of semiconductors constitutes one of the most R&D-intensive activities, alongside pharmaceuticals, air and spacecraft manufacturing, and software development. Data from the OECD’s *Science, Technology and Industry Scoreboard* (OECD, 2017[6]) show business R&D to account for a much larger proportion of value added in the information, technology and communication (ICT) industry[7] – which includes semiconductors – than in most other activities of the International Standard Industrial Classification (ISIC). Consulting firm McKinsey likewise described R&D as “the lifeblood of the semiconductor industry” (McKinsey and Co., 2011[2]), showing the sector to surpass even pharmaceuticals when R&D spending is expressed as a share of firm revenue (Figure 1.2). This sets the production of semiconductors apart, given that much R&D involves sunk costs that firms incur over many years, with little or no assurance that the investments thus made will yield productive assets (e.g. proprietary knowledge) down the line.

[7] This refers to division 26 of the fourth revision of the ISIC, namely “Computer, electronic and optical products”.

Figure 1.2. Production of semiconductors is one of the most R&D-intensive activities

R&D as a share of company revenue in 2014, %



Note: 1) Excluding semiconductors.
Source: McKinsey and Co. (2017[7]).

At a broad level, R&D encompasses a wide range of activities that differ in how far removed they are from commercialisation. The OECD's *Frascati Manual* (OECD, 2015[8]) defines R&D as the "creative and systematic work undertaken in order to increase the stock of knowledge […] and to devise new applications of available knowledge." There are nevertheless important differences between R&D efforts that aim to advance fundamental scientific knowledge and those undertaken for commercial profit. Many countries choose to rely for statistical purposes on the OECD's approach that distinguishes between basic research, applied research, and experimental development.[8] The distinction is, however, difficult to make in practice, especially since much R&D is firm-specific (Helfat, 1994[9]) and its characterisation often stems from managers' own subjective assessments of how far advanced their activities are (Amsden and Tschang, 2003[10]). For this and other reasons (e.g. commercial confidentiality), one may only be able to ascertain the true nature of R&D projects *ex post*, once they are completed.

In semiconductors as in other knowledge-intensive industries, upstream R&D efforts often bring together private firms, academia, and the government, albeit to a varying extent. Regardless of the exact nature of R&D projects, governments commonly share in the risks and costs of R&D either by participating in the research itself (e.g. in the context of public-private consortiums) or by contributing funding (e.g. through grants and tax concessions). Publicly performed R&D has tended to focus more on basic research that firms might not have carried out otherwise, whereas publicly funded but privately performed R&D usually has a targeted focus to yield more immediate results (OECD, 2008[11]). Government participation notwithstanding, the business-enterprise sector remains by far the largest contributor to total R&D expenditure and personnel in most industrialised countries, driven by firms' motivation "to differentiate themselves from competitors […] and to increase profits" through technological rents (OECD, 2014[12]). This is especially true in

8 Experimental development consists in R&D that is "directed to producing new products or processes or to improving existing products or processes" (OECD, 2015[8]), such as engineers building a prototype.

semiconductor R&D, where the private sector was the main driving force behind the industry's birth and early development in the United States throughout the 1950s (Box 1.1).[9]

The costs of engaging in semiconductor R&D are unusually large and have kept increasing over time as firms push out the technological frontier. This has pressured the industry to consolidate (Lapedus, 2015[13]), with only the largest firms able to incur growing investments in basic and applied research. One indication of the size of R&D investments is corporate labs, which can group in one location thousands of full-time researchers covering multiple scientific disciplines (Amsden and Tschang, 2003[10]). To spread the costs of R&D and avoid duplication of efforts, semiconductor firms often join forces and collaborate upstream in 'pre-competitive' research. The practice was made easier in the United States with the adoption in 1984 of the National Cooperative Research Act, which "gives companies engaged in cooperative [R&D] partial exemption from antitrust laws" (Randazzese, 1996[14]). Since then, research collaborations have grown to become the dominant form of strategic partnerships in the semiconductor industry (Figure 1.3).

Box 1.1. A short history of the early development of semiconductors

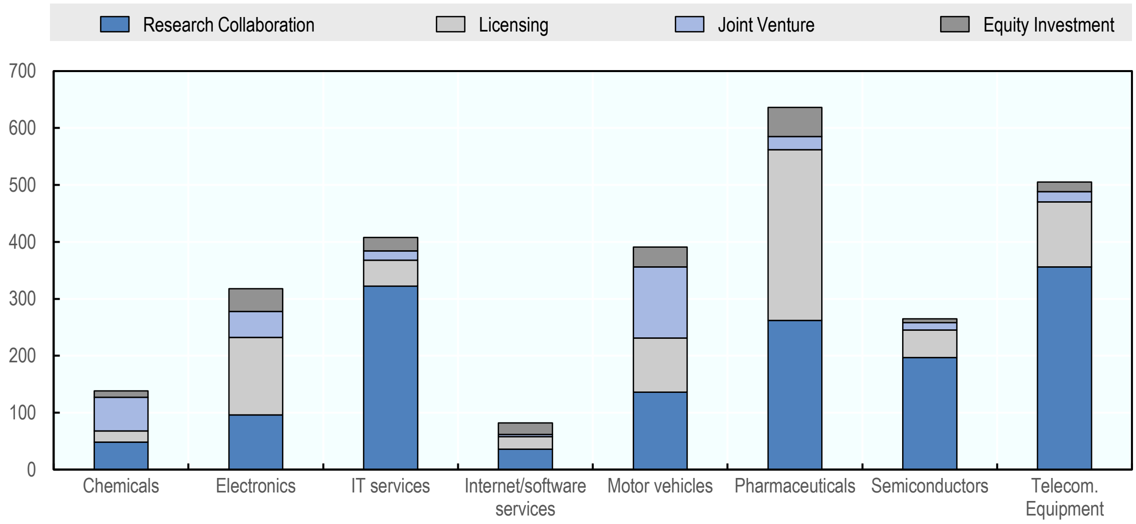
- 1947-48: Physicists John Bardeen, Walter Brattain, and William Shockley invent the first transistor consisting of two gold wires and a piece of processed germanium. All three were working at the time for Bell Laboratories in New Jersey, a private research organisation then owned by telephone company AT&T.
- 1954: Dallas-based Texas Instruments, Inc. designs and manufactures the first transistor radio. Gordon Teal, an employee of the company and former engineer at Bell Laboratories, develops the first commercial silicon transistor.
- 1955: William Shockley leaves Bell Laboratories to found the Shockley Semiconductor Laboratory, a division of Beckman Instruments, Inc., in his home town of Palo Alto (California).
- 1956: John Bardeen, Walter Brattain, and William Shockley are awarded the Nobel Prize of Physics "for their researches on semiconductors and their discovery of the transistor effect."
- 1957: Robert Noyce, Gordon Moore, and six other young recruits resign from Shockley Semiconductor Laboratory to establish their own semiconductor company, Fairchild Semiconductor, in nearby Mountain View (California). They become known as the 'traitorous eight'.
- 1958: Jack Kilby, a new employee at Texas Instruments, invents the first germanium-based integrated circuit. Later that year, Robert Noyce at Fairchild creates the first silicon-based integrated circuit, independently of Kilby's invention.
- 1962: The NASA announces that it will use integrated circuits in its prototype Apollo guidance computer.
- 1967: Texas Instruments develops the first electronic hand-held calculator known as the "Cal Tech".
- 1968: Robert Noyce and Gordon Moore leave Fairchild Semiconductor to found their own company, the Intel Corporation.
- 1971: Intel creates the first commercially available microprocessor (the Intel 4004) while Texas Instruments unveils the first single-chip microcontroller (i.e. a small computer on a single integrated circuit).
- 2000: Jack Kilby is awarded the Nobel Prize of Physics "for his part in the invention of the integrated circuit."

Sources: Company websites, Wolfe (1983[15]), and Slomovic (1988[16]).

9 Government involvement was more apparent on the demand side, with procurement (e.g. from NASA) rising to account for the majority of all purchases of US-made chips in the mid-1960s (Peck, 1985[50]). That share subsequently fell below 10% in the 1970s (Slomovic, 1988[16]).

Figure 1.3. Research collaborations have grown to become the dominant form of strategic partnerships in the semiconductor industry

Strategic partnership by industry and type (number of relationships)



Note: The figure above is based on a limited sample of large firms for each sector. It shows the number of partnerships but not their value, for which data were not available at the time of writing. The proportion of partnership types in different industries may differ once accounting for the value of partnerships.
Source: Andrenelli, Gourdon and Moïsé (2019[17]).

With much variation in the scope and modalities of research collaborations, evidence for their success is mixed. On the one hand, partnerships can enable firms to pool resources and build on each other's research to advance knowledge further than they would on their own. Although not specific to semiconductors, the OECD found that "firms that collaborate on innovation spend more on innovation than those that do not", thereby suggesting that "collaboration is unlikely to be undertaken mainly as a cost-saving measure" (OECD, 2010[18]). Yet participation in research collaborations may also obey more strategic motives, such as firms' 'fear of missing out'. Collaborations may also prompt some degree of collusion among participants, particularly where they require members to have a certain minimum size (Irwin and Klenow, 1996[19]). In such cases, "research joint ventures tend to restrict the dissemination of an innovation relative to an independent researcher" while also weakening incentives to develop an innovation (Reinganum, 1989[20]). Conversely, a broad-based membership may erode the perceived benefits of collaborations by making it harder for participants to coalesce around a shared research agenda.[10]

Firms taking part in research collaborations are usually themselves large producers of semiconductors or semiconductor manufacturing equipment. Founding members of US consortium Sematech, which was formed in 1987 in response to Japan's growing market share in semiconductors, included, for instance, large chip producers such as Advanced Micro Devices (AMD), IBM, Intel, Micron, and Texas Instruments (Randazzese, 1996[14]; Irwin and Klenow,

[10] Randazzese (1996[14]) suggests this was the case in the early days of Sematech, once a leading US research consortium on semiconductors.

1996[19]). Although the consortium was initially restricted to US-owned semiconductor firms[11], it subsequently morphed into a broader research clearing house as membership widened to include large foreign producers such as Samsung Electronics (Korea) and TSMC (Chinese Taipei). Interest in Sematech has since waned, however, as Intel, Samsung, and TSMC all opted to leave the consortium, which was eventually folded into the SUNY Polytechnic Institute in New York State (Lapedus, 2015[13]). An initiative to develop 450 mm silicon wafers,[12] the Global 450 Consortium (G450C), met the same fate, failing to maintain interest among prominent members such as Intel, Samsung, and TSMC (Rulison, 2017[21]).[13] Joint efforts to develop and commercialise so-called 'extreme ultra-violet' lithography technology[14] have met more success, however, led by Dutch equipment maker ASML in partnership again with Intel, Samsung, and TSMC. The industry has reportedly spent more than USD 20 billion over the years developing that technology (Lapedus, 2015[13]).

Besides firms, universities (and affiliated labs) frequently take part in upstream research collaborations. This enables, for example, doctoral students to work and train in research labs, which in turn benefit from "the latest theoretical knowledge from Ph.D. students" (Amsden and Tschang, 2003[10]). Belgium-based IMEC (*Institut de microélectronique et composants*) is a case in point, having been created in 1984 near the Catholic University of Leuven to provide an international R&D centre specialised in nanoelectronics and digital technologies. IMEC today counts about 4 000 researchers and collaborates with major semiconductor firms, including Arm (United Kingdom), GlobalFoundries (United States), Huawei (China), Micron (United States), SK Hynix (Korea), and Sony (Japan). It has taken part, for instance, in ASML's efforts to develop extreme ultra-violet lithography technology and in a joint venture with SMIC (China) to develop 14 nm chips (Ernst, 2015[3]). In Israel, the Hebrew University of Jerusalem likewise collaborates with Intel through the Intel Collaborative Research Institute for Computational Intelligence.

Although most R&D funding generally comes from the private sector, government agencies often participate in semiconductor research collaborations. France's CEA-Leti, a government research institute created in 1967, has long been involved in upstream semiconductor R&D, collaborating most recently with US firms GlobalFoundries and Intel and with Stanford University's SystemX engineering alliance. In Asia, Japan, Korea, and Chinese Taipei have all created government-related agencies to co-ordinate the R&D efforts of their own semiconductor industry. Japan's then Ministry of International Trade and Industry launched in 1976 the public-private VLSI[15] Technology Research Association to co-ordinate the R&D activities of five Japanese semiconductor firms, namely Fujitsu, Hitachi, Mitsubishi Electric, NEC, and Toshiba (Sakakibara, 1983[22]). A decade later Korean authorities created their own VLSI collaborative research project that brought together domestic chipmakers and the Electronic and Telecommunication Research Institute (ETRI), a government research organisation (Cho, Kim and Rhee, 1998[23]; Hwang and Choung, 2014[24]). More recently, the Korean Government initiated in 2013 a R&D public-private partnership for developing new chip-manufacturing technology, which involves domestic chipmakers (Samsung

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[11] As discussed later in Section 2 of this report, Sematech also benefitted from an annual USD 100 million subsidy in matching funds from the US Department's Defense Advanced Research Projects Agency (DARPA) over the period 1987-1997.

[12] The current industry standard is to use 200 mm or 300 mm silicon wafers.

[13] This happened in spite of G450C receiving public support from the State of New York's Empire State Development Corporation.

[14] Photolithography consists in using light to print and etch circuit designs onto silicon wafers.

[15] VLSI stands for Very Large-Scale Integrated circuit.

Electronics and SK Hynix), large international equipment manufacturers (e.g. ASML and Applied Materials), universities, and public research institutes (Hwang and Choung, 2014[24]). Chinese Taipei offers a similar example with the creation in 1973 of the Industrial Technology Research Institute (ITRI) that undertakes collaborative semiconductor R&D and serves as an incubator for local firms, most of which are located in the Hsinchu Science and Industrial Park, an innovation cluster (Mazzoleni and Nelson, 2007[25]; Hwang and Choung, 2014[24]).

There are many more examples of successful R&D collaborations in semiconductors (e.g. in Israel and Singapore), many of which are international in scope as firms set to establish global innovation networks that mimic their own participation in global production chains. Branstetter et al. (2018[26]) note, for example, how US multinationals in the IT industry have internationalised their R&D efforts since the 1990s, contributing to the emergence of new innovation hubs around the world. This globalisation of research also "coincides with an increasingly global market for the highly skilled" as R&D-heavy firms generally compete for talent worldwide (OECD, 2010[18]).

Altogether, the above discussion paints a picture of upstream semiconductor R&D that is complex, mixing domestic and foreign firms as well as public and private actors. The role played by governments in nurturing semiconductor R&D appears particularly important at times, which raises questions about what distinguishes market-correcting (welfare-improving) R&D policies from trade-distorting industrial policy. Section 2.1 of this report discusses this question further.

1.2. Middle segment: The design, manufacturing, testing, and assembly of semiconductors

1.2.1. From silicon wafers to packaging: The production process for semiconductors

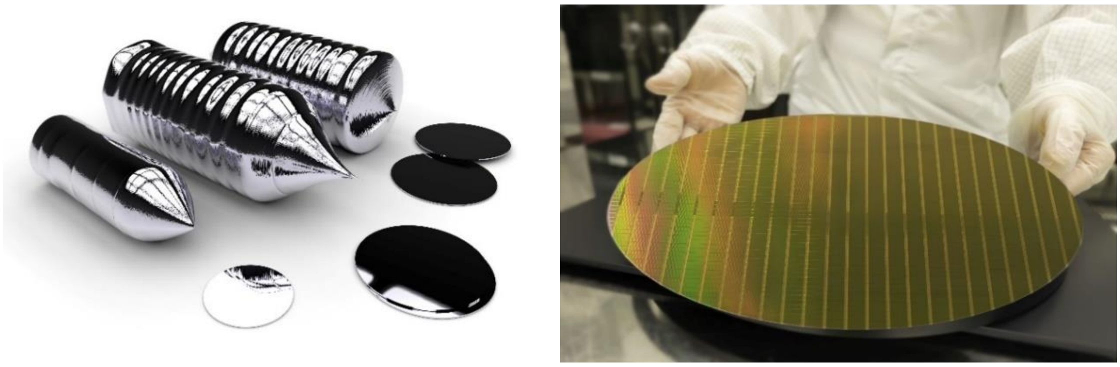
The production of semiconductors begins with the design stage (Figure 1.1), whereby engineers use computer-aided design software to draw a detailed map of the myriad electronic components that form an integrated circuit. The output of that design stage is a code file that usually follows a format known as GDSII, and which contains all the specifications producers need to manufacture a given semiconductor. That stage of the value chain is largely knowledge- and skill-intensive, relying on research conducted upstream and on the provision, where applicable, of pre-designed intellectual-property (IP) cores.[16] Talent and intangible assets are hence key inputs at the design stage. Specialised design software, known as Electronic Design Automation (EDA) software, is another one.

Besides having a code file with detailed product specifications, the manufacturing of semiconductors also hinges on a supply of tangible intermediate inputs. First among them is silicon, which gave its name to a part of the Santa Clara valley in California where industry pioneers located as early as the 1950s (Box 1.1). The basic material for semiconductors is high-purity silicon wafers, which one obtains from raw quartz found in common sand. The process involves extensive refining so that silicon reaches a 99.9999% level of purity, thus making silicon wafers "the purest product manufactured on a commercial scale" (Williams, Ayres and Heller, 2002[27]). That level of purity is an absolute necessity in electronics at the nanoscale, where the slightest impurity may cause chips to malfunction. Once purified, silicon is shaped in the form of ingots that are then sliced into razor-thin wafers (i.e. discs), which are eventually cleaned, polished, and oxidised for later transformation into semiconductors (Figure 1.4).

16 Semiconductor IP cores are reusable and customisable blocks of circuits that chip designers can combine with circuits of their own conception to produce an integrated circuit. The most common IP cores use ARM architectures, named after British firm Arm that sells and licenses them.

Figure 1.4. From silicon ingots to individual chips on a wafer

Left: High-purity silicon ingots are sliced into razor-thin raw wafers
Right: Multiple chips are fabricated onto a single silicon wafer



Source: © I'm Thongchai – Adobe Stock; © frog – Adobe Stock.

Photolithography is the process by which ultra-violet light is used to print and etch circuits directly onto the surface of a silicon wafer. This requires that a 'photomask' be first fabricated using the information contained in the code file produced earlier at the design stage. Much like a stencil, light then goes through this mask to imprint directly onto the silicon wafer the circuit patterns that form a semiconductor. The use of a reducer lens serves to shrink these patterns so they can fit on a chip the size of a fingernail. Other important inputs into this process include numerous chemicals and gases that manufacturers use, e.g. to alter a wafer's sensitivity to light or enhance its electrical properties (a process known as 'doping').

Crucially, the machines and equipment used in photolithography represent for firms a heavy investment that determines largely their fabrication capabilities (Box 1.2). This makes semiconductor fabrication a very capital-intensive activity that is prone to economies of scale. To enable semiconductors to be mass-produced profitably, manufacturers aim to fabricate as many chips as possible on each individual silicon wafer[17], thus spreading fixed costs over larger volumes (Figure 1.4). This implies in principle that the larger the wafer, the lower chips' unit costs. Today's silicon wafers generally measure 200 mm or 300 mm in diameter, with upstream R&D efforts to develop 450 mm wafers having proven unsuccessful thus far (Rulison, 2017[21]). Given a certain wafer size, the industry measures productivity or 'yield' by calculating the percentage of functional chips produced out of all chips that a single wafer can possibly contain. That yield is itself a function of various factors, such as equipment quality and vintage and facilities' cleanliness.

Once fabricated and tested, chips ('dies') are cut and separated from their wafers before they are each packaged and further tested in a final stage prior to downstream use in electronic equipment. In packaging, producers often encase individual chips into protective lead frames and an exterior resin shell that can either fit onto a printed circuit board or be inserted directly into an electronic device (as is the case with SIM cards, a type of semiconductor that users insert into mobile phones). Chips then undergo an additional round of testing to ensure they are functional and ready for integration into electronic equipment. Compared with earlier stages in the semiconductor production chain, assembly, testing, and packaging form a *relatively* labour-intensive set of tasks that does not require as much capital and skills. For that reason, it was the first stage in the chain that semiconductor producers began outsourcing as production grew in volume and scope (Semiconductor Industry Association and Nathan Associates, 2016[5]).

[17] The industry often refers to chips as 'dies' at the manufacturing stage.

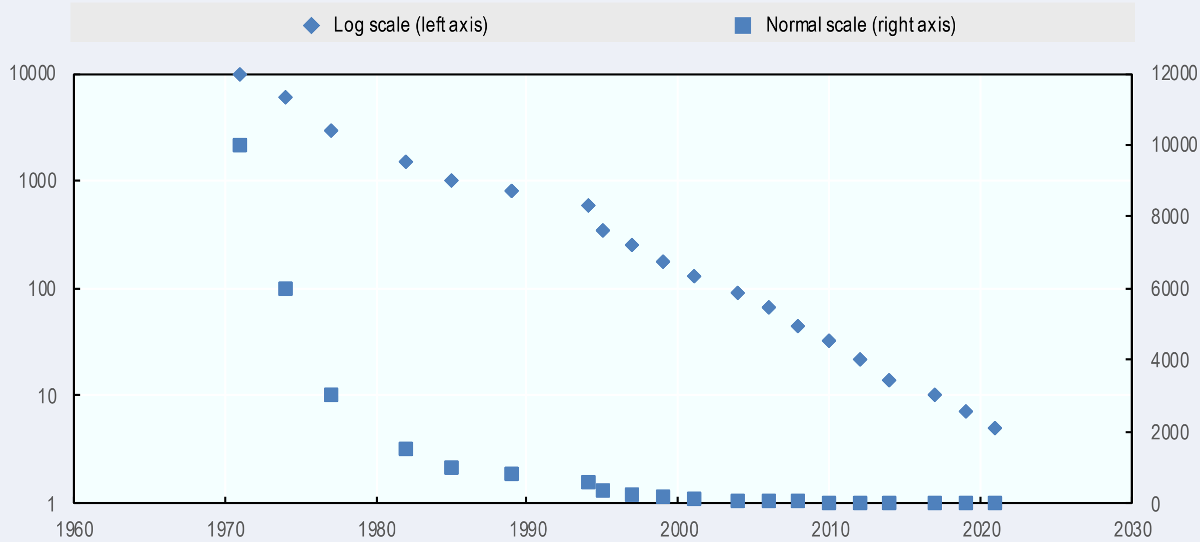
Box 1.2. The lithography process as an indicator of technological advancement

The semiconductor industry has traditionally viewed the minimum size of technology nodes as one indicator of technological advancement. At the risk of over-simplifying, technology nodes reflect the minimum size attainable by a given photolithography process, whereby more advanced technologies enable producers to reach ever smaller nodes. Smaller nodes imply smaller feature size, which enables more circuit elements (e.g. transistors) to fit onto a single chip. Denser chips require in turn less power and shorter processing times.

While the industry used to express technology nodes in micrometres (µm), advances over the last two decades have shrunk node measurement to smaller nanometres (nm), with firms such as Samsung, Intel, and TSMC having reached 10-7 nm in certain cases. This progress has gone hand-in-hand with the development of new lithography equipment, such as extreme ultra-violet (EUV) technology that some claim will be instrumental in reaching 5-3 nm nodes (Moore, 2018[28]). There are, however, concerns that further progress may run into obstacles as costs soar and silicon approaches performance limits, signalling a possible end to Moore's Law for most types of chips (Bailey, 2018[29]). The size of process nodes has also lost some of its original meaning, serving more as a name or label in recent years rather than indicating the physical dimensions of chip components (Hattori, 2015[30]).

Figure 1.5. Process technologies have improved over time but may be approaching limits

Technology nodes (in nanometres)



Note: Numbers for 2019-20 are forecasts.
Source: 2017 edition of the *International Roadmap for Devices and Systems* (IRDS) and earlier editions of the *International Technology Roadmap for Semiconductors* (ITRS).

1.2.2. An industry structured around two business models: The IDM model and the fabless-foundry model

All of the tasks described above involve a complex ecosystem of suppliers and multinationals that spreads across the globe. No single country or firm dominates all of the stages, with some specialising in the provision of parts and equipment, others in IP and specialised software and services (e.g. design, testing, and packaging), and still others in large-scale semiconductor manufacturing. Since data on trade in value added are not available at the level of the semiconductor industry, this report chooses to approach and describe the semiconductor value chain from the standpoint of individual firms. While this implies obvious limitations in relation to sampling, it enables the analysis to better convey the complexity of the semiconductor GVC in which goods, services, capital, knowledge, and talent all cross borders to create more value.

The industry estimates that the global market for semiconductors amounted to about USD 470 billion in 2018, with the top 20 firms accounting for 81% of that global total (Table 1.1). This indicates a large degree of market concentration among semiconductor vendors, with the top five companies representing half of global revenue. American and Korean multinationals dominate the ranking, followed by Japanese and European firms. While top semiconductor vendors undoubtedly enjoy a leading position in the market, they generally co-exist with a large number of small and medium-sized enterprises (SMEs) that provide specialised chip-design services, and which do not need to own the large physical assets used in semiconductor manufacturing. An example would be UK start-up Graphcore, which has about 200 employees and specialises in the design of chips in relation to artificial intelligence (AI). Market concentration in semiconductors also varies significantly depending on the type of chips that vendors produce, be they DRAM memory chips or graphics processing units (GPUs).

Table 1.1. Top 20 semiconductor vendors, by revenue

Rank	Company name	Revenue in 2018 (USDmn)	Estimated market share	Home economy
1	Samsung Electronics[1]	78 430	17%	KOR
2	Intel	70 848	15%	USA
3	SK Hynix	36 761	8%	KOR
4	Micron	30 391	6%	USA
5	Broadcom	20 848	4%	SGP[2]
6	Qualcomm[1]	17 400	4%	USA
7	Texas Instruments	15 784	3%	USA
8	Nvidia	11 716	2%	USA
9	Toshiba Memory Corporation[4]	11 444	2%	JPN
10	Western Digital[1]	10 117	2%	USA
11	STMicroelectronics	9 612	2%	CHE
12	NXP	9 407	2%	NLD
13	Infineon	8 968	2%	DEU
14	Sony Semiconductor[1]	7 962	2%	JPN
15	MediaTek	7 892	2%	TWN
16	HiSilicon (Huawei)[1]	7 573	2%	CHN
17	Apple[1,3]	7 449	2%	USA
18	Renesas[1]	6 703	1%	JPN
19	AMD	6 475	1%	USA
20	Analog Devices	6 201	1%	USA
	TOTAL	381 982	81%	
	Estimated global market size	470 000		

Notes: Vendors comprise IDMs and fabless firms only. The total may differ slightly from the sum of individual company numbers due to rounding errors. 1) Semiconductor segment only. 2) Broadcom was domiciled in Singapore until 2018 when it moved to the United States. 3) Estimated. 4) Toshiba Memory is in the process of being renamed Kioxia.
Source: Companies' financial statements and websites, and World Semiconductor Trade Statistics for global market size.

Two different business models have emerged over time that have shaped the way semiconductor vendors operate. The industry often refers to them as the integrated device manufacturer (IDM) model and the fabless-foundry model. Of the top 20 firms listed in Table 1.1, about half are IDMs, meaning that they undertake most of the tasks in the value chain internally. Intel, Samsung, and Texas Instruments are examples of such IDMs in that they have facilities worldwide that conduct upstream R&D, chip design, manufacturing, as well as testing and assembly. By contrast, vendors in the fabless-foundry model (e.g. Qualcomm and Nvidia) are companies that choose to focus essentially on chip design – i.e. they are 'fabless' in the sense of not having fabrication facilities or 'fabs' – while outsourcing manufacturing to specialised firms known as 'contract foundries' or 'pure-play foundries'. In addition, both IDMs and fabless firms often outsource part or all of their assembly, testing, and packaging to another set of specialised companies known as outsourced semiconductor assembly and testing (OSAT) firms.

Top contract foundries are few but not necessarily located in the same economies as semiconductor vendors. Because they are highly capital-intensive[18], foundries need to spread their considerable capital expenditures over large production volumes and attain high production yields. Together with the fast pace of innovation in semiconductors – which pushes foundries to replace their equipment on a regular basis – this has led foundry players to consolidate operations around a few large units in Asia (Table 1.2). With the notable exceptions of GlobalFoundries[19] (United States), TowerJazz (Israel), and X-Fab (Belgium), all major contract foundries are based in Chinese Taipei, China, and Korea. TSMC (Chinese Taipei) alone accounted for a staggering 54% of the estimated global foundry market in 2018 while the top 10 firms together made up as much as 87% of global sales. Besides pure-play foundries, a number of large IDMs (e.g. Intel and Samsung) have also begun offering contract-foundry services to other vendors, with varying success.

Table 1.2. Foundry players have consolidated operations around a few large units in Asia

Top 10 pure-play foundries, by revenue

Rank	Company name	Revenue in 2018 (USDmn)	Estimated market share	Home economy
1	Taiwan Semiconductor Manufacturing Company (TSMC)	34 197	54%	TWN
2	GlobalFoundries	6 200	10%	USA[1]
3	United Microelectronics Corporation (UMC)	5 015	8%	TWN
4	Semiconductor Manufacturing International Corporation (SMIC)	3 360	5%	CHN
5	Powerchip Technology	1 402	2%	TWN
6	Tower Semiconductor (TowerJazz)	1 304	2%	ISR
7	Vanguard International Semiconductor (VIS)	959	2%	TWN
8	Hua Hong Semiconductor	930	1%	CHN
9	DB HiTek[2]	608	1%	KOR
10	X-FAB Silicon Foundries	588	1%	BEL
	TOTAL	54 562	87%	
	Estimated global market size	62 872		

Notes: The total may differ slightly from the sum of individual company numbers due to rounding errors. 1) GlobalFoundries is based in the United States but fully owned by the Mubadala Investment Company, Abu Dhabi's sovereign wealth fund. 2) Formerly DongBu HiTek.
Source: Companies' financial statements and websites.

18 Lewis (2019[35]) notes, for example, that "a modern semiconductor fab can now cost between [USD] 7 billion and [USD] 14 billion to build and may be out of date after five or six years." That cost can even exceed USD 20 billion for fabs at the frontier technology (e.g. 5 nm).

19 GlobalFoundries acquired IBM's semiconductor assets in 2014. It is based in the United States but fully owned by the Mubadala Investment Company, Abu Dhabi's sovereign wealth fund.

Despite thinner margins, the global market for the contract assembly, testing, and packaging of semiconductors appears as concentrated as that for contract foundries. Because the tasks involved are *relatively* less skill- and capital-intensive than at other stages of the chain[20], they were the first that the industry chose to offshore, predominantly to Asia. The Semiconductor Industry Association (SIA) traces the first such move back to Fairchild Semiconductor's decision to assemble its chips in Hong Kong, China in 1961 (Semiconductor Industry Association and Nathan Associates, 2016[5]). Since then, the OSAT industry has grown into a large global market that remains dominated by Asian economies (Table 1.3). With the exception of US firm Amkor, all major OSAT firms are based in East Asia.

Table 1.3. Asian economies dominate the OSAT industry

Top 10 OSAT firms, by revenue

Rank	Company name	Revenue in 2018 (USDmn)	Estimated market share	Home economy
1	Advanced Semiconductor Engineering (ASE)[1]	12 123	40%	TWN
2	Amkor	4 316	14%	USA
3	Jiangsu Changjiang Electronics Technology (JCET)[2]	3 606	12%	CHN
4	Powertech Technology (PTI)	2 256	8%	TWN
5	TongFu Microelectronics (TFME)	1 092	4%	CHN
6	Tianshui Huatian Technology	1 076	4%	CHN
7	UTAC	788	3%	SGP
8	King Yuan Electronics Corp. (KYEC)	690	2%	TWN
9	Chipbond	621	2%	TWN
10	ChipMOS	613	2%	TWN
	TOTAL	27 181	91%	
	Estimated global market size	30 000		

Notes: The total may differ slightly from the sum of individual company numbers due to rounding errors. 1) Includes SPIL, which ASE recently acquired. 2) Includes Singapore's STATS ChipPAC, which JCET acquired in 2015.
Source: Companies' financial statements and websites.

Firms operating along the semiconductor value chain rely largely on external suppliers for equipment and numerous intermediate inputs. Although it is beyond the scope of this study to inventory all such inputs and suppliers, a few notable products and companies stand out:

- At the design stage, semiconductor vendors generally rely on other companies to obtain IP cores and specialised EDA software. The former are largely provided by British firm Arm[21] while three companies dominate most of the EDA software market: Cadence (United States), Mentor Graphics (a unit of Siemens, Germany), and Synopsys (United States).
- At the manufacturing stage, foundries purchase specialty industrial gases (e.g. helium and hydrogen fluoride etching gas) and chemicals (e.g. photoresist) from specialised firms such as chemicals group Entegris (United States) – which primarily serves the semiconductor industry – and multinationals such as BASF (Germany), Air Products & Chemicals (United States), and Showa Denko (Japan). Other companies produce and sell silicon wafers to foundries, including: Shin-Etsu (Japan), the SUMCO Corporation (Japan), Wafer Works

20 Compared with sectors outside the semiconductor value chain, the assembly, testing, and packaging of semiconductors remain a capital- and R&D-intensive sector, with increasing returns to scale.

21 Arm is based in the United Kingdom but owned by Japan's SoftBank.

(Chinese Taipei), Siltronic (Germany), Sil'tronix Silicon Technologies (France), Okmetic (Finland-China[22]), and Shanghai Simgui Technology (China). Finally yet importantly, are suppliers of key manufacturing equipment (e.g. 'steppers', used in photolithography), which are usually large firms that invest considerable resources in upstream R&D to collaborate on the development of new lithography processes and precision equipment. Important companies in this market include ASML (Netherlands), Applied Materials (United States), Tokyo Electron (Japan), and Lam Research (United States).

- At the assembly, testing, and packaging stage, OSAT providers use machines made by specialised firms such as: KLA-Tencor (United States), Advantest (Japan), and Teradyne (United States) for testing equipment; and Besi (Netherlands), ASM Pacific Technology (Singapore), and Towa (Japan) for assembly equipment.

Although the distinction between IDMs and the fabless-foundry model is helpful in understanding the structure of the semiconductor value chain, it does not amount to a strict separation but rather is indicative of a variety of business models. As noted above, a number of IDMs such as Intel and Samsung offer foundry services to third-party semiconductor vendors, with Samsung having become an important player in that market. Some IDMs also offer customised testing and packaging services, thus competing against specialised OSAT firms, as do certain large foundries like TSMC. At the same time, numerous IDMs also outsource part of their own foundry, testing, and packaging work, with Texas Instruments noting, for instance, in its 2017 annual report that "[it] sourced about 20% of [its] total wafers from external foundries and about 40% of [its] assembly/test services from subcontractors." This has led some in the industry to talk of an emerging 'fab-lite' or 'asset-lite' IDM model, thus further blurring the distinction between IDMs and fabless firms.

1.2.3. Global trends in semiconductor production

At all stages of the semiconductor value chain, a broad movement of industry consolidation is apparent in the increasing number and value of mergers and acquisitions (M&As) that have taken place over the past two decades. That movement was especially pronounced in the year 2015 (Figure 1.6), which some have described as "a tsunami of M&A deals in the global semiconductor industry" (Ernst, 2015[3]). The average value of individual deals also seems to have increased over time, suggesting that buyers targeted larger firms or that company valuations have increased across the board. The proportion of cross-border deals in total transactions does not reveal a clear pattern, however. One explanation for this trend toward industry consolidation may be found in accelerating increases in the costs of semiconductor R&D and capital equipment, which have made it harder for smaller firms to compete. This acceleration stems in part from diminishing returns in the downsizing of technology nodes (Box 1.2).[23] As a result, only three firms (Samsung, Intel, and TSMC) accounted for as much as 60% of all capital expenditures at global semiconductor facilities in 2014 (Ernst, 2015[3]).

While the United States and Japan have long been playing a central role in the semiconductor value chain, the emergence of Korea and Chinese Taipei as central hubs of semiconductor activity is more recent. Both economies entered the semiconductor value chain in the 1960s when US companies began offshoring assembly and testing (Semiconductor Industry Association and Nathan Associates, 2016[5]; Hwang and Choung, 2014[24]; Tung, 2001[31]), but have since moved into higher

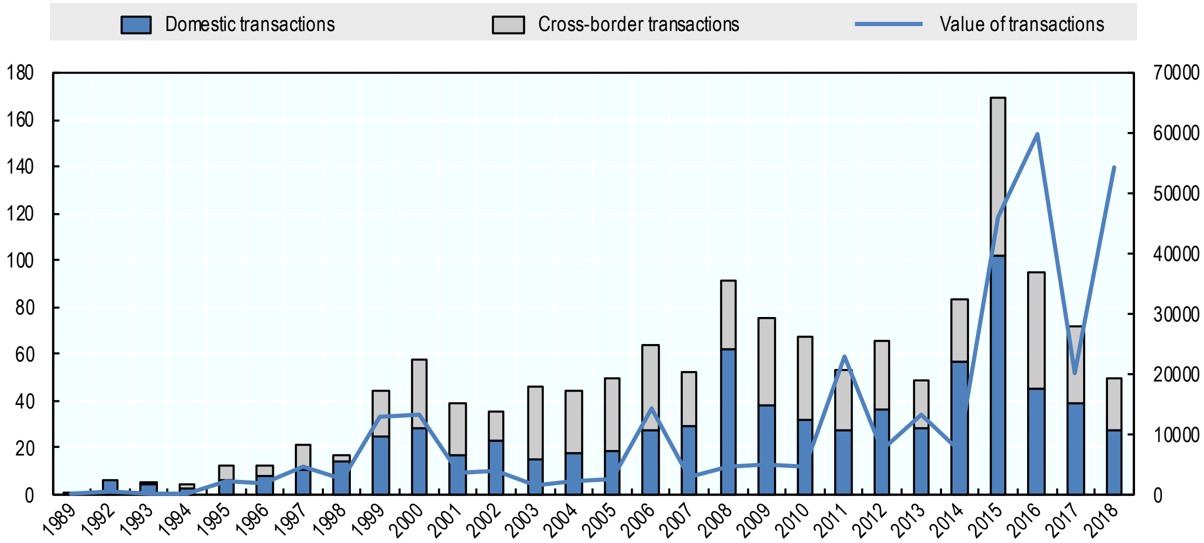
[22] China's state-backed National Silicon Industry Group (NSIG) acquired Finnish firm Okmetic in 2016.

[23] An early study also found the semiconductor industry to be prone to firm-specific learning-by-doing, which implies that "firms face dynamic increasing returns to scale that promote market concentration" (Irwin and Klenow, 1994[47]).

value-added segments while maintaining a strong export orientation. Large homegrown conglomerates have played a dominant role in the development of the semiconductor industry in Korea, using their scale and access to capital markets to enter the DRAM memory segment in the 1980s. Together with heavy R&D investments and the licensing of US technology, this enabled a firm like Samsung to catch up with foreign producers rapidly (Kim, 1997[32]).

Figure 1.6. The year 2015 saw a record amount of semiconductor-related M&As

Number of buyers in M&A transactions (left axis)
total value of transactions in USD millions, current (right axis)



Note: Individual transactions can have a large impact on the total value of deals in any given year. Examples include the USD 34 billion acquisition of Broadcom by Avago in 2016 and Freescale's USD 16 billion acquisition by NXP in 2015. See Box 2.4 for a discussion of the sample of firms considered here.
Source: OECD based on the FactSet database.

The acquisition of foreign technology and government backing likewise helped Chinese Taipei's semiconductor industry to catch up. The origins of today's large contract foundries – including UMC (1980), TSMC (1987), and Vanguard International Semiconductor (1994) – can be traced back to early efforts by the Electronic Research Service Organization (ERSO), a public research institute, to disseminate the knowledge it had acquired from foreign firms and from its own R&D activities. TSMC also innovated by pioneering the contract-foundry model, which allowed the company to gain exposure to foreign clients such as Intel and Motorola and upgrade its technology (Tung, 2001[31]). Within approximately ten years, TSMC was able to close the gap with foreign foundries. The possibility to use the services of nearby contract foundries also encouraged local entrepreneurs, oftentimes returnees from the United States, to establish their own design start-ups, contributing to the rise of Chinese Taipei as a major actor in the semiconductor value chain (Wang, 2007[33]; Song, 2000[34]). Chinese Taipei differs in that regard from Korea in having an interdependent network of specialised firms as opposed to large conglomerates serving as IDMs (Hwang and Choung, 2014[24]).

Although it is a relatively small producer compared with neighbouring Korea and Chinese Taipei, China has noticeably increased its presence in the semiconductor value chain in recent years. This growing participation owes much to the performance of a few firms, and in particular HiSilicon (Huawei's fabless unit), SMIC (a foundry), Tsinghua Unigroup (a fabless that is currently expanding into foundries), and Jiangsu Changjiang Electronics Technology (JCET, an OSAT provider). While HiSilicon is China's only chip vendor to feature in the global top 20 (Table 1.1), Chinese companies have been investing heavily over the past few years in the construction of large semiconductor fabs, with such investments said to amount to more than half of worldwide semiconductor construction spending in 2018 (Lewis, 2019[35]). Tsinghua Unigroup alone is planning to spend almost USD 100 billion jointly with central and local authorities over the next few years for constructing memory fabs in Chengdu (Sichuan), Chongqing[24], Nanjing (Jiangsu), and Wuhan (Hubei) (Feng et al., 2018[36]). Overseas acquisitions have also helped increase China's presence in the global semiconductor value chain[25], although Chinese firms continue to trail in chip design and especially in foundry technology, which is said to be behind foreign peers (Ernst, 2015[3]; Fuller, 2016[37]; Lewis, 2019[35]). As a result, much semiconductor production in China continues to involve subsidiaries of foreign firms: e.g. Intel in Dalian, Samsung in Xi'an, SK Hynix in Wuxi, and TSMC in Nanjing (IC Insights, 2019[38]).

1.3. Downstream segment: The use of chips in downstream electronics

Telecommunications equipment, computers, and other consumer electronics use today the majority of all semiconductors (Table 1.4). Mobile phones and smartphones in particular account for the largest portion of all semiconductor sales, followed by personal computers (PCs). Together with the demand stemming from servers, network equipment, and connected objects (known as the Internet of Things, or IoT), this makes the ICT sector the largest consumer of chips. The automotive sector dominates industrial demand for semiconductors, though the production of medical devices is also a sizable contributor. Other consumer electronics constitute another important source of demand in the form of digital TVs, tablets, video-game consoles (e.g. Sony's PlayStation and Microsoft's Xbox), and set-top boxes (i.e. cable boxes). Demand originating from government and the military remains relatively small, however. This echoes earlier statements by the US Defense Science Board, that "the defense fraction of the total integrated circuits market [is] minuscule (1 or 2% now versus 7% in the 1970s)" (Defense Science Board, 2005[39]).

Table 1.4. Telecommunications equipment, computers, and other consumer electronics use today the majority of all semiconductors

Destination of semiconductor sales	Estimated sales in 2017 (USD billion)
Mobile phones	90
Standard PCs	69
Automotive	28
Internet of Things (IoT)[1]	21
Servers	17
Digital TVs	14
Tablets	12
Video-game consoles	11
Medical	6
Set-top boxes (i.e. cable boxes)	6
Wearables	4
Government & Military	4

Note: 1) Covers only the Internet connection portion of systems.
Source: IC Insights cited in Lapedus (2017[40]).

[24] See also http://xxgk.liangjiang.gov.cn/ljxqgzxxw_content/2019-08/28/content_559698.htm (accessed on 8 November 2019).

[25] Section 2.3 discusses these acquisitions in more detail.

The chips placed on the motherboard usually represent the largest cost component for smartphones. A single phone, be it a Samsung Galaxy, an Apple iPhone, or a Huawei Mate, often combines semiconductors obtained from different vendors, with each chip obeying a specific function: Korean firms Samsung and SK Hynix may supply memory chips; NXP Semiconductor (Netherlands) and ON Semiconductor (United States) may supply analog devices for audio and power management; and Qualcomm (United States) may supply built-in wireless modems. Other notable suppliers of semiconductors used in smartphones (and mobile phones more generally) include Infineon (Germany) and MediaTek (Chinese Taipei) among many others.

The three leading smartphone vendors (Apple, Huawei, and Samsung) have all come to rely to a varying extent on their own chip-making capabilities. Both Apple and Huawei, for example, have ramped up their chip-design activities while outsourcing most chip manufacturing to TSMC, the leading foundry from Chinese Taipei.[26] The two companies have also outsourced the assembly of their phones to Foxconn, another firm from Chinese Taipei. That reliance on external suppliers is even more pronounced for other phone vendors that do not yet have their own chip-design capabilities. Chinese phone-maker Xiaomi depends, for instance, on chipsets sourced from Qualcomm, Nvidia, and Broadcom[27] (among others) while also using Foxconn for assembling its phones (Ernst, 2015[3]; Xing and He, 2018[41]).[28] Oppo, another Chinese phone-maker, likewise sources the chips on its motherboards from Qualcomm, Samsung, Murata (Japan), and others (Xing and He, 2018[41]).

Demand for the processor chips that firms like AMD and Intel produce comes predominantly from the ICT hardware industry, which incorporates processors into its own products. According to Intel's 2017 annual report, the company's major customers include, for example, Apple and PC-makers Dell, HP, and Lenovo. Computer servers are other large users of semiconductor chips that have witnessed rapid growth in recent years owing to the advent of cloud computing, machine learning, and blockchain technology. Much of that demand has favoured graphics processing units (GPUs) that firms like Nvidia and AMD design for use in image processing and the video-game industry, but also for general-purpose computing, where GPUs are coupled with CPUs to undertake complex calculations on large volumes of data. Besides online gaming, large customers of GPUs thus include cloud-service providers (e.g. Amazon, Baidu, and Microsoft) and crypto-currency miners.

At the aggregate level, while most intermediate demand for semiconductors appears to originate in China, this does not reflect final consumption patterns but rather the country's specialisation in the assembly of electronics (the 'factory China' model). As a result, the majority of chips are not 'consumed' in China but instead re-exported to other countries in the form of electronic equipment (e.g. phones, TVs, and tablets). Ernst (2015[3]) mentions that this proportion may have reached at times 75% of all Chinese demand for chips, though more recent estimates suggest this number fell to about 55% in 2016 (Credit Suisse, 2017[42]). The decrease in the proportion of chips that China re-exports reflects the Chinese economy's gradual rebalancing towards more consumption-based economic growth, evident in, for example, the growing share of the population that owns a smartphone. In contrast to saturated phone markets in OECD countries, Chinese consumers have

[26] Huawei also uses Chinese foundry SMIC for chips that require less advanced technology nodes (e.g. 28 nm). Apple was initially relying on Korean group Samsung for manufacturing its chips but has since switched suppliers.

[27] Those three fabless firms in turn rely on external foundries for manufacturing the chips they design.

[28] This is despite Xiaomi's chip-related R&D activities and its recent acquisition of minority stakes in domestic semiconductor companies (e.g. Nanjing Big Fish and VeriSilicon Holdings).

provided a growing source of demand for smartphones in recent years. Yet there are signs that this source may be drying up too (Ernst, 2015[3]), with several semiconductor firms reporting weaker earnings on the back of declining phone sales in China.[29]

China's increasing role as an Internet powerhouse has also fuelled domestic demand for those semiconductors used in data centres. China has invested considerable resources into the construction of new data storage and processing capacity, which created growth opportunities for foreign chipmakers such as Intel, AMD, and Nvidia. As with smartphones, there are, however, indications that this growth may be slowing down, partly as China is facing overcapacity in data storage. This is especially the case in those provinces (e.g. Guizhou) that are further away from coastal economic hubs and that have offered large subsidies (e.g. cheap electricity and land) for establishing data centres locally (Feng and Lucas, 2018[43]). The resulting slowdown in investment – aggravated by the collapse of the crypto-currency market in 2018 – has eroded the earnings of several chipmakers specialised in CPUs and GPUs.

Trade tensions have magnified the effects of declining smartphone sales and plummeting investment in data centres, causing semiconductor sales to fall globally in late 2018 and early 2019 (Figure 1.7). In anticipation of the imposition by the United States of export controls on purchases of certain inputs by designated entities in China[30], a number of Chinese companies appear to have stockpiled semiconductors by front-loading their imports. This had the effect of accelerating semiconductor sales in the short-run before later reversing that impetus as new purchases of semiconductors were no longer needed in the same proportions as before. Data from Chinese customs show that China's imports of integrated circuits accelerated in the summer of 2018, peaked in September 2018, and then fell by 46% between that peak and February 2019.

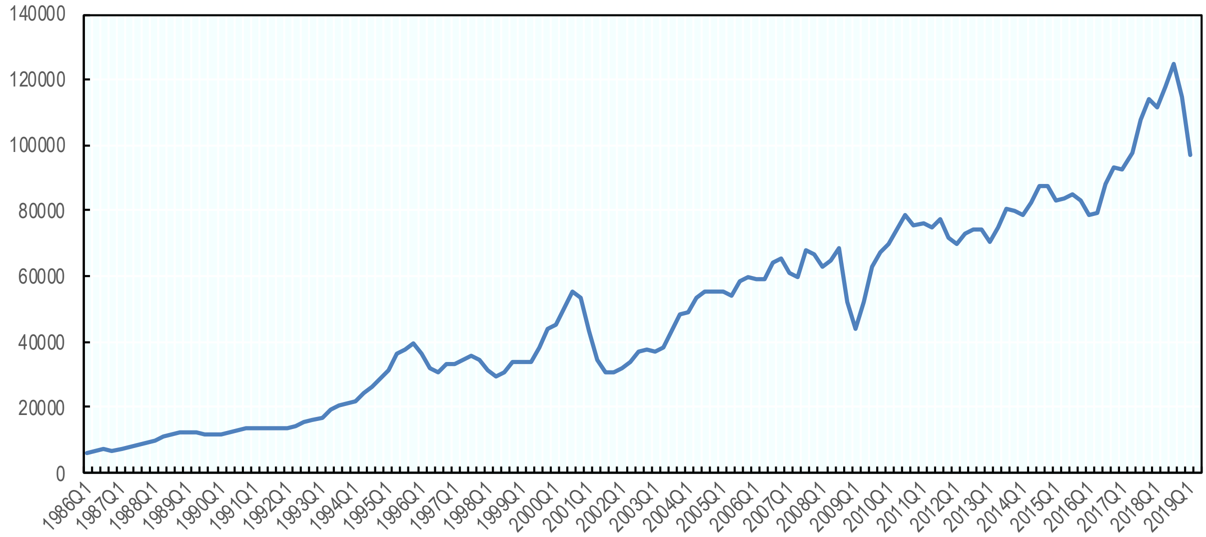
Looking forward, the demand for semiconductors appears to be shifting away from general-purpose chips and more towards 'systems-on-chip' (SoCs) that are tailored to specific uses. General-purpose chips have long enabled producers to achieve economies of scale by spreading costs over large production volumes. The rollout of nascent technologies such as machine learning, 5G, driverless cars, and the IoT may nevertheless accelerate the movement towards customised chips and prompt other firms to enter the semiconductor market (e.g. Cerebras and Graphcore), with possible implications for industry concentration and the sustainability of the IDM model. Non-semiconductor technology groups such as Alphabet (Google), Amazon, and Facebook have invested considerable resources into developing their own application-specific integrated circuits (ASICs), such as Google's tensor processing units (TPUs). Microsoft has likewise opted to design itself the chips that power its HoloLens headset. These larger groups are also joined by other smaller entrants that specialise in the provision of specific modular 'chiplets' that can be assembled into complex integrated circuits.

29 This concerns, for example, TSMC (White, 2019[111]) and Samsung (Jung-a, 2019[112]). The slowdown has not affected all smartphone vendors in the same manner, however.

30 Designated entities are companies that the US Government has selected for inclusion on its 'entity list' for reasons of national security. The entity list "specifies the [export] license requirements and policy that apply to each listed party." See (accessed on 1 July 2019): http://2009-2017.state.gov/strategictrade/redflags/index.htm.

Figure 1.7. Semiconductor sales collapsed globally in late 2018 and early 2019

Global quarterly semiconductor billings, USD millions, current



Source: World Semiconductor Trade Statistics.

2. Government involvement in the semiconductor value chain

Government involvement has been a recurring feature in the semiconductor value chain, beginning with NASA's mass purchase of integrated circuits back in the 1960s, and continuing with governments' sustained efforts to support the research activities of semiconductor firms. Government support for R&D is in fact one of the more common forms of state intervention in the semiconductor value chain. Less common is for governments to intervene directly in the production of semiconductors, either through direct ownership of semiconductor companies or by exerting strong influence on the decisions of local firms.

The previous section has shown the semiconductor value chain to be complex and international in scope, with large vertically integrated multinationals operating alongside more specialised firms. This section discusses the extent to which governments are involved in the semiconductor value chain, and the form that this involvement usually takes. Understanding the nature of government intervention in the value chain is an important pre-requisite to examining the nature and prevalence of government support for semiconductors, in particular since close government involvement with firms can make the identification of particular support measures more difficult.

The first part of this section concentrates on (i) the role of R&D policy as a main instrument of governments for supporting their semiconductor industry. In a second part, the discussion turns to (ii) trade and investment policy as other tools that governments have used to influence competitive conditions in the semiconductor value chain. The third part follows by looking at the broader question of (iii) international technology transfers in semiconductors, in particular where they are aided by government policy. Last, the final part discusses the prevalence of (iv) state ownership, investment, and influence in the semiconductor value chain, as well as the implications this may have for government support and international competition.

2.1. Government involvement in R&D: Motivation and the policy record

State involvement in the semiconductor value chain is very common at the upstream R&D stage, where governments have long aimed to support what they view as a socially desirable activity. That support is often posited as a remedy to the perceived market failure that private firms will tend to under-invest in R&D absent public support. This reasoning has led many governments to consider support for R&D to be justified on efficiency and competition grounds. The practice of identifying and measuring market failures is fraught with difficulties, however (Zerbe and McCurdy, 1999[44]). Given the potential for error and discretionary judgment, the OECD has stressed the importance of "a sound rationale for government intervention" in this area (OECD, 2010[18]). The need to assess such sound rationales is becoming ever more important in the context of a global economy increasingly shaped by knowledge- and R&D-intensive activities, but so is the difficulty of making such assessments (Box 2.1).

Box 2.1. The pros and cons of government support for R&D, with examples from the semiconductor industry

Of all the arguments put forward in favour of government support for R&D, the most common remains the existence of knowledge spillovers that prevent private firms from fully appropriating the results of their own R&D efforts, thus leading them to underinvest in research.[1] Empirical analysis generally supports the existence of knowledge spillovers at the aggregate level, such that "the gap between private and social rates of return [to R&D] is quite large" (Griffith, 2000[45]). Recent estimates find marginal social returns on R&D to exceed marginal private returns by a factor of three or four (Lucking, Bloom and Van Reenen, 2018[46]).

Earlier evidence for semiconductors specifically is more varied, finding learning-by-doing to be prevalent in the industry (especially in the memory segment), although firms tend to appropriate most of their learning, resulting in only small inter-firm and international spillovers (Irwin and Klenow, 1994[47]). Not only does this suggest a tendency toward dynamic returns to scale and market concentration, but it also indicates that some amount of semiconductor R&D is firm-specific, i.e. not readily transferable across firms (Helfat, 1994[9]). Better yields in chip production often hinge, for example, on factory-specific conditions, including cleanliness of facilities, equipment vintage, management practices, etc. On the other hand, process technologies, talent, and chip designs have all been shown to be transferable between plants, firms, and even countries.

Besides the issue of whether knowledge spillovers warrant government intervention in the first place, much of the debate surrounding government support for R&D has to do with policy effectiveness, and in particular whether public support spurs additional private R&D spending or instead crowds it out. Evidence is as often mixed. A recent meta-analysis of empirical findings arrived at the conclusion that public R&D support does not in general trigger "additional firm-financed R&D spending beyond the amount of the subsidy" (i.e. there is no additionality) but that support does not crowd out private R&D either (Dimos and Pugh, 2016[48]). In other words, "[R&D] subsidies are generally not wasted" – in the sense that they fund activities that firms would not have undertaken otherwise –, though they fail to elicit additional, matching R&D spending by private firms (*ibid*).

This contrasts with earlier studies that had found public R&D to crowd out some amount of private R&D, e.g. by inflating the salaries of researchers (Goolsbee, 1998[49]). Although limited and dated, evidence for the semiconductor industry suggests that the United States' Very High Speed Integrated Circuit (VHSIC) programme[2] might have had an adverse impact on US semiconductor firms by diverting the supply of specialised engineers and physicists away from the commercial industry, thus exacerbating the shortage of professionals that prevailed at the time (Peck, 1985[50]). Interestingly, Intel management was said to be "one of the most persistent critics of the program" (*ibid*).

The desirability and additionality of public support for R&D depends partly on whether governments target those research projects most likely to generate knowledge spillovers, i.e. positive externalities. It is, however, difficult to identify *ex ante* projects that yield high social returns, particularly "projects that firms would not undertake without the subsidy" (Feldman and Kelley, 2006[51]). Absent information permitting such an assessment, there is a risk that considerations other than economic efficiency end up determining which projects or firms obtain public R&D funding. This problem is compounded where the decision to award R&D subsidies serves as a signal to investors and other government agencies that public authorities look favourably upon the recipient project, thus enabling it to attract even more funding. Evidence suggests this has been an issue in the context of China's R&D policies (Boeing, 2016[52]; Wu, 2017[53]), with research grants usually favouring domestic, well-connected firms (Fuller, 2016[37]; Cheng et al., 2019[54]).

1. This can happen despite firms appropriating some of the knowledge they generate through IP rights. Another common argument relies on capital-market imperfections (e.g. information asymmetries between inventors and investors) to justify government support for R&D (Dimos and Pugh, 2016[48]).

2. The VHSIC was at the time of its establishment in 1980 the "largest single non-weapons R&D program of the [US] Department of Defense" (Peck, 1985[50]). It involved developing prototype microchips and industrial processes in semiconductor fabrication.

As shown in Section 1.1, semiconductors are one of the most (if not the most) R&D-intensive industry, thus potentially making government support for R&D activities a key source of competitive advantage in the value chain. Government assistance can take the form of direct support through public-private consortiums and initiatives (as discussed in Section 1.1) or research grants, or indirect support, such as favourable tax treatment. R&D in semiconductors is also influenced and enabled by IP protection.

From the perspective of international competition and trade, the precise nature of R&D projects that governments choose to support is important. There is a general understanding that public support for R&D should target upstream, 'pre-competitive' research as this minimises distortions to competition while maximising social returns in the form of knowledge spillovers. The OECD's 2014 *Science, Technology and Industry Outlook* notes, for instance, that many governments have come to favour support "at the upstream stage and for generic technologies, so as not to impede downstream competition or infringe the state aid rules embodied in international treaties (WTO, EU)" (OECD, 2014[12]). By contrast, policy should refrain from 'picking winners' and from extending R&D subsidies at downstream stages that are closer to commercialisation.

Short product cycles in semiconductors can make it difficult to establish a firm separation between pre-competitive, basic research on the one hand, and product development on the other. This reflects the more general consideration that "with shorter product cycles, arguably the time allotted for *all* types of [firm-level] R&D has been truncated and tends to converge" (Amsden and Tschang, 2003[10]). That trend also coincides with growing pressures to make public and academic research closer to markets and demonstrate product applications sooner. Altogether, the distinction between pre-competitive and competitive R&D appears increasingly hard to make, which can create challenges for international competition and the design of trade rules in this area.

Of the range of support provided for R&D, **grants** are common and have often been used in conjunction with government co-ordination of research efforts for encouraging the development of new semiconductor technology. In the United States, the Defense Advanced Research Projects Agency (DARPA) long provided an annual subsidy of USD 100 million in matching funds to support the Sematech R&D consortium[31], which the government established in 1987 in response to growing competition from Japanese semiconductor firms (Irwin and Klenow, 1996[19]; Randazzese, 1996[14]). More recently, DARPA launched in June 2017 the Electronics Resurgence Initiative to support public-private R&D efforts in the development of defence-oriented specialised circuitry, with total multi-year funding of USD 1.5 billion. Award recipients include a consortium formed by EDA-software firm Cadence, fabless Nvidia, and three universities, which together obtained funding of USD 24.1 million for facilitating automation of the chip-design process. In Europe, the European Commission announced in December 2018 that it had approved plans by France, Germany, Italy, and the United Kingdom to spend a total EUR 1.75 billion over five years in support of joint R&D projects in microelectronics. While not disbursed at the time of writing, individual R&D grants will support research and innovation in advanced chip technology as part of the European Union's Important Projects under Common European Interest (IPCEI) framework.[32]

[31] Sematech stands for SEmiconductor MAnufacturing TECHnology. The consortium's focus was on fostering research co-operation between chipmakers and lithography equipment suppliers. Sematech also obtained in 2004 an additional USD 40 million grant from the Texas Enterprise Fund.

[32] See the official press release: http://europa.eu/rapid/press-release_IP-18-6862_en.htm (accessed on 5 March 2019).

Although most countries have sizable R&D funding programmes in place, information is not always available as to which sectors or companies have benefitted the most. In China's case, government spending for science and technology amounted to CNY 2.4 trillion (about USD 360 billion) over the period 2006-12, driven largely by the country's *Medium and Long-Term Plan for Science and Technology 2006-2020* that prioritises 16 areas, including "core electronic components" (e.g. chip design and software) and "advanced IC[33] manufacturing" (Fuller, 2016[37]; Lewis, 2019[35]). A subsequent round of R&D funding emanated from China's 2010 *Strategic Emerging Industries* (SEI) initiative,[34] which again singled out "next generation IT" as one of seven sectors to be encouraged by means of dedicated funding. While information exists on those programmes, it is difficult to obtain specifics on how much they actually benefitted China's semiconductor industry. Data collected for this report and presented in Section 3.2 indicate nevertheless that large Chinese semiconductor firms have obtained sizable R&D funding from Chinese authorities.

Difficulties in assessing the proportion of public R&D funding that specifically benefits semiconductors are not confined to China. Firm-level information can be helpful in that regard, as well as in providing additional insights on the different agencies and jurisdictions that support semiconductor R&D. Analysis in Section 3.2 indicates, for example, that US firm Intel has obtained small R&D grants (e.g. EUR 10 million in 2017) from the Irish Industrial Development Authority, an agency in charge of promoting foreign investment into Ireland. The group also received R&D support from Israeli authorities in connection with investments to expand its foundries in Kiryat Gat (southern Israel). This adds to US federal R&D grants that Intel received over the years for research conducted under the auspices of the Department of Energy, the Department of Defense (DoD), and the National Security Agency (NSA). Those various grants totalled about USD 80 million over the entire 2007-17 period. Another US firm, Micron, likewise benefitted from limited federal funding under DoD programmes (e.g. about USD 3 million in 2016).

Favourable tax treatment for firms' R&D spending is perhaps the largest and most common measure in support of semiconductor R&D. This reflects a broader trend in R&D policy, whereby "R&D tax incentives have become a way to increase the attractiveness of the national research ecosystem and to engage in tax competition to attract foreign R&D centres" (OECD, 2014[12]). Subsidy disciplines and trade rules may also explain partly that shift away from targeted direct support and toward blanket tax provisions on R&D spending (*ibid*). Not only is that support increasingly generous, but it is also becoming more widespread, with the vast majority of OECD countries having one or more such measures in place (Figure 2.1). This group includes Austria, Belgium, France, Japan, Korea, the United Kingdom, and the United States.[35] Examples abound outside the OECD as well, including Singapore's R&D tax benefits and China's additional deduction for R&D costs.

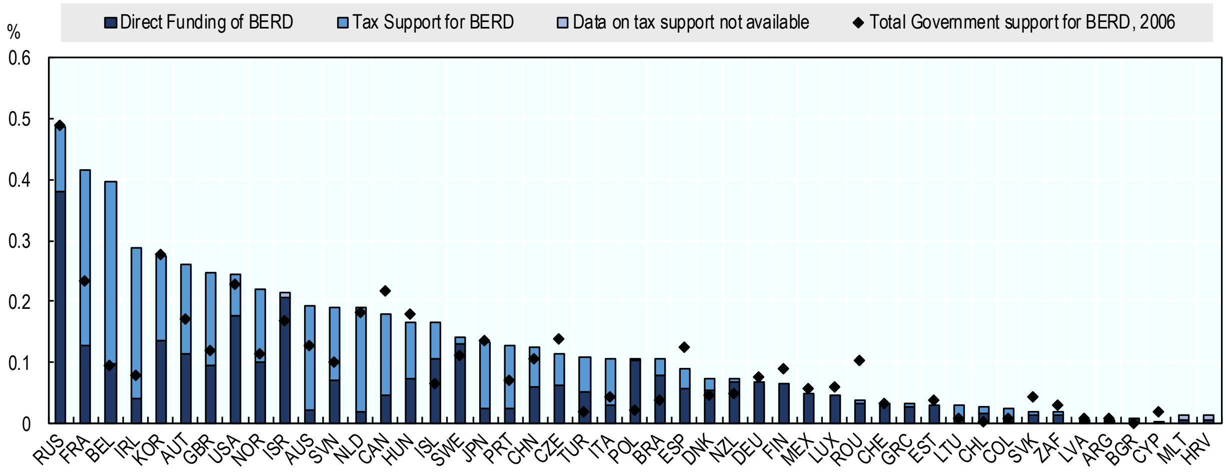
[33] "IC" is industry shorthand for "integrated circuit".

[34] SEI was a precursor to the *Made in China 2025* initiative, which later expanded the catalogue of sectors covered originally by the SEI.

[35] Germany was a notable exception until 2019, when the Federal Government introduced R&D tax incentives starting in January 2020.
See www.bundestag.de/dokumente/textarchiv/2019/kw26-de-forschungszulagengesetz-646314 (accessed on 8 November 2019).

Figure 2.1. The majority of advanced and emerging economies have R&D tax incentives in place

Direct government funding and tax support for business R&D, % of GDP (2016)



Note: BERD stands for business enterprise research and development. The numbers above concern all R&D spending and not just that related to semiconductors or the ICT industry. Data on tax incentive support are not available for Israel. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.
Source: OECD, R&D Tax Incentives database, http://oe.cd/rdtax.

Although not government support, countries' **IP regimes** take on particular importance in the semiconductor value chain, where incentives to invest in R&D depend largely on the level of protection afforded to intellectual property rights (IPRs).[36] That protection is especially important at the design stage, enabling fabless firms to thrive knowing that competitors and governments will not claim their layout-designs. Patents are a common instrument for protecting IPRs, including in semiconductors.[37] Data from the World Intellectual Property Organization (WIPO) show that Huawei, Intel, Qualcomm, Samsung Electronics, and ZTE[38] all belonged to the top 10 corporate filers for international patent applications under the Patent Cooperation Treaty (PCT) in 2018.[39] In that same year, semiconductors ranked as the tenth largest industry for international patent applications under the PCT. The absolute number of patent applications is not necessarily an accurate indicator of R&D activities and technological advancement, however. China's soaring patent numbers owe much, for example, to the introduction by the authorities of subsidies on patent applications in a direct bid to increase firms' R&D activities. These efforts have met with limited success to date, due in part to insufficient quality checks on patent applications and to an excessive reliance on quantitative targets by local government officials (Fuller, 2016[37]; OECD, 2017[55]). The result has been a deterioration in the quality of patents (Cheng et al., 2019[54]; Boeing and

36 This report does not address the question of the impacts of deficiencies in countries' IP regimes, which, while important, are already covered by a large literature. See, for example, Dinopoulos and Segerstrom (2010[114]).

37 This is in spite of the short product cycles that characterise the semiconductor industry.

38 ZTE was founded by China's Ministry of Aerospace in partnership with the Shenzhen Municipal Government. Sanechips (ZTE Microelectronics), a subsidiary of ZTE, is China's third largest chip designer by revenue after Huawei's HiSilicon and Tsinghua Unisoc.

39 See www.wipo.int/pressroom/en/articles/2019/article_0004.html (accessed on 3 April 2019).

Mueller, 2016[56]), which have so far failed to translate into significant productivity increases (OECD, 2019[57]).

While most countries provide some form of support for R&D activities, only a few appear to have succeeded in becoming leading producers of semiconductors. One explanation may lie in the time it takes for semiconductor firms to build research capabilities and catch-up with industry frontrunners, given the importance of learning by doing and deep specialised knowledge in the sector. According to some experts, "even for the subsidiary of a multinational firm, […] the building of local [R&D] capabilities may take several years at best, involving the gradual acquisition of solid research personnel and the forging of links with corporate R&D headquarters" (Amsden and Tschang, 2003[10]). It is also unclear whether R&D subsidies are enough to succeed in a highly globalised industry characterised by fast product cycles and a few dominant players. As noted in Section 1.2, despite being often cited as examples of rapid technological catch-up, it has taken more than a decade for Korea and Chinese Taipei to overcome entry barriers and become world-class competitors in semiconductors. Replicating this success would likely also take time, requiring new entrants to undertake the same process of inserting themselves in global production networks and gradually ascend the value chain. Trade and investment are especially important in that regard, allowing countries to gain access to more advanced foreign equipment and expertise and to benefit from international transfers of technology.

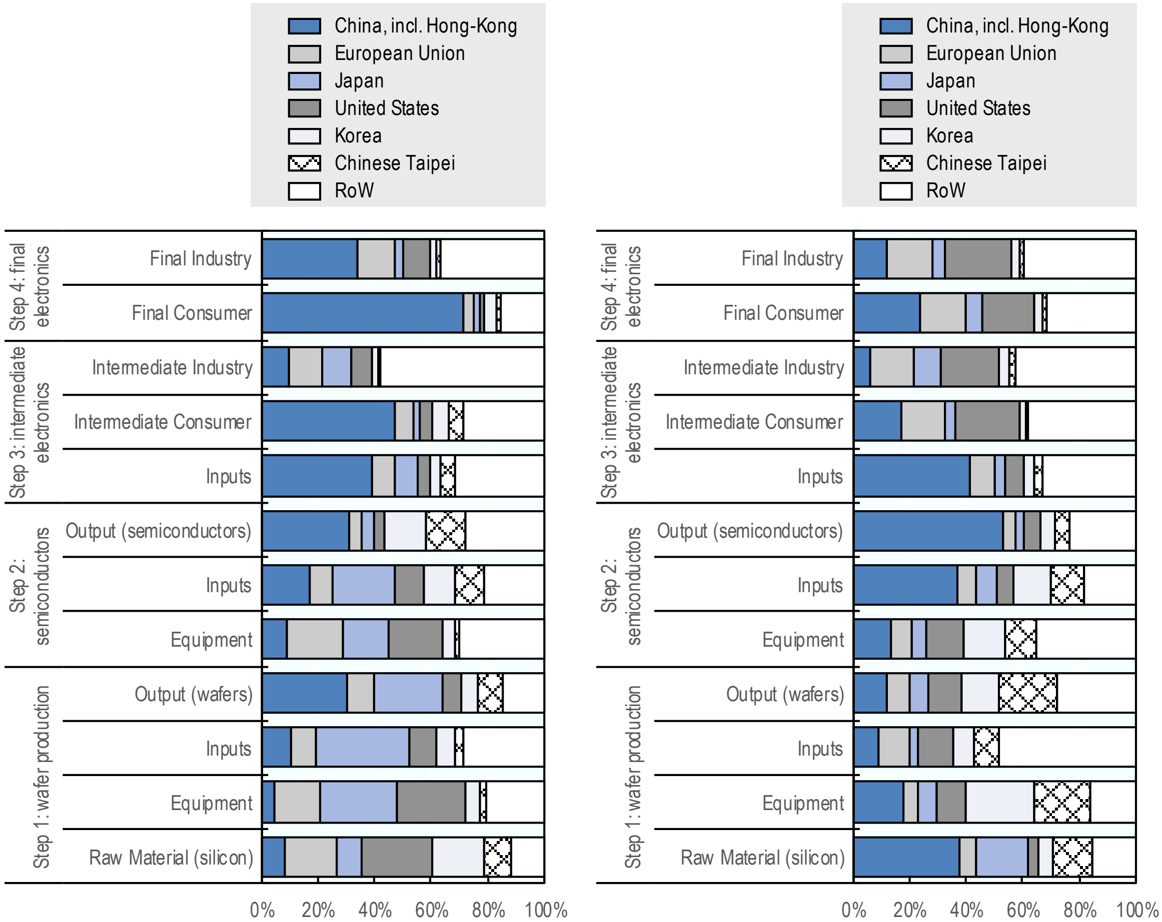
2.2. Trade and investment measures in the semiconductor value chain

One reason for the semiconductor value chain's global reach is that chips offer an unparalleled value-to-weight ratio: one chip might weigh just a few grams but sell for a hundred USD or more. This greatly encourages trade and offshoring by lowering the proportion of shipping in total supply costs. Trade and investment have therefore become an essential operational aspect of semiconductor production, giving importance to the impacts – positive and negative – that trade and investment policies might have on the value chain (Semiconductor Industry Association and Nathan Associates, 2016[5]).

Although the following jurisdictions – China; the European Union; Hong Kong, China; Japan; Korea; Malaysia; Singapore; Chinese Taipei; and the United States – are involved at different steps in the chain (Figure 2.2), together they account for close to 80% of world trade in semiconductor-related goods (Box 2.2). Japan largely concentrates, for example, on exports of inputs and equipment for the production of silicon wafers (step 1) and for the fabrication of semiconductors (step 2), as well as being a large exporter of silicon wafers themselves (the output of step 1). Unsurprisingly, this also makes the country a large importer of raw silicon. The European Union and the United States are exporting mostly equipment used in the production of wafers and semiconductors (steps 1 and 2), while importing large amounts of intermediate and final electronics (steps 3 and 4). China exports primarily the intermediate and final consumer electronics that it assembles for foreign and Chinese firms (steps 3 and 4), while importing large quantities of inputs and semiconductors (step 2). Although they are large exporters of semiconductors relative to their size, Korea and Chinese Taipei make little contribution downstream, probably due to their small direct involvement in electronics assembly (e.g. firms like Samsung and Foxconn usually outsource or conduct assembly of electronic products in China).

Figure 2.2. Export and import shares of large semiconductor-producing economies

Shares of world exports (left) and imports (right) in value, %, 2017 data

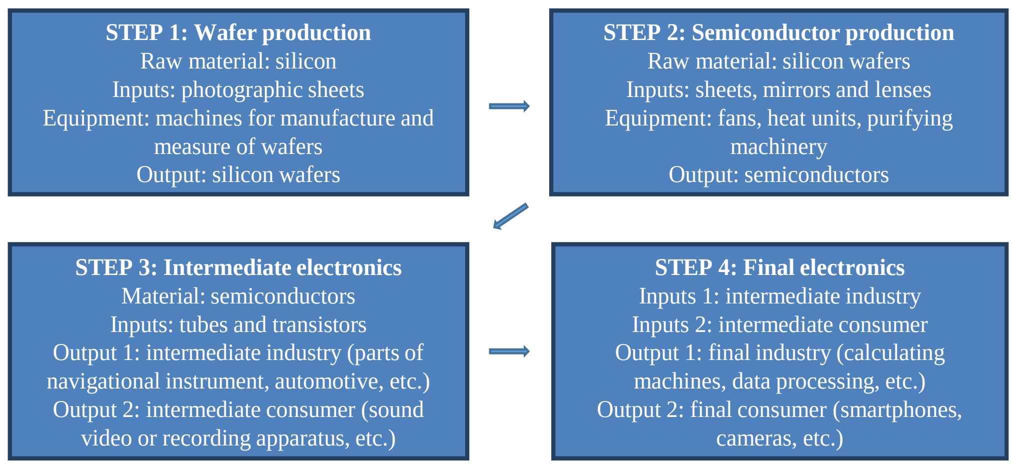


Note: The classification of goods under each step follows the method described in Box 2.2. China and Hong Kong, China are counted together in this graph since much of China's trade in semiconductor-related goods takes place through Hong Kong, China. RoW = Rest of the World.
Source: OECD based on the BACI database.

Box 2.2. The semiconductor value chain in trade statistics

Existing trade statistics – whether measured in gross or in value-added terms as in the TiVA database – do not readily capture the different stages of the semiconductor value chain. For goods trade, this forces the analysis to focus on a different and narrower set of activities that are here grouped in four steps: (1) the production of silicon wafers; (2) the fabrication of semiconductors; (3) the use of semiconductors in intermediate electronics; and (4) the production of final electronics incorporating semiconductors. For each such step, the analysis identifies a number of raw materials (where applicable), intermediate inputs, equipment, and outputs (Figure 2.3). This goods classification originates in country studies conducted by the Duke University Global Value Chains Center, and which provide a helpful mapping of the electronics value chain (Frederick and Gereffi, 2013[58]). The technical appendix at the end of the report provides the HS codes included under each step.

Figure 2.3. Measuring goods trade in the semiconductor value chain



In sum, the general picture that emerges from trade data confirms the industry structure described in Section 1: OECD countries mainly occupy upstream segments of the chain, exporting silicon wafers (e.g. Japan), specialty gases and chemicals, and lithography equipment (e.g. the European Union, Japan, and the United States), while China imports vast amounts of semiconductors that it then uses in assembling electronics for re-export to OECD countries. Korea and Chinese Taipei usually stand in the middle of that chain, with their semiconductor foundries importing silicon wafers and equipment for producing the chips that they then export to China for integration into consumer electronics. As a result, although semiconductors constitute China’s largest imported good in value, the data underline that many of these chips do not stay in China but are instead re-exported abroad embedded in electronic equipment. This trend may evolve, however, as Chinese consumers become wealthier and the country’s GDP growth becomes less reliant on exports and investment.

The international division of tasks in the semiconductor value chain has created important interdependencies between economies that have helped the industry grow into a USD 470 billion global business. The benefits derived from cross-border research networks and production chains underline the importance of countries maintaining open and predictable trade policies. They also suggest that carrying out the entire semiconductor manufacturing process in a single jurisdiction is neither feasible nor economically desirable. The most commonly encountered instruments of trade policy in the semiconductor value chain are reviewed below.

Trade policy has previously provided a large impetus to trade in semiconductor-related goods through the WTO's plurilateral Information Technology Agreement (ITA), which, as of September 2019, counted 82 participants, representing about 97% of world trade in IT products.[40] Seeking to eliminate **import tariffs** on a large range of IT products, 29 participants initially concluded the ITA at the Singapore Ministerial Conference in December 1996. The ITA was then expanded in December 2015 at the Nairobi Ministerial Conference to cover an additional 201 products, although participants in this second version of the ITA number only 54. Of these 201 products, 33 concern directly semiconductors or semiconductor-related equipment, including so-called 'multi-component integrated circuits'. Although it is a plurilateral agreement, tariff eliminations under the ITA apply on a most-favoured-nation (MFN) basis, thus benefitting all WTO members.

The ITA and its expansion have had a discernible impact on semiconductor trade, reducing the average tariff, and eliminating selected tariffs, imposed on semiconductor-related goods along the value chain (Figure 2.4). There are exceptions, however, in particular since the ITA's goods coverage does not exactly match the definition of semiconductor-related goods covered by this report. Data on import tariffs are also not available consistently for the years after 2017, which misses important reductions of import tariffs on certain semiconductor-related goods that have taken place since (e.g. in Korea). Following its participation in the two ITA rounds, China has generally reduced its average tariffs along the chain. They remain high in relative terms, however. Given China's dependence on imported chips, low tariffs on semiconductors are not surprising (output of step 2), although higher tariffs on certain equipment and inputs likely penalise domestic chip producers.[41]

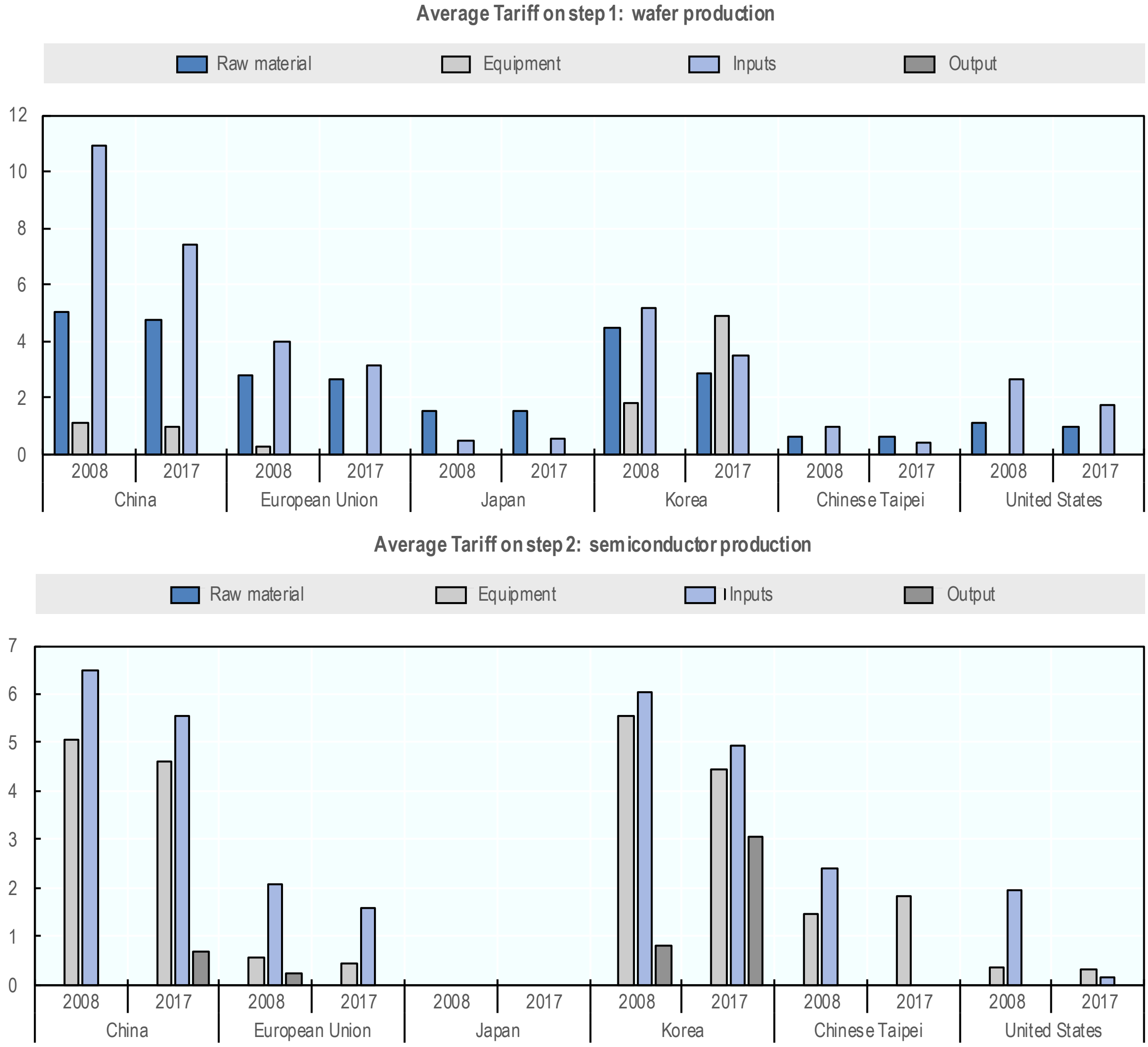
With import tariffs relatively low and decreasing thanks in part to the ITA, other trade measures might gain in importance in the semiconductor value chain, starting with **non-tariff measures (NTMs)** in relation to standards, IPRs, and government procurement. Although this report was not able to identify NTMs affecting specifically semiconductors and related equipment, information from ECIPE's *Digital Trade Estimates* database indicate the existence of broader measures affecting ICT goods in general (which include semiconductors and related equipment). These measures include provisions restricting non-resident foreigners from submitting patent applications, measures mandating the local certification of encryption products, or local-content requirements for ICT equipment used in the banking sector. Restrictions imposed on foreign ICT equipment in **government procurement** are also common, though they often stem from concerns over national security. In addition, there can be broad-based **investment restrictions**, e.g. restrictions on the composition of corporate boards or residency requirements for directors.

40 See www.wto.org/english/tratop_e/inftec_e/inftec_e.htm (accessed on 23 September 2019).

41 Increased import tariffs imposed over the course of 2019 by the United States on a broad set of products from China pursuant to a Section 301 investigation include electronic equipment and may therefore affect trade patterns along the semiconductor value chain.

Figure 2.4. The ITA and its expansion have generally reduced average tariffs on semiconductor-related goods

Simple average of applied import tariffs, %



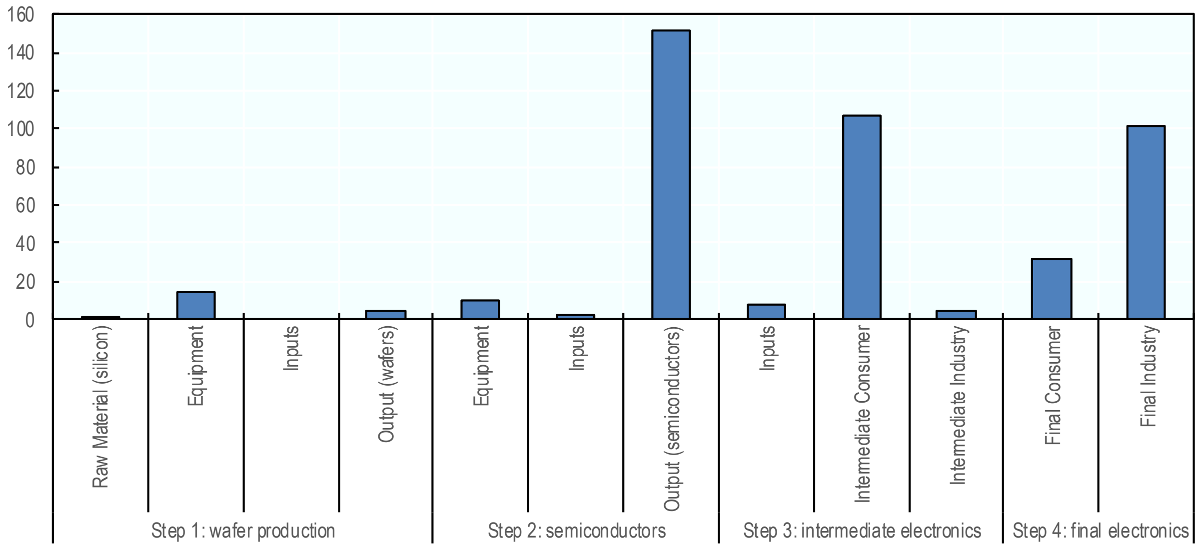
Note: The coverage of goods in the ITA does not exactly match the definition of semiconductor-related goods covered by this report, which may include more inputs and raw materials than the ITA (see Technical Appendix). The classification of goods under each step follows the method described in Box 2.2.
Source: OECD based on the Trains database.

Export restrictions (including voluntary export restraints) and export controls are another form of NTM that has affected the semiconductor value chain. An early example was the 1986 Semiconductor Trade Arrangement between Japan and the United States, following which Japan voluntarily restrained its exports of semiconductors to the United States (Irwin and Klenow, 1994[47]; Cho, Kim and Rhee, 1998[23]). One unintended consequence of this arrangement was to provide an opportunity for chip producers in Korea to increase volumes shipped abroad, filling the gap left by Japan in the DRAM market (Cho, Kim and Rhee, 1998[23]). While China levies export taxes on selected products, they do not appear to cover semiconductor-related goods. The Chinese authorities also rebate about 90-95% of the value-added taxes levied on semiconductor-related exports (up from VAT rebates of about 75-85% prior to the 2008-09 financial crisis).

A number of measures attributed to national security and defence concerns have at times restrained exports of chips and other semiconductor-related goods. The *Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies* of 1996 has restricted exports of certain pieces of equipment in relation to semiconductors that participants[42] deemed could contribute to military capabilities. Although not legally binding, the arrangement's product lists contain numerous IT goods of importance for the semiconductor value chain (Figure 2.5). An assessment undertaken in the early years of the arrangement suggested that it did not affect at the time "China's ability to obtain semiconductor manufacturing equipment primarily because the United States is the only member of the Wassenaar Arrangement that considers China's acquisition of semiconductor manufacturing equipment a cause for concern" (United States General Accounting Office, 2002[59]). According to consulting firm McKinsey, Wassenaar participants subsequently updated the arrangement in 2010 to prevent exports of <65 nm node technology[43] to China (McKinsey and Co., 2011[60]). Around the same time, however, Chinese Taipei signed with China the *Export Promotion and Cooperation Agreement* "that allows the export of manufacturing technology that is [two] generations behind leading edge" (*ibid*).

Figure 2.5. The Wassenaar arrangement on dual-use products covers numerous semiconductor-related products

Number of semiconductor-related products at the ten-digit HS level that are covered by the arrangement



Source: OECD based on the Trains database.

42 Participants to the Wassenaar Arrangement include most OECD countries, non-OECD EU Member States, Argentina, India, the Russian Federation, South Africa, and Ukraine.

43 See Box 1.2 for more on technology nodes.

Legislation at the national level also provides for controls on exports of certain dual-use ICT products from the European Union, Japan, Korea, the United States, and several other countries. Measures may range from outright export bans for certain destinations to compulsory licensing and screening.

2.3. International transfers of semiconductor technology

International transfers of technology are common in the semiconductor value chain since it can take a long time for countries to upgrade their technology and catch up with firms at the leading edge (Box 2.3). This time lag creates a strong incentive for new entrants to 'leapfrog' technological stages in order to join the ranks of leading producers of semiconductors. One way of doing so is by acquiring advanced technology from abroad through a variety of channels: imports of equipment, inward FDI, technology licensing, outward acquisitions, movement of talent, etc.

International transfers of technology (ITT) are a normal and desirable fact-of-life in globalised production networks.[44] They are indeed a major incentive for developing economies to join global value chains, as they seek to benefit from transfers of skills and know-how and progressively move into more value-adding activities. ITT constitute in that regard one particular type of knowledge spillover that usually requires economies to enhance their domestic absorptive capacity in order to maximise the expected benefits (Andrenelli, Gourdon and Moïsé, 2019[17]). The Semiconductor Industry Association notes, for example, how Chinese Taipei "has moved steadily up the value chain since the 1960s", benefitting from US firms having located their assembly plants there early on (Semiconductor Industry Association and Nathan Associates, 2016[5]). Korea had a similar experience, initially entering the semiconductor market as a subordinate partner of US multinational corporations before Korean firms moved up the chain into higher-value segments (Hwang and Choung, 2014[24]).

Inward FDI may not always result in the systematic transfer of the latest technology, however. As in Korea and Chinese Taipei, the local subsidiaries of foreign firms have played an important role in transferring technology to Chinese producers of semiconductors. There are indications, however, that these transfers have concerned at times processes and technologies that are less advanced than those that multinationals use elsewhere. A number of foreign semiconductor firms have built or acquired foundries in China that run comparatively older processes (e.g. using 65 nm technology nodes while the companies may run 22 nm processes domestically and in other jurisdictions in which they operate). There are several reasons that could explain this trend, including demand patterns and a shortage of local talent. Moreover, multinationals may be fearful of losing ownership of technologies that they deem commercially sensitive, which causes them to "refuse to bring their best technologies and products to the market" (European Union Chamber of Commerce in China, 2017[61]). While not unique to China, concerns over transfers of semiconductor technology usually gain in importance in jurisdictions where the state plays a strong steering role in the economy, as discussed further below.

44 Although this falls outside the scope of this report, some governments may be promoting and forcing ITT through unlawful channels such as espionage, cyber-theft, and criminal activity. This is particularly true at the chip-design stage, where "IP is most easily expropriated during the transfer of designs from the design houses to the foundries because all the necessary data are encapsulated in a GDSII digital file" (Fuller, 2016[37]).

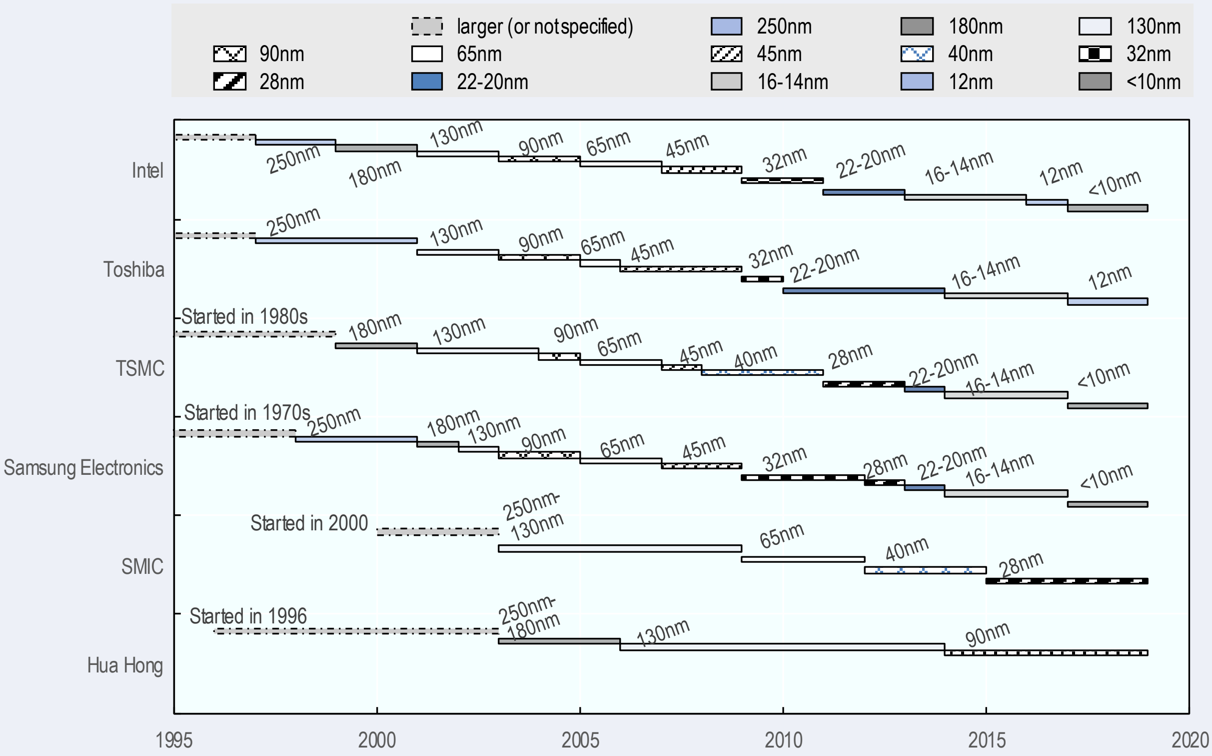
Box 2.3. Measuring distance to the technological frontier for semiconductor foundries

As explained in Box 1.2, the semiconductor industry has traditionally relied on the size of process nodes to distinguish between generations of semiconductor manufacturing technology, with smaller nodes usually corresponding to more advanced technology. Reductions in node size have typically occurred at two-to-three-year intervals since the 1970s (Flamm, 2018[62]). This pattern is evident for Intel as well as for Samsung and TSMC, with the latter two companies having caught up relatively fast to reach frontier technology around the 1990s (Figure 2.6). Progress has been markedly slower for Hua Hong Semiconductor and SMIC. More than 20 years after Chinese authorities created the company, Hua Hong Semiconductor continues to produce at 90 nm technology nodes, i.e. generations behind leading firms. SMIC appears in a better position, relying mostly on 28 nm technology, while having introduced 14 nm technology at the risk-production stage in 2019.[1]

Technological upgrading in semiconductor manufacturing necessitates large investments and accumulated knowledge in the face of short product cycles. These characteristics can make it harder for latecomers to catch up quickly and reach the frontier (Rho, Lee and Kim, 2015[63]). They can also erode the profitability of incumbents, with a number of firms having recently opted to exit the race for developing smaller node technology. Examples include GlobalFoundries and Texas Instruments, which have stopped at 45 nm nodes due to concerns over escalating R&D spending and capital costs.

Figure 2.6. Reductions in node size have typically occurred at two-to-three-year intervals since the 1970s

Smallest size of process nodes at the company level, in nanometres



Note: SMIC relies mostly on 28 nm technology but has introduced 14 nm technology at the risk-production stage in 2019.
Source: OECD research based on firms' annual reports and websites.

1. See www.smics.com/en/site/news_read/7741 (accessed on 3 October 2019).

Licensing of foreign technologies has historically been another important channel of ITT, enabling Korea and Chinese Taipei to upgrade their processes. Samsung licensed, for example, designs for 64K DRAM chips from Micron (United States) when it entered the memory business in 1983 (Song, 2000[34]) and later acquired manufacturing technology from a Japanese firm (Kim, 1997[32]). In Chinese Taipei, authorities established the public research institute ERSO in 1974, which went on to license manufacturing technology from RCA (United States) and transfer it to domestic foundry UMC in 1980 (Tung, 2001[31]). Another domestic foundry, TSMC, likewise benefitted from Philips's 2 µm technology (Chen and Sewell, 1996[64]). Chip-fabrication agreements with large foreign customers such as Intel and Motorola also helped TSMC further upgrade its technology (Tung, 2001[31]).

Imports of capital equipment, inward FDI, and licensing are not the only ways in which ITT can occur in the semiconductor value chain. Some firms also hire experienced foreign staff or returnees in the hope that they will bring new skills, modernise operations, and transfer knowledge to their co-workers. The **movement of talent** is common in R&D-heavy industries as it "contributes to the creation and diffusion of knowledge, particularly tacit knowledge" (OECD, 2010[18]). Tacit knowledge matters in particular for helping translate knowledge that is otherwise firm specific into transferable insights, thus overcoming the pitfalls of imperfectly mobile resources (Helfat, 1994[9]). There are many successful examples of talent mobility in the semiconductor value chain, including: Samsung sending engineers to California to assimilate newly licensed technology from Micron and Zytrex (Kim, 1997[32]); Intel's early hiring of Israeli staff at top positions, who then steered the company into establishing R&D and foundry operations in their home country (The Wharton School, 2014[65]); returnees from the United States setting up IC design companies in Chinese Taipei (Song, 2000[34]); and the prominent role that top engineers from Chinese Taipei and the United States (e.g. Richard Chang and David N.K. Wang) played in the creation and development of contract foundries in China in the early 2000s (Fuller, 2016[37]).

Another common form of ITT in the semiconductor value chain is through **outbound mergers and acquisitions (M&As)**, whereby a buyer company acquires some or all of the shares of a foreign target company in order to gain access to the target's technology portfolio. As noted in Section 1.2, recent years have seen a wave of consolidation in the semiconductor industry in the form of a record volume of M&As. While many of these transactions were domestic (meaning buyers and targets were from the same economy), almost half were cross-border acquisitions when measured in number of buyers (Figure 1.6). Looking only at cross-border transactions that involve semiconductor firms narrowly defined (Box 2.4), the data show the United States as the largest buyer throughout the period 1989-2018, followed by China (Figure 2.7). The majority of these cross-border deals targeted companies based in the United States (for non-US buyers), Europe, Japan, Singapore, and Chinese Taipei (Figure A A.1).

Box 2.4. The identification of individual M&A deals in the semiconductor industry

This report uses FactSet's Mergerstat micro-data to construct a deal-level database of M&As that involve the main multinationals operating in the semiconductor industry. The dataset thus obtained covers the M&A transactions of 45 major semiconductor-related companies, their affiliates, and ten government funds and fund managers, for the sample period 1989-2018. The technical appendix at the end of the report provides the list of buyer entities covered.

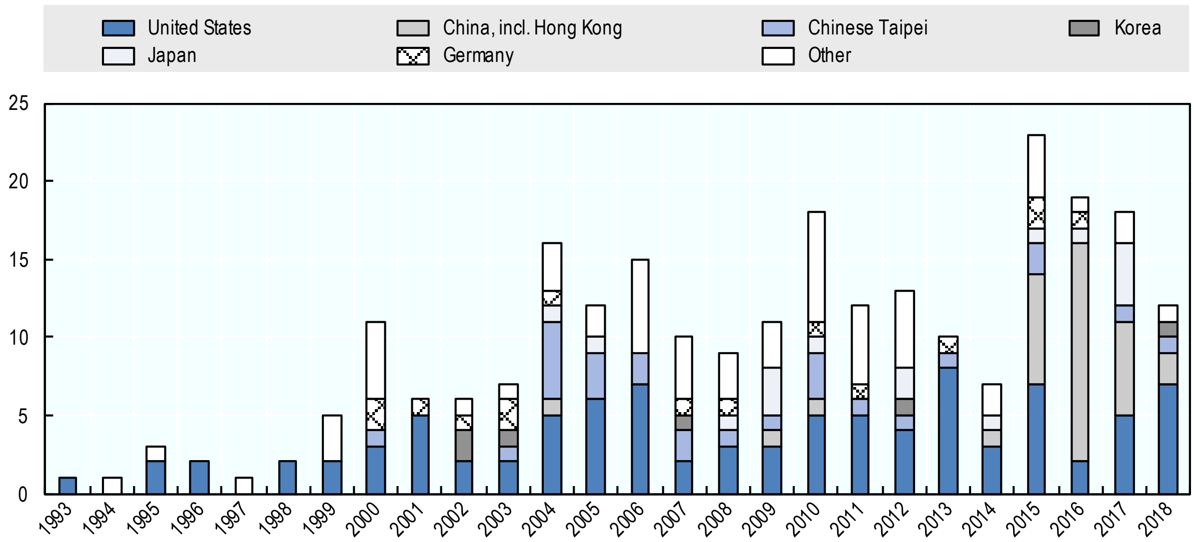
Variables that the analysis considers include: the number and value of concluded deals (excluding announced deals, deals pending approval, and rumoured deals); the jurisdiction and city of origin of buyers and targets of the transactions; the most recent annual sales of target firms; and the percentage of equity shares that buyers seek to acquire through the transaction. Where foreign affiliates are the targets of acquisitions, the analysis records information based on their parent's home economy.

The analysis excludes transactions that involve target firms operating outside semiconductors and related industries (even if the buyer is a semiconductor firm), with the objective being to capture only deals that are of interest for ITT in the semiconductor value chain. Related industries comprise, for example, Computer Peripherals, Electronic Production Equipment, and various Technology Services (see the technical appendix for a full list). A transaction is deemed cross-border based on the nationality of buyer and target firms as provided by FactSet.

The resulting dataset covers 1 016 single M&A transactions – 471 of which are cross-border – and gathers data on 1 384 different buyer entities (single transactions often feature more than one buyer). Data for 546 deals disclose actual transaction values: the total disclosed value of all such deals amounted to USD 315 billion, of which cross-border deals represented USD 128 billion. Acquisitions of companies in semiconductors narrowly defined (Figure 2.7) represented the lion's share of the value spent on all cross-border deals (79%), followed by Computer peripherals (6%), Packaged Software (5%) and Telecommunications Equipment (3%) as related industries.

Figure 2.7. The United States was the largest acquirer of foreign semiconductor firms in the period 1989-2018, followed more recently by China

Number of buyers in cross-border M&A transactions in semiconductors, by origin



Note: See Box 2.4.
Source: OECD based on the FactSet database.

The predominance of buyers originating from the United States reflects partly the weight of US firms in the semiconductor value chain (e.g. by revenue and profit), as large groups can more easily raise funding to acquire smaller players. While there are several possible reasons for acquiring foreign companies (e.g. accessing foreign markets or increasing capacity), many acquisitions in semiconductors appear to involve access to specific technologies, often in relation to businesses strategies for entering related market segments by leveraging complementary capabilities. Intel's venture-capital arm, Intel Capital, invests, for example, in technology start-ups around the world (e.g. in China, Israel, Japan, and of course the United States) in domains as varied as 5G, artificial intelligence, big data, and robotics. Micron's acquisition of Elpida, a Japanese memory-chip IDM, helped strengthen the company's position in the memory segment. Deals initiated in the United

States, other OECD countries, Singapore, and Chinese Taipei have therefore been a regular feature over the period studied.[45]

Chinese acquisitions of foreign semiconductor firms happened almost exclusively in the years 2014-18, with 2015-16 the record years. This followed the creation in 2014 of China's National IC Fund, which authorities initially endowed with CNY 139 billion (about USD 23 billion) to invest in the country's semiconductor industry.[46] This national fund has since been flanked by a series of sister funds at provincial and city levels, e.g. Beijing IC Industry Equity Investment Fund. One explicit aim of the National IC Fund is "to promote industry upgrades", including through "mergers and regroupings", in the context of broader efforts to "encourage domestic integrated circuit companies to strengthen international cooperation, integrate international resources, and open up international markets."[47] China's National IC Fund partly financed, for example, the acquisition in October 2015 of Singaporean OSAT STATS-ChipPAC by Jiangsu Changjiang Electronics Technology (JCET), a Chinese OSAT firm that has since become the third largest worldwide by revenue (Table 1.3). Following an initial surge in cross-border acquisitions in 2015-16, Chinese buyers appear to have subsequently scaled down their international M&A activities, with the years 2017-18 witnessing a lower number of deals.

There are at least two reasons behind the more recent slowdown in Chinese semiconductor acquisitions. One is the tightening of China's restrictions on capital outflows, which the authorities undertook in response to downward pressures on the yuan and declining foreign-currency reserves (OECD, 2019[57]). Another reason is a general trend towards more stringent foreign-investment screening mechanisms, as an increasing number of countries have adopted a more cautious stance on foreign investment in what they perceive to be strategic or sensitive industries (OECD, 2018[66]). With acquisitions abroad becoming more difficult, Chinese producers of semiconductors may seek to acquire Chinese subsidiaries of foreign firms (e.g. the local fab of a foreign semiconductor multinational), though these usually lag behind in process technologies, as mentioned above. Another option has been for Chinese firms to obtain foreign technology through licensing, a strategy which Tsinghua Unigroup appears to have followed after the Committee on Foreign Investment in the United States (CFIUS) blocked the firm's bids to acquire a number of US firms (Ernst, 2016[67]).

[45] Individual deals can have a large impact on total measured M&A activity due to the discrete nature of the data, as with Renesas's multi-billion acquisition of US semiconductor firm Intersil Corp. in 2017. As explained in Box 2.4, there are often multiple buyers in any single deal, which may give more weight to transactions that number many such buyers. The alternative would be to count deals as the unit of observation, though this makes it difficult to express transactions in terms of buyers' jurisdiction of origin where buyers are many and come from different jurisdictions.

[46] Formally known as "China Integrated Circuit Industry Investment Fund Co., Ltd.", which this report discusses later in Section 2.4. As of May 2019, shareholding in China's National IC Fund included: the Ministry of Finance (36%); China Development Bank Capital (22%); China National Tobacco, a central SOE (11%); and Beijing E-Town International Investment & Development, a local SOE (10%).

[47] As per the State Council's 2014 *Guideline for the Promotion of the Development of the National Integrated Circuit Industry*, discussed in more detail in Section 2.4. Feng et al. (2018[36]) note, for example, that "the powerful national IC industry investment and financing platform provides Tsinghua Unigroup with an important source of hundreds of millions of dollars in funds for international M&A." Tsinghua Unigroup (Ziguang) is a large state-owned ICT conglomerate 51% owned by Tsinghua University and ultimately co-supervised by China's Ministry of Finance and the Ministry of Education. The company's combined semiconductor subsidiaries make it the second largest chip vendor in China, after Huawei's HiSilicon. See also Box 2.8.

Overseas acquisitions by Chinese firms have been increasingly the subject of regulatory scrutiny due to concerns about the potential role of the Chinese state in these deals. Acquisitions abroad by state-backed[48] companies can arouse suspicion that buyers are benefitting from privileged access to finance and subsidies, and that the technology thus acquired will be effectively transferred to the state. For example, private Chinese firm NavTech (Beijing Navgnss Integration Co., Ltd.) acquired in 2016 Swedish foundry Silex Microsystems after having received funding from China's National IC Fund and a Beijing sister semiconductor fund.[49] Shortly after, the company announced it had established a new plant that uses Silex's technology in one of Beijing's state-run industrial parks (Feng, 2019[68]).[50] China's National Silicon Industry Group (NSIG) – an investment fund backed by Sino IC Capital, the manager of the country's national semiconductor fund – similarly acquired Finnish wafer producer Okmetic in 2016[51] and 14.5% of French wafer producer Soitec.[52] Hua Capital Management – a Beijing-based private-equity fund co-founded by Tsinghua Unigroup and tasked with managing Beijing's semiconductor fund – acquired OmniVision, a US semiconductor company, in 2015. While these acquisitions may have been undertaken out of purely commercial interests, according to Ernst (2015[3]), Chinese authorities have indicated that "they intend to use the national [semiconductor] funds selectively" in order to acquire foreign technology.

Concerns about the role of the Chinese state in acquisitions abroad can be heightened by lack of transparency regarding the ownership of companies or the source of their financing.[53] While the United States was the largest acquirer of foreign semiconductor firms over the period that this analysis covers, the OECD did not find any evidence linking these acquisitions to US state institutions or agencies. The only other recent examples of state-backed, cross-border acquisitions in semiconductors that the analysis has been able to identify are those involving Abu Dhabi's sovereign wealth fund, Mubadala, which acquired both US firm GlobalFoundries in 2012 and stakes in AMD, as well as Japanese company Renesas's acquisition of US firm Intersil Corp. in 2017.

Finally, there is also unease in the industry regarding practices that may amount to forced technology transfers, whereby government interventions create the conditions where foreign firms may be required to transfer technology to local partners or to share information that can be accessed by competitors. Earlier OECD work has identified a number of factors that can turn otherwise

48 Some firms might not be state-owned but state-backed in the sense of being politically connected, supported, financed, and strongly influenced in their decisions by the state, including local authorities (Hsieh, Bai and Song, 2019[76]).

49 See www.chinagoabroad.com/en/recent_transaction/beijing-navgnss-integration-to-acquire-a-majority-control-of-sweden-s-mems-chip-maker-for-115m (accessed on 29 October 2019).

50 The plant in question has apparently benefitted from local government subsidies. See: www.yicaiglobal.com/news/swedish-8-inch-semiconductor-processing-technology-settles-in-beijing-e-town-to-produce-iot-chips (accessed on 29 October 2019).

51 See http://globenewswire.com/news-release/2016/09/15/872002/0/en/Okmetic-Oyj-applies-for-delisting-of-its-shares-from-the-official-list-of-Nasdaq-Helsinki.html (accessed on 29 October 2019).

52 See www.usine-digitale.fr/article/pourquoi-un-fonds-chinois-entre-au-capital-de-soitec.N378551 (accessed on 29 October 2019). NSIG's stake in Soitec has since been lowered to 11.49%.

53 See, for example, the failed acquisition of US firm Lattice Semiconductor by Canyon Bridge Capital Partners, a California-based investment fund controlled by China Reform Holdings, itself an "investment holding company controlled by China's State Council with indirect links to the Chinese government's space program" (U.S.-China Economic and Security Review Commission, 2017[110]). The CFIUS ultimately blocked the acquisition.

benign or “grey-area” ITT channels into areas of concern for forced technology transfer (Andrenelli, Gourdon and Moïsé, 2019[17]). Key among these aggravating factors are lack of transparency; conditions that discriminate against foreign firms (either directly, or indirectly through unequal access to legal redress); and the role that the state plays in the economy, not only through its ownership of companies but also through the influence that it exerts on private firms (Box 2.5).

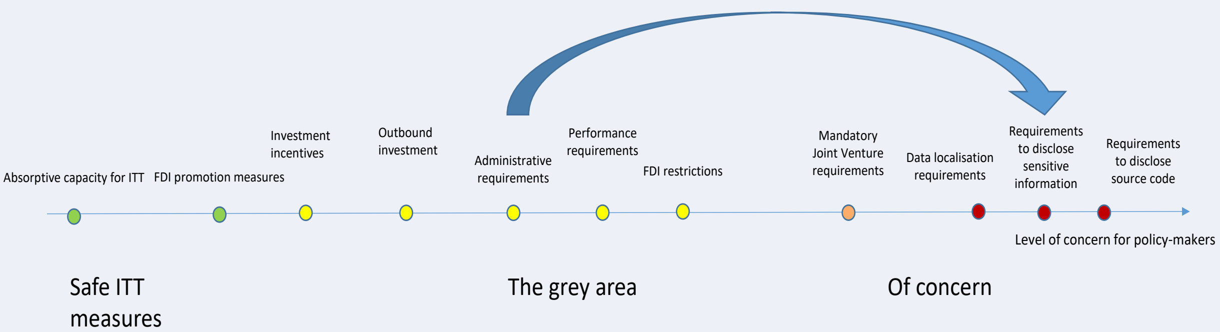
Box 2.5. Identifying forced international technology transfers

While ITT measures are a normal fact-of-life in globalised production networks, they can raise concerns for global competition where they jeopardise the ability of foreign companies to control their proprietary technology, ‘forcing’ the transfer of technology on terms that are not voluntary or mutually agreed.

Recent OECD work has developed a continuum that maps ITT policies according to the level of concern they raise for policy-makers. This continuum covers measures from absorptive-capacity policies and FDI-promotion measures – which generally raise few concerns over forced technology transfer – to administrative requirements, performance requirements, and FDI restrictions (e.g. joint-venture requirements) – which can raise concern where certain aggravating factors apply. The specific design of measures and their surrounding policy environment are crucial in defining the potential of measures to compel transfer of technology from foreign companies to local counterparts or competitors.

For example, administrative requirements such as licensing or certification procedures can become under certain conditions channels for compelling ITT. This can be the case, for example, where there is a lack of transparency regarding the protection or use by the regulator of requested sensitive information. Concerns that this may lead to the transfer of sensitive information to competitors are aggravated where the state itself owns or maintains close ties with competitors. A strong role of the state in the economy could thus make otherwise ordinary measures ‘leap’ along the ITT continuum (Figure 2.8). More generally, the interaction between aggravating factors[1] and policies might turn otherwise ordinary ITT measures into measures of concern for global competition.

Figure 2.8. The disclosure of sensitive information in the course of administrative requirements



Source: Andrenelli, Gourdon and Moïsé (2019[17]).

1. Beyond the role of the state, additional factors include “the extent to which [a given ITT] measure sets up a *quid pro quo* between access to a given market and transfer of proprietary technology”, “lack of observance of non-discrimination”, and “lack of transparency” (Andrenelli, Gourdon and Moïsé, 2019[17]).

In addition to having implications for global competition and trade, forced technology-transfer policies may further stifle innovation and technological progress over the longer run by discouraging future investments in R&D. They may also backfire on countries that adopt such practices by eventually undermining incentives for mutually agreed and beneficial ITT. This suggests a wide range of negative impacts on the supply-side that could make forced technology transfers a self-defeating proposition, in particular given fast product cycles in the semiconductor sector.

2.4. Direct state participation in the semiconductor value chain

As discussed above, state involvement in the semiconductor value chain is very common at the upstream R&D stage, where governments use a variety of policies to support the research activities of semiconductor firms. More uncommon is state involvement further down the chain, in particular where it takes the form of direct state ownership of semiconductor firms or producer subsidies, financial or otherwise. The remainder of this section looks into the question of state ownership and influence in the semiconductor value chain, leaving Section 3 to discuss the question of subsidies and other forms of government support.

State ownership of semiconductor firms is not in itself a problem but can become one where it serves to confer unfair advantages to state-owned producers. Some state-owned enterprises (SOEs) may be managed commercially and at arms' length by authorities that behave like any other shareholder ('competitive neutrality'). In other cases, full or partial ownership by central and local authorities may serve as a conduit for government support (financial or otherwise) and technology acquisition. The empirical record shows unambiguously that in countries where the state plays a strong role in the economy, SOEs obtain on average more subsidies and more loans at cheaper interest rates than their private counterparts (Harrison et al., 2019[69]; Ru, 2018[70]; Herrala and Jia, 2015[71]; Jiang and Packer, 2017[72]). Previous OECD work has shown that certain SOEs are also providers of government support themselves, channelling below-market finance and inputs to firms favoured by the state (OECD, 2019[11]). This support is most problematic where recipients operate internationally in competitive markets since it can distort competition and undermine innovation, particularly in R&D-intensive industries such as semiconductors. For all these reasons, this report next explores the extent to which the state owns semiconductor producers and related firms.

State ownership of, and investment in, semiconductor firms is unevenly distributed in the value chain, reflecting important differences in the economic models of major producing jurisdictions. In the United States, large semiconductor firms are all fully private[54], with the exception of GlobalFoundries and AMD (both companies are owned in full or in part by Mubadala Investment Company, a subsidiary of Abu Dhabi's sovereign wealth fund). In Japan and Korea, large private groups likewise dominate semiconductor production (e.g. Toshiba Memory[55] and Samsung Electronics). A rare exception is Japanese firm Renesas, which is 33% owned by the Innovation Network Corporation of Japan, a subsidiary of the Japan Investment Corporation that is itself 96% owned by the Government of Japan. Most semiconductor companies in Europe are also privately owned, with a few exceptions. The French and Italian governments[56] together own, for instance, STMicroelectronics Holding, which controls about 28% of European semiconductor firm STMicroelectronics. In Chinese Taipei, the "National Development Fund, Executive Yuan", the economy's public investment fund, owns about 17% of Vanguard International Semiconductor and 6% of TSMC, the world's largest contract foundry.

54 The largest shareholders of semiconductor firms in the United States tend to be the "Big Three index fund managers", namely BlackRock, the Vanguard Group, and State Street Global Advisors (Hirst and Bebchuk, 2019[113]).

55 Also known as Kioxia.

56 Through their ownership of Bpi France and the Cassa Depositi e Prestiti (CDP SpA), respectively.

Ownership or investment by the state in semiconductor firms is very largely a Chinese phenomenon, with central and local authorities possessing stakes in nearly all domestic value-chain participants, be they fabless, foundries, or OSAT firms (Box 2.7). Government stakes range from indirect participations below 20% to majority direct ownership, depending on which level of government is involved and firms' own history. Tracing and mapping government ownership of Chinese semiconductor firms can be a difficult exercise, however. Adding to the opacity and complexity of certain ownership structures is the fact that many such firms do not conform to China's own definition of an SOE, nor to the government-ownership thresholds commonly found in regional trade agreements that have SOE chapters (e.g. CPTPP, USMCA, or the Japan-EU EPA) (Box 2.6).

Lack of clarity on the ownership structure of semiconductor firms can have implications for international competition by misrepresenting the reach of the state. According to one expert, "some analysts have mistaken many effectively state-owned or controlled firms for private firms or at least non-state-owned firms because they do not bear the official SOE designation" (Fuller, 2016[37]).[57] Wu (2016[73]) likewise notes that in China "the labels associated with formal shareholding structures can mislead." Moreover, only few SOEs remain purely state-owned in China, "with the majority of [them] now state-controlled shareholding corporations" following a series of reforms undertaken in the 1990s (Song, 2018[74]). One consequence of the reforms has been the development of ownership linkages between state enterprises themselves, such as SASAC-owned Datang Telecom possessing about 19.5% of the shares of contract foundry SMIC.

The distinction between SOEs and other companies in China is made harder by the "blurring of boundaries between the state and private interests" through "critical avenues of state influence" (Harrison et al., 2019[69]; Wu, 2016[73]; OECD, 2019[1]).[58] This leads some to argue that political connections are at least as strong a determinant of government support as state ownership (Tan, Huang and Woo, 2016[75]). This would appear to be particularly the case at the subnational level, where "Chinese local governments have enormous administrative capacity and use it to provide a 'helping hand' to favoured firms" (Hsieh, Bai and Song, 2019[76]). While not unique to China, such practices contribute to further obscuring the boundaries between the state and the private sector, with implications for how one assesses the scope of state ownership and influence. For these reasons and others, the exercise of control rights and the composition of a company's board may sometimes provide a better sense of state influence than the proportion of shares owned by the state. Likewise, the OECD often uses the broader 'state enterprise' terminology to refer to "state-owned, state-controlled or otherwise state-influenced enterprises" (Kowalski and Rabaioli, 2017[77]).

[57] A report by the Rhodium Group and the Asia Society (Rosen, Leutert and Guo, 2018[79]) also states that "actual SOE presence may be significantly higher if firms ultimately controlled by the state via complicated shareholder structures are included."

[58] Cheng et al. (2019[54]) argue, for example, that "Chinese firms can obtain political connection to the government by acquiring seats for their CEOs in [the People's Congress] or (more often) [the Chinese People's Political Consultative Conference]." State influence can also be exercised through the requirement that companies of a certain size in China, including private and foreign ones, establish internally a Communist Party Committee (Wu, 2016[73]).

Box 2.6. Definitions of a state-owned enterprise in different legal contexts

While preferential trade agreements (PTAs) often include rules on state-owned enterprises (SOEs) or state-enterprises (SEs), there is no one standardised definition of them. The following are the definitions of SOEs found in the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP), the Agreement between the European Union and Japan for an economic partnership (EU-Japan EPA), and the Agreement between the United States, Mexico, and Canada (USMCA), all major PTAs that were recently signed.

CPTPP (Article 17.1): **State-owned enterprise** means an enterprise that is principally engaged in commercial activities in which a Party:

(a) directly owns more than 50 per cent of the share capital;
(b) controls, through ownership interests, the exercise of more than 50 per cent of the voting rights; or
(c) holds the power to appoint a majority of members of the board of directors or any other equivalent management body.

EU-Japan EPA (Article 13.1 (h)): "State-owned enterprise" means an enterprise that is engaged in commercial activities in which a Party:

(i) directly owns more than 50 per cent of the share capital;
(ii) controls, directly or indirectly through ownership interests, the exercise of more than 50 per cent of the voting rights;
(iii) holds the power to appoint a majority of members of the board of directors or any other equivalent management body; or
(iv) has the power to legally direct the actions of the enterprise or otherwise exercises an equivalent degree of control in accordance with its laws and regulations.

USMCA (Article 22.1): **State-owned enterprise** means an enterprise that is principally engaged in commercial activities, and in which a Party:

(a) directly or indirectly owns more than 50 percent of the share capital;
(b) controls, through direct or indirect ownership interests, the exercise of more than 50 percent of the voting rights;
(c) holds the power to control the enterprise through any other ownership interest, including indirect or minority ownership; or
(d) holds the power to appoint a majority of members of the board of directors or any other equivalent management body.[1]

Looking at national laws, although Chinese law, for instance, does not appear to have a clear definition of a state-owned enterprise, the term "state-owned and state-holding enterprises" has been used since the mid-1990s for statistical purposes, where "state-owned enterprises" mean wholly state-funded firms and "state-holding enterprises" mean those firms whose majority shares belong to the government.

Considering that SOEs or SEs are defined differently in different legal contexts, this report uses "government-invested firms" to refer to firms in which governments, as a factual matter, have invested, but without prejudice to the size of those investments or the implications they have for the effective level of state control. The terminology of "government invested" thus covers a broader range of state investments in a manner which does not have implications for the legal treatment of such investments.

1. "[T]he term "indirectly" refers to situations in which a Party holds an ownership interest in an enterprise through one or more state enterprises of that Party. At each level of the ownership chain, the state enterprise – either alone or in combination with other state enterprises – must own, or control through ownership interests, another enterprise." (footnote 7) Regarding the subparagraph (c), "a Party holds the power to control the enterprise if, through an ownership interest, it can determine or direct important matters affecting the enterprise, excluding minority shareholder protections. In determining whether a Party has this power, all relevant legal and factual elements shall be taken into account on a case-by-case basis. Those elements may include the power to determine or direct commercial operations, including major expenditures or investments; issuances of equity or significant debt offerings; or the restructuring, merger, or dissolution of the enterprise." (footnote 8).

Box 2.7. Measuring state investment in the semiconductor value chain

To help measure the extent of state investment and influence in the semiconductor value chain, the OECD has looked into the individual ownership structure of all major semiconductor firms in large chip-producing economies (China, Europe, Japan, Korea, Chinese Taipei, and the United States). The exercise relied primarily on information gathered through a detailed search of companies' annual reports, financial statements, other financial documents, and websites, with a view to mapping each economy's semiconductor 'eco-system' and the role that the state plays therein.

Without prejudice to the legal definition of "public bodies" or certain countries' legal definitions of an "SOE", this measurement exercise treats stakes held by state enterprises or state investment funds as investments by the state. Stakes held by several state entities into one company are therefore considered cumulative as they all have the same beneficial owner, i.e. the state.

It should be noted that a high proportion of shares owned by the state in one particular company does not necessarily imply that this firm received government support, nor does a low share exclude any support received through other channels. As such, information on state ownership only serves to indicate *potential* channels of state support and influence. It should be seen as only one piece of the bigger picture set out in this report.

The mapping exercise finds that, out of the identified top 10 Chinese semiconductor companies by revenue, China's National IC Fund and Chinese SOEs together held more than 25% of at least five firms. State participation increases further when state investments at the subsidiary level of these semiconductor companies, where local governments and provincial funds often partner with other state actors, are included. This contrasts with all other jurisdictions studied, where government investments appear to be isolated cases.

Recent years have seen Chinese authorities increase significantly their stakes in domestic semiconductor firms through the creation of several state investment vehicles. The creation in 2014 of the USD 23 billion[59] China Integrated Circuit Industry Investment Fund Co., Ltd. (also known as "the National IC Fund" or "the Big Fund") marked in particular a decisive turn towards greater state control and co-ordination of China's semiconductor industry. This was followed by the creation of numerous sister funds at provincial and city levels that further increased state ownership of semiconductor assets through the injection of fresh capital. One example mentioned above in the context of acquisitions abroad is the Beijing IC Industry Equity Investment Fund, with initial funding of about USD 5 billion (CNY 32 billion), although there are other similar funds in Fujian, Shanghai, Hubei, and Nanjing, to name a few. Some Chinese industry participants go as far as estimating that total funding under both national and local funds could reach USD 150 billion (CNY 1 trillion) by 2020 (Wang, 2018[78]).[60]

[59] Corresponding approximately to initial funding of CNY 139 billion at 2014 exchange rates. A second round of funding for the National IC Fund was completed in 2019, which added USD 29 billion for investments into upstream, domestic semiconductor companies. See www.scmp.com/tech/science-research/article/3020172/china-said-complete-second-round-us29-billion-fund-will (accessed on 29 October 2019). The vehicle for this second round of funding was incorporated in October 2019. Major shareholders included, as of October 2019, the Ministry of Finance (15%); China Development Bank Capital (11%); Shanghai Guosheng Group (7%); China National Tobacco (7%); and Beijing E-Town International Investment & Development (5%).

[60] By way of comparison, IC Insights estimated China's semiconductor market at USD 155 billion in 2018 (IC Insights, 2019[38]).

Besides the National IC Fund and its sister funds, there has been increasing participation by Chinese venture-capital investors in domestic semiconductor firms. Many of these investors appear, however, to have explicit or implicit ties to the state. Shanghai Pudong Science and Technology Investment Co., Ltd. (PDSTI), for example, remains today a state-owned investment firm that focusses on "high-tech M&A opportunity", particularly in integrated circuits.[61] This is despite the company having "completed its state-owned enterprises of mixed-ownership reform in 2014, and transformed from a pure state-owned enterprise into a multi-shareholder company". Current shareholders appear to include the SASAC of Shanghai Pudong New Area and Shanghai Shangshi Asset Management, which is ultimately owned by the Shanghai Municipality. In a similar vein, Shanghai Alliance Investment (SAIL), a venture-capital arm of the Shanghai Municipality, has large indirect stakes in state-owned semiconductor group Hua Hong Semiconductor (17%), its parent the Hua Hong Group[62] (47%), and Shanghai Huali Microelectronics (50%), a foundry joint venture. While these examples cast a particular light on the role played by the Shanghai Municipality, similar state-owned venture funds exist elsewhere in China, e.g. Beijing E-Town International Investment & Development Co., Ltd.

All of the investment vehicles described above have profoundly reshaped China's semiconductor industry, combining to give the state a stronger influence over domestic companies. This influence is further strengthened by government intervention in the country's stock market to support the value of stocks, as famously happened in 2015 (Rosen, Leutert and Guo, 2018[79]; Wu, 2016[73]).[63] The overall picture that emerges is one of opaque ownership linkages in China's semiconductor industry, where it can be difficult to identify the ultimate beneficial owners of companies and to ascertain the precise extent of state influence or ownership.[64] Not only does this have implications for international competition, but it may also have ramifications for the screening of state-backed foreign investments in a context of growing scrutiny of cross-border M&As (OECD, 2018[66]).[65]

Growing direct participation by the state in China's semiconductor industry proceeds from a broader policy push to turn the country into a leading producer of semiconductors over the medium-term. With China currently importing most of the chips it uses (Figure 2.2), authorities are aiming to support the development of an indigenous semiconductor eco-system consolidated under the aegis of national champions (Lewis, 2019[35]). This strategic goal has been outlined in a series of policy documents issued in recent years, beginning with State Council Circular No. 4 in 2011 (Guo Fa [2011] No. 4) on *Several Policies for Further Encouraging the Development of the Software Industry and Integrated Circuit Industry*. These policies not only lowered income-tax rates for

61 See Ernst (2015[3]) and the firm's own website: http://en.pdsti.com/english/about.htm (accessed on 12 March 2019).

62 Both the Hua Hong Group and its subsidiary are also partly owned by the China Electronics Corporation, a centrally managed SOE under the SASAC.

63 See also www.caixinglobal.com/2018-10-19/caixin-explains-how-a-stock-market-crash-created-chinas-national-team-101337087.html (accessed on 12 March 2019).

64 This problem extends beyond semiconductors. Hsieh, Bai and Song (2019[76]) use the example of Anbang Insurance to document the opacity of certain shareholding structures involving state-owned entities, holding shells, and individuals.

65 See the earlier discussion in Section 2.3.

semiconductor companies that use specific technology nodes[66], but also provided for specific concessions on value-added tax and non-specific calls for extending support for semiconductor investment. According to Ernst (2015[3]), the 2011 circular departed from earlier practices by focussing on "selectively supporting a small group of semiconductor firms with global market share and the capacity for technological innovation."

The *Guideline for the Promotion of the Development of the National Integrated Circuit Industry* that the authorities announced in June 2014 and the *Made in China 2025* initiative unveiled the following year both reinforced the government's emphasis on import substitution and its support for national semiconductor champions. The 2014 Guideline is especially noteworthy in that it provides for the creation of the National IC Fund and its local sister funds (discussed above), as well as extending financial support and tax incentives. The document calls in particular for "setting up local integrated circuit industry investment funds and encourag[ing] various social venture capital and equity investment funds to enter the industry", while also encouraging and guiding "domestic development banks and commercial banks to continually provide financial support to the integrated circuit industry."[67] *Made in China 2025*'s technical roadmap has meanwhile set an aspirational goal for China to achieve 40% self-sufficiency in chips by 2020 and 70% by 2025. With Chinese semiconductor production amounting to only 12% of the domestic market in 2018, the chances of reaching those ambitious government targets appear slim at present (IC Insights, 2019[38]).

China's semiconductor policies have so far had more success in consolidating the domestic industry around a few central actors. Four stand out in particular for their importance in China's semiconductor eco-system: namely, the China Electronics Corporation (CEC), Jiangsu Changjiang Electronics Technology (JCET), the Semiconductor Manufacturing International Corporation (SMIC), and Tsinghua Unigroup (Box 2.8). With explicit backing from the National IC Fund and local sister funds, these four groups have come to largely dominate the domestic semiconductor value chain, from R&D down to the OSAT stage.[68] ZTE, a state enterprise, and Huawei[69] are two other important actors at the chip-design stage. Revenue rankings usually show HiSilicon, Huawei's fabless subsidiary, to be China's largest chip vendor (Table 1.1) but information on that particular entity is scarce. The consolidation notwithstanding, there are still many smaller firms operating in China's semiconductor industry, many of which have also obtained funding from state investment vehicles (e.g. Rockchip, Hangzhou Silan, Goke Microelectronics, GigaDevice, and Goodix). In effect, the state has become a minority or majority shareholder in most medium- and large-sized semiconductor enterprises in China.

66 The tax concessions can be very specific. The circular provides, for example, that technology nodes below 0.25 µm and foundry investments exceeding CNY 8 billion benefit from a full five-year income-tax exemption, followed by a five-year period of lower rates (the so-called 5+5 Chinese tax formula).

67 See https://members.wto.org/CRNAttachments/2014/SCMQ2/law47.pdf (accessed on 10 April 2019).

68 Foreign groups implanted in China continue, however, to be collectively the country's largest chip producers.

69 Huawei describes itself as 99% owned by the Trade Union Committee of Huawei Investment & Holding in the company's preliminary bond offering circular dated 4 May 2015. The remaining 1% of shares are reportedly owned by the founder of the group, Ren Zhengfei.

Box 2.8. The evolving participation of the state in China's large semiconductor firms

Semiconductor Manufacturing International Corporation (SMIC)

SMIC is China's largest contract foundry and the country's third largest semiconductor firm by revenue. It is also the world's fourth largest contract foundry. The company was originally established in 2000 as a largely private enterprise that profited from its partnerships with foreign firms and from the hiring of experienced ethnic-Chinese entrepreneurs and returnees (from Singapore, Chinese Taipei, and the United States mostly). This made SMIC the most advanced foundry in China as measured by technology nodes, ahead of its then domestic rival Grace.

Recent changes in China's semiconductor landscape have had, however, a profound impact on SMIC's ownership structure. Total state participation in the company went from less than 15% in 2004 to more than 45% as of 2018, driven mainly by participations from the National IC Fund (19%), state-owned Datang Telecom (19%), and Tsinghua Unigroup (7%). Government stakes in SMIC are even greater when participation by state investment vehicles in some of the firm's subsidiaries (e.g. Semiconductor Manufacturing North China [Beijing] and Semiconductor Manufacturing South China Corporation) are considered.

China Electronics Corporation (CEC)

The CEC is a large state-owned firm under the direct supervision of China's central SASAC. According to its website[1], "CEC is committed to building a national team for network security and information technology industry." The company is currently presiding over two of China's large semiconductor groups, namely Hua Hong Semiconductor and Huada Semiconductors.

Hua Hong Semiconductor is itself a product of China's efforts in the 1990s to create domestic semiconductor champions in the context of 'Project 909'. The then Ministry of Information Industry and the Shanghai Municipality together established the Hua Hong Group (Hua Hong Semiconductor's direct parent) to be "the Chinese SOE that would hold a majority share in the 200-mm [joint venture] fab that was the center-piece of the [909] project" (Fuller, 2016[37]). Hua Hong later grew in importance when it finalised its acquisition of Chinese foundry Grace (SMIC's direct competitor at the time) in 2014 in order to form a foundry group under control of the Shanghai Municipality and the CEC. The National IC Fund has since injected additional capital into the company, owning 19% of Hua Hong Semiconductor and 29% of Hua Hong Wuxi, a semiconductor fab structured as a joint venture.

Huada Semiconductors, a firm mostly focussed on chip design, also originates in the Projects 908 and 909 that the government initiated in the 1990s. It has now evolved into a chip-design group fully owned by the CEC, and consolidates the activities of various listed subsidiaries: Shanghai Belling, Solomon Systech, China Electronics Huada Technology, etc.

Tsinghua Unigroup

Tsinghua Unigroup is a large state-owned IT conglomerate that emanates from Tsinghua University, and which is controlled, administered, and supervised jointly by China's Ministry of Education and the Ministry of Finance. The group has lately expanded its semiconductor activities with the acquisition in 2013 of two independent fabless firms, Spreadtrum and RDA, in anticipation of the June 2014 *Guideline* that created the National IC Fund. Tsinghua Unigroup itself claims to benefit from "favorable government policies" and that its "strong state-owned background lays solid foundation for development", while "MOF/MOE, Tsinghua University, and Tsinghua Holdings play a significant role in operations" (Tsinghua Unigroup, 2015[80]). Although it initially focussed on chip design, the firm has made recent forays into the foundry business, collaborating with local governments and the National IC Fund to invest in the construction of new memory fabs in Chengdu (Sichuan), Chongqing, Nanjing (Jiangsu), and Wuhan (Hubei). Once completed, those investments might eventually reach about USD 100 billion (Feng et al., 2018[36]). Although there had been talk of transferring ownership of Tsinghua Holdings (Unigroup's parent) from Tsinghua University to another state entity (state-owned Shenzhen Investment Holdings), the change does not appear to have taken place at the time of writing.

Jiangsu Changjiang Electronics Technology (JCET)

Like SMIC, JCET started as a private company owned by the Xinchao Group. It operates downstream of the chain, where it specialises in contract assembly and testing. Following its acquisition of Singaporean firm

STATS-ChipPAC in 2015, JCET has grown to become the third largest OSAT firm worldwide by revenue. This acquisition was partly funded through equity from China's National IC Fund and SilTech Semiconductor, a fully owned subsidiary of SMIC, as well as through loans provided by the Bank of China.[2] The resulting share distribution now gives the state control over about 20-35% of JCET depending on how SMIC is classified.

1. See http://en.cec.com.cn/jtjj/list/index_1.html (accessed on 13 March 2019).
2. See www.bankofchina.com/aboutboc/ab8/201509/t20150923_5672779.html (accessed on 29 October 2019).
Source: Ernst (2015[3]); Fuller (2016[37]); Tsinghua Unigroup (2015[80]); Feng, et al. (2018[36]); and OECD research.

For the period that this report covers, China is unique in having policies and funds that target semiconductors specifically, with the explicit aim of consolidating the industry around a selection of national champions that can compete globally. State investment vehicles do exist in other jurisdictions, and some have invested in semiconductor firms, as noted in the cases of Mubadala (Abu Dhabi) and the Innovation Network Corporation of Japan. Saudi Arabia's Public Investment Fund is another instance, having indirectly invested (through SoftBank's Vision fund) in chip designer Nvidia, although SoftBank has since sold those shares. Chinese Taipei also has a public fund (the "National Development Fund, Executive Yuan") that owns about 6% of TSMC and 17% of Vanguard International Semiconductor.[70] None of the above funds are specific to semiconductors, however, with their investments directed at sectors as varied as biotechnology, transportation, green energy, and fintech. Most also do not explicitly seek to create national champions. Of all these funds, only that of Chinese Taipei is related to a specific industrial policy, with Article 30 of the *Statute for Industrial Innovation* stating that the fund may be used to "enhance the efficiency of industries or improve the industrial structure, in line with the national industrial development strategy."[71]

While many jurisdictions do not have national semiconductor funds and policies in place, governments may still use other policy tools to encourage the development of private semiconductor champions. Lax competition policy or failure to enforce antitrust standards may allow private domestic companies to reach a dominant size and to rival foreign competitors. Alternatively, antitrust policies can also be used by some governments to prevent foreign competitors from entering new markets.

Although this goes beyond this report's primary focus on government support, the issue of anti-competitive practices in the semiconductor value chain has at times been a cause for concern for governments. Most recently, the US Federal Trade Commission filed in 2017 "a complaint in federal district court charging Qualcomm Inc. with using anticompetitive tactics to maintain its monopoly in the supply of a key semiconductor device used in cell phones and other consumer products."[72] While that particular case was ongoing at the time of writing, the broader issue of antitrust infringements serves as a reminder that state ownership and government support are not the sole sources of market distortions in the semiconductor value chain. It also underlines that government action may sometimes be necessary to achieve a level playing field in competition.

70 As per the fund's annual report for the year 2017. A number of sub-funds and incubators (so-called 'Special Project Investments') under the "National Development Fund" also have stakes in domestic semiconductor SMEs.

71 See https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0040051 (accessed on 13 March 2019).

72 See www.ftc.gov/enforcement/cases-proceedings/141-0199/qualcomm-inc (accessed on 24 July 2019).

3. Estimating government support in the semiconductor value chain

The end of Section 2 looked into state ownership in the semiconductor value chain, finding it to be unevenly distributed across countries. As noted in that section, while state ownership is not in itself a problem for global competition, it can become so where it serves as a conduit for trade-distorting government support, finance, and technology. This section looks at a sample of 21 large semiconductor firms, some fully private and some with government investment (government-invested), in order to estimate how much government support, financial or otherwise, they have received over recent years.

3.1. The OECD's approach to measuring government support

3.1.1. The OECD matrix of support measures

The OECD has longstanding work identifying and measuring government support in a number of sectors, beginning with agriculture in the late 1980s and continuing with fossil fuels, fisheries, and more recently the aluminium value chain (OECD, 2019[1]). That experience has enabled the OECD to refine its tools over time and arrive at a set of definitions and concepts for measuring support, such as those described in the *PSE Manual*[73] for agriculture (OECD, 2016[81]). With the expansion of this work to non-agricultural sectors, the OECD has also developed a broad-based taxonomy of government support measures, encapsulated in a matrix (Table 3.1).[74]

The OECD's two-dimensional taxonomy distinguishes support measures based on their formal incidence and their transfer mechanism. Formal incidence refers to whom or what a transfer is first made, enabling distinctions to be made between support measures that target output levels (i.e. enterprise income), unit returns, intermediate inputs, knowledge (e.g. R&D and IP), or other value-adding factors that are either variable (e.g. labour) or quasi-fixed (e.g. capital and land). Transfer mechanisms describe how a transfer is generated, whether through a direct cash transfer; tax or other revenue foregone by the government; transfers induced by regulations or price controls; or the assumption by the government of risks that would otherwise be borne by the private sector. Taken together, transfer mechanisms and formal incidence encompass most instruments that governments can use to support particular firms or industries. The particularities of each sector, or the policy question at hand, then determine which cells of the matrix are to be the focus of the analysis.

While it is not exhaustive, the OECD's matrix of government support is notably wider than some conceptions of 'subsidy': it encompasses any financial or regulatory measures that can affect costs, prices, or the profitability of market actors in any portion of the value chain, wherever they operate. This includes, for example, transfers benefitting R&D (column G) but also support provided through the financial system (rows 3-5, column F), analysed later in the present section. While the examples of support measures listed in the matrix are not exhaustive in the sense that they do not explicitly describe each and every government practice, the matrix could in principle accommodate even the most complex and multidimensional types of government intervention. It should be viewed as a living taxonomy that can be refined in the context of future work.

73 PSE stands for Producer Support Estimate.

74 See the OECD's own work on government support in the aluminium value chain for more background on the OECD matrix of support measures (OECD, 2019[1]).

Table 3.1. Indicative matrix of support measures, with illustrative examples

Transfer mechanism (how a transfer is created)			Statutory or formal incidence (to whom and what a transfer is first given)							
			Production							Consumption
						Costs of value-adding factors				
			A: Output returns	B: Enterprise income	C: Cost of intermediate inputs	D: Labour	E: Land and natural resources	F: Capital	G: Knowledge	H: Direct support to consumers
	1: Direct transfer of funds		Output bounty or deficiency payment	Operating grant	Input-price subsidy	Wage subsidy	Capital grant linked to acquisition of land	Grant tied to the acquisition of assets, including foreign ones	Government R&D	Unit subsidy
	2: Tax revenue foregone		Production tax credit	Reduced rate of income tax	Reduction in excise tax on input	Reduction in social charges (payroll taxes)	Property-tax reduction or exemption	Investment tax credit	Tax credit for private R&D	VAT or excise-tax concession
	3: Other government revenue foregone			Waiving of administrative fees or charges	Under-pricing of a government good or service		Under-pricing of access to government land or natural resources	Debt forgiveness or restructuring	Government transfer of intellectual property rights	Under-pricing of access to a natural resource harvested by final consumer
	4: Transfer of risk to government		Government buffer stock	Third-party liability limit for producers		Assumption of occupational health and accident liabilities	Credit guarantee linked to acquisition of land	Loan guarantee; non-market-based equity injection and debt-equity swap		Price-triggered subsidy
	5: Induced transfers		Import tariff or export subsidy; local-content requirements; discriminatory GP	Monopoly concession	Monopsony concession; export restriction; dual pricing	Wage control	Land-use control	Credit control (sector-specific); non-market mergers and acquisitions	Deviations from standard IPR rules	Regulated price; cross subsidy
		-- Including advantages conferred through state enterprises			Provision of below-cost electricity by a state-owned utility			Below-market loan by a state-owned bank		

Note: This matrix is a work in progress and may be refined in the future. Some measures may fall under a number of categories (e.g. debt-equity conversions may involve elements of both risk transfers and revenue foregone).
GP = Government procurement.

3.1.2. Government support from the perspective of individual firms

Similar to earlier OECD work measuring government support in the aluminium value chain, this report identifies and estimates support in the semiconductor value chain at the level of individual firms. This choice is borne out of necessity given the lack of transparency and granularity on how much countries spend in support of their semiconductor industry. As mentioned earlier in the context of R&D spending (Section 2.1), while it is possible to obtain data on aggregate R&D spending by country and by broad industry grouping, that information often does not single out semiconductors, much less individual segments of the chain (e.g. fabless or foundries).

Although selecting a representative sample of companies can be difficult, the semiconductor value chain should lend itself in principle to firm-level analysis of support. As shown in Section 1.2 (on industry structure), the middle segments of the value chain are all highly concentrated, due in part to high fixed costs and above-average capital intensity. Many semiconductor firms are also vertically integrated to some extent as they engage in upstream R&D, chip design, manufacturing, and assembly and testing. Contract foundries themselves invest considerable resources into upstream R&D even though they focus their activities on manufacturing chips designed by others. This implies that covering a critical mass of firms should prove sufficient to attain some degree of representativeness in terms of measuring market distortions. In what follows, this report shows results obtained for a sample of 21 firms operating at different stages of the value chain and based in different jurisdictions.

The 21 firms in the sample had a combined semiconductor revenue that exceeded USD 370 billion in 2018, thereby accounting for more than two-thirds of global industry revenue.[75] Of those 21 firms, ten are IDMs, three are fabless, five are contract foundries, and three are OSAT companies (Table 3.2). The selection of firms has sought to achieve a balance between economic significance (e.g. a company’s share of global revenue in a given market segment) and geographical diversity in order to cover all main semiconductor-producing economies or regions. Accordingly, three of the IDMs are from the United States, another three are from Europe (Germany, the Netherlands, and Switzerland), two are from Japan, and two are from Korea. Out of the three fabless companies in the sample, two are from the United States, reflecting that country’s predominance in chip design. The other fabless in the sample, China’s Tsinghua Unigroup, is gradually evolving towards the IDM model through the construction of large memory fabs. The sample also includes three of Chinese Taipei’s largest contract foundries and China’s two largest, as well as the three largest OSAT companies globally: one from Chinese Taipei, one from the United States, and one from China.

Availability of detailed information at the company level is another determinant of which firms are included in the sample. Because they are not publicly listed, large semiconductor companies such as Huawei’s HiSilicon and Mubadala-owned GlobalFoundries could not be included in the present study due to their lack of regular financial disclosure. Although their parent companies have at times released detailed bond prospectuses, those cover only a short period of time that does not match the recent years that are the focus of the present analysis (2014-18). Lack of detailed information similarly complicates efforts to estimate the support received by Tsinghua Unigroup, China’s second largest fabless company after HiSilicon. Recent financial statements for the group could be located, however, enabling the present analysis to cover that company, albeit imperfectly.

[75] This is adding together the global semiconductor revenue of chip vendors, foundries, and OSAT firms.

Companies in the sample are very largely specialised in semiconductors, with the exception of three firms: Samsung Electronics, Toshiba, and Tsinghua Unigroup. While the analysis would ideally distinguish semiconductor-related activities from the groups' other business segments, that distinction can be problematic to make in practice. One reason is the lack of sufficient information at the business-segment level, especially for China's Tsinghua Unigroup. Another reason is the synergies that might exist between the different segments of a group, such as where a company's chips feed into its own smartphone business. Overall, this makes it difficult to establish a strict separation between firms' activities and the choice was therefore made to use financial information at the group level, without manipulating or adjusting numbers further. In any event, semiconductors represented about 35% and 76% of the consolidated revenue and profits of Samsung Electronics in 2018, respectively, thus making chips a central part of the group's results. For Toshiba, the analysis concentrates on the period 2013-17 – prior to the group spinning off its memory chip business – to ensure consistency over time. During that period, "storage & electronic devices solutions" were by far the largest contributor to the group's revenue (33% in FY2016/17), profits (92% in FY2016/17), capital expenditure, and R&D spending.[76] Finally, although semiconductors represented only a modest part of Tsinghua Unigroup's consolidated revenue in 2018 (about 20%), this does not account for the massive investments the group is currently undertaking to build new semiconductor manufacturing capacity in the memory segment, and in connection with which it received large equity injections from the government. The company envisages these investments to reach almost USD 100 billion in coming years, which would turn the company into a central actor in China's semiconductor eco-system.

Table 3.2. Overview of the firm sample

Firm name	Home economy	VC activity	Main business segments
Infineon	DEU	IDM	Analog and logic devices for the automotive industry and other industrial applications
Intel	USA	IDM	Microprocessors, logic, non-volatile memory, and FPGAs for computers, servers, and other electronic equipment
Micron	USA	IDM	Memory and logic
NXP	NLD	IDM	Analog and logic devices for the automotive industry and other industrial applications
Renesas	JPN	IDM	Analog and logic devices for the automotive industry and other industrial applications
Samsung Electronics	KOR	IDM	Memory and logic
SK Hynix	KOR	IDM	Memory mainly
STMicroelectronics	CHE	IDM	Analog and logic devices for the automotive industry and other industrial applications
Texas Instruments	USA	IDM	Analog and logic devices for the automotive industry and other industrial applications
Toshiba[1]	JPN	IDM	Memory mainly
Tsinghua Unigroup	CHN	IDM/Fabless[2]	Phone-related devices and memory mainly
NVIDIA	USA	Fabless	GPUs and SoCs
Qualcomm	USA	Fabless	Wireless modems and other phone-related devices for the most part
Hua Hong Semiconductor	CHN	Foundry	Contract foundry
SMIC	CHN	Foundry	Contract foundry
TSMC	TWN	Foundry	Contract foundry
UMC	TWN	Foundry	Contract foundry

76 This implies that any tax credit for investment or R&D benefits primarily the company's semiconductor activities.

Firm name	Home economy	VC activity	Main business segments
Vanguard International Semiconductor	TWN	Foundry	Contract foundry
Advanced Semiconductor Engineering	TWN	OSAT	Contract assembly and testing
Amkor	USA	OSAT	Contract assembly and testing
JCET	CHN	OSAT	Contract assembly and testing

Notes: 1) Toshiba Memory was only spun-off from the broader Toshiba group in June 2018. Toshiba Memory is in the process of being renamed Kioxia. 2) Tsinghua Unigroup was originally a fabless company but has recently diversified into memory foundries.

3.2. Budgetary government support

In the following, information on government support is organised into two separate categories, namely: (i) budgetary government support, which covers support not provided through the financial system (e.g. direct transfers of funds, tax revenue foregone, and subsidised inputs); and (ii) support provided through the financial system, which refers to government actions that lower the cost of financing for semiconductor firms below their normal full cost of capital. This distinction is purely for practical, not conceptual, reasons as both sets of measures fit equally in the OECD matrix of support measures. The difference is necessitated, however, because most data on budgetary government support were obtained from primary sources (e.g. companies themselves or governments) while data on financial support are usually non-transparent and imprecise, and have been estimated by the OECD using a number of assumptions. Section 3.2 first discusses budgetary support before Section 3.3 turns to support provided through the financial system.

Methodology

Data on the amounts of budgetary government support received by the 21 semiconductor firms in the sample were in general obtained from companies' own publications and financial disclosures. This includes firms' annual reports, filings with the US Securities and Exchange Commission, financial statements, bond prospectuses, etc. In a few cases, the data were complemented with information obtained from governments themselves, especially for grants and property-tax concessions conferred by local authorities (e.g. states, provinces or counties). Other data sources include the European Commission's State Aid Transparency Public Search and the USA Spending government database.

For each measure identified, the OECD has sought to collect data annually for as large a time period as possible, as well as to organise that information in line with the categories shown in the matrix of support measures (Table 3.1). This has involved indicating the transfer mechanism and the formal incidence corresponding to each measure in the dataset. Other variables serve to indicate whether the measures are provided by central or sub-national jurisdictions, the data sources used by the OECD and, where available, the starting year for each measure.

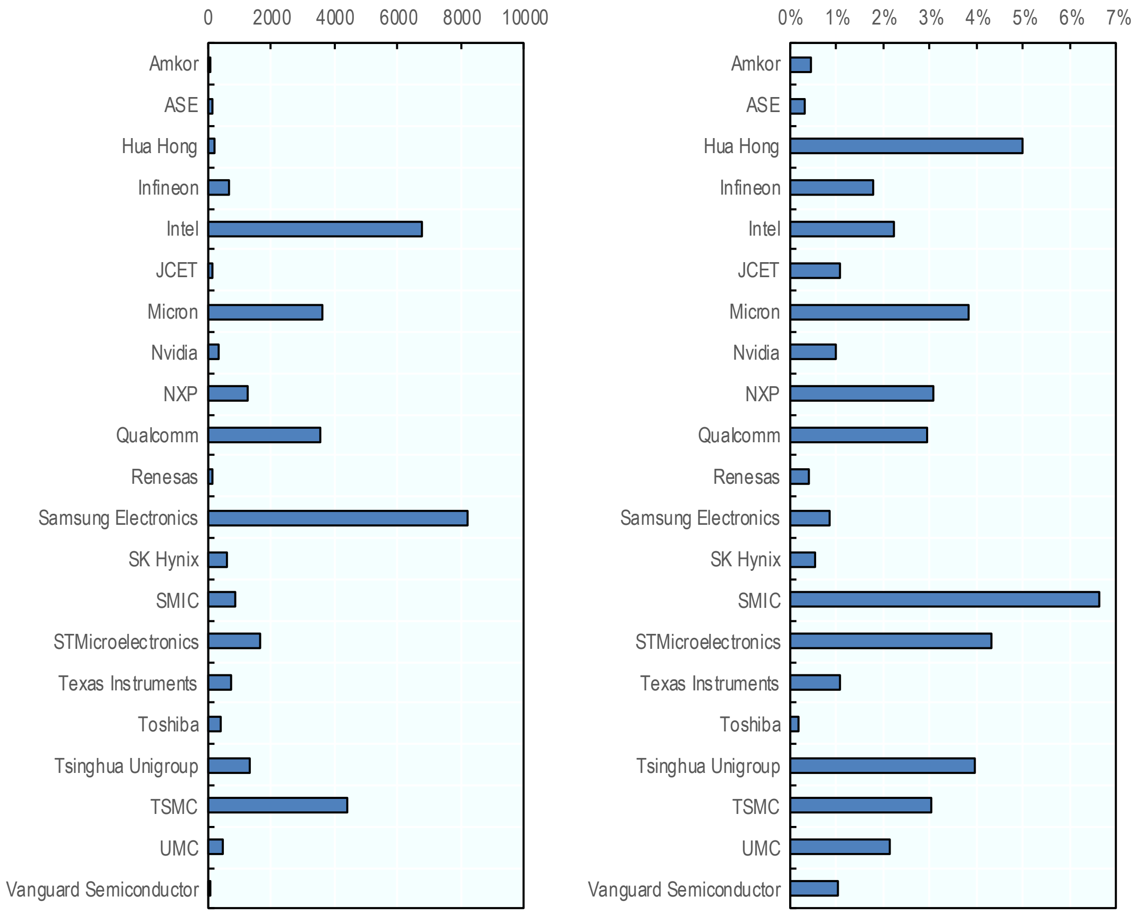
In what follows, support estimates are aggregated over a five-year interval given considerable year-to-year variability in the amounts reported annually by individual firms. This is notably the case where support measures are one-off payments, or where measures terminate abruptly from one year to the next. Showing numbers that sum several years in a row helps smooth these variations, thereby providing a more representative picture of total support to the sector. The five-year period chosen for this report is 2014-18. Only for Toshiba is that period changed to 2013-17 to account for Toshiba Memory's spin-off in 2018. Although the OECD has collected data going back further than 2014, these numbers were not always available consistently for all companies in the sample.

Results and discussion

Total budgetary government support for the 21 firms in the sample amounted to USD 36 billion over the period 2014-18 (Figure 3.1). Consistent with industry structure, budgetary support is highly concentrated at the top, with the three largest firms – Samsung Electronics, Intel, and TSMC – together representing about 54% of the total. There are very large size differences between the 21 firms in the sample, however. While Samsung Electronics generates close to USD 200 billion in revenue annually, that number falls to USD 930 million for Chinese foundry Hua Hong Semiconductor. Expressing support amounts as a share of total revenue over the same period (in order to account for firm size) provides an alternative view that highlights apparent firm reliance on government support. This shows SMIC, Hua Hong, STMicroelectronics, Tsinghua Unigroup, and Micron to be the largest recipients of budgetary government support as a share of company revenue.

Figure 3.1. Total budgetary government support for all 21 firms in the sample amounted to USD 36 billion over the period 2014-18

Left: Total budgetary support, 2014-18, USDmn, current
Right: Total budgetary support, 2014-18, % of firm revenue



Note: Data for Toshiba are for 2013-17.
Source: OECD research.

While expressing support relative to company revenue is more meaningful for capturing the extent to which government assistance helps particular firms, it does not reflect the impact that support may be having on global semiconductor markets. Assessing that impact is complex, as it depends on a host of intertwined factors. The absolute magnitude of support is one such factor, though not all support measures can be expected to have the same impact on global markets. Measures supporting upstream R&D by semiconductor firms are likely less distortive (or even market-correcting if well designed), for instance, than investment tax credits or income-tax holidays, which have a direct bearing on firms' investment and production decisions.

The impact of this support on global markets will also vary depending on firms' market share, which itself hinges on competition dynamics in particular sub-segments of the semiconductor industry. While global semiconductor market shares such as those presented in Table 1.1 are helpful in gauging the relative size of firms, they do not convey these firms' competitive positions in the production of particular chips such as CPUs, GPUs, wireless modems, FPGAs, analog devices, 3D-NAND, or DRAM memory chips. By way of example, while AMD and Nvidia have low market shares in the overall semiconductor market (1% and 2% respectively), they account for a much larger share of the narrower market for GPUs, in which the two companies compete for customers in the video-game and data-centre industries. A further complication arises as market share can change quickly, and can itself be a function of government support, albeit with a lag. In that sense, a smaller competitor receiving large amounts of support today may be in a better position to become a more significant player in the market tomorrow. Although it is beyond the scope of this report to conduct a full-fledged analysis of the impact that government support is having on global semiconductor markets, the above discussion suggests that this impact is likely multi-faceted and nonlinear.

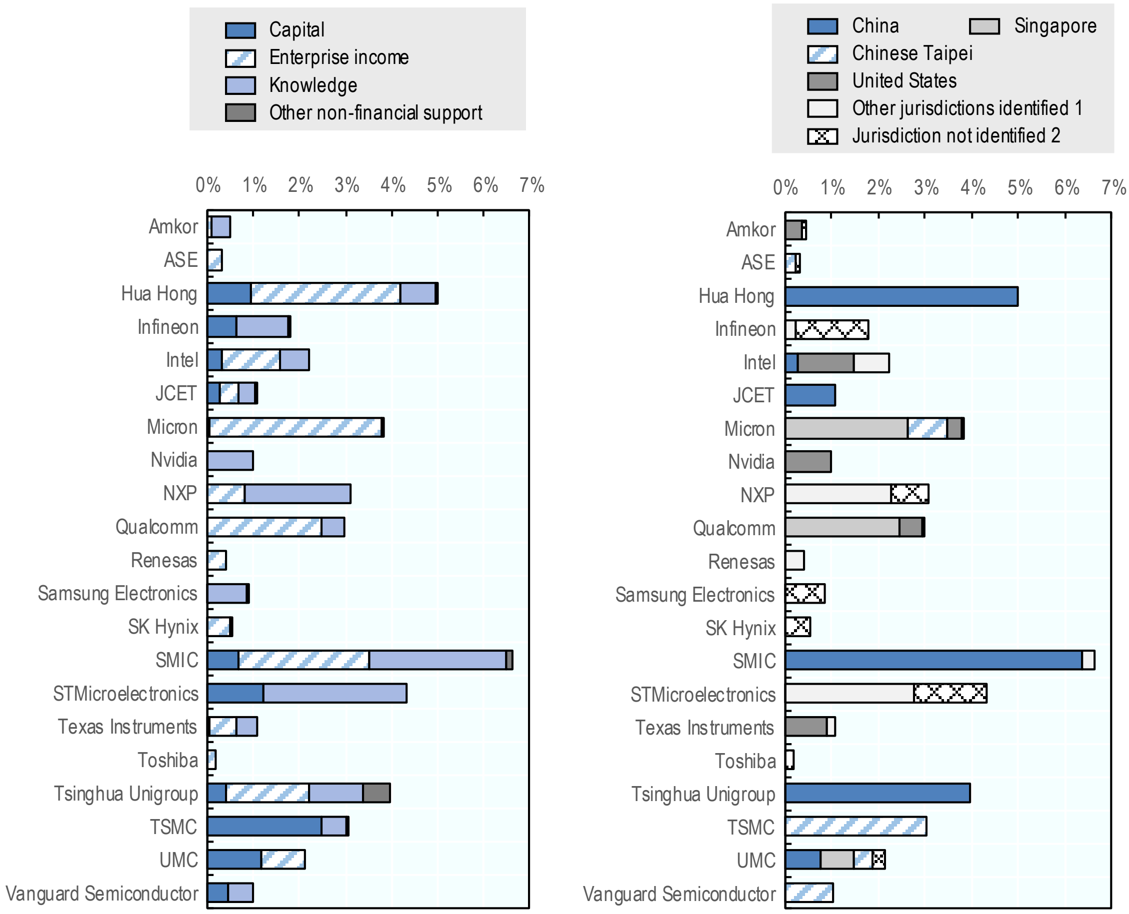
Lack of transparency remains a general concern, with few companies providing detailed accounts of the support measures from which they benefit. Most firms disclose aggregate numbers (e.g. "tax credits") that are not broken down by measure or country, which complicates efforts to categorise support and trace it back to the different jurisdictions by which it is provided. It is therefore difficult to rank accurately jurisdictions in terms of the amounts of support they provide. On the basis of the information available, and keeping in mind the many limitations that apply, the jurisdictions that appear to provide the most budgetary support in absolute terms are China, Korea, Singapore, Chinese Taipei, and the United States (Figure 3.2).

Similar to earlier findings by the OECD in the context of the aluminium value chain (OECD, 2019[1]), multinational semiconductor enterprises do not necessarily obtain the majority of this support from their home economies, but instead often receive more generous assistance in the other jurisdictions in which they operate. This is notably the case for US firms Micron and Qualcomm, which both obtained relatively little support from US authorities but received more significant aid from their operating bases in Southeast Asia, particularly Singapore. Intel has received considerable support from Israel, where its fabs are the country's largest employer. Although it is headquartered in Switzerland, European firm STMicroelectronics has obtained most of its support from France and Italy, where most of the company's fabs are located.[77] Asian semiconductor firms appear, however, to obey a different pattern, with most support coming from their home jurisdictions (UMC is an exception).

[77] The company was historically formed through the merger of France's Thomson Semiconducteurs and Italy's SGS Microelettronica. The French and Italian states together retain a 28% stake in the company.

Figure 3.2. Most budgetary government support targets R&D, capital investment, and company income

Left: Total budgetary support by formal incidence, 2014-18, % of firm revenue
Right: Total budgetary support by jurisdiction, 2014-18, % of firm revenue



Notes: 1) "Other jurisdictions identified" include Austria, France, Germany, Ireland, Israel, Italy, Japan, Malaysia, the Netherlands, the Philippines, and the United Kingdom. 2) "Jurisdiction not identified": the OECD has not been able to identify the geographical origin of all the support reported by some companies due to lack of transparent reporting. Data for Toshiba are for 2013-17.
Source: OECD research.

Using the categories of formal incidence highlighted in the OECD matrix of support measures (Table 3.1), most budgetary support appears to target knowledge (e.g. R&D), capital investment, and company income (Figure 3.2). These results are consistent with the semiconductor industry's high R&D and capital intensity. They also contrast with earlier OECD findings for the aluminium value chain, where support for R&D was found to be relatively minor (OECD, 2019[1]). Besides support for knowledge and capital investment, semiconductor companies also obtained relatively large support in connection with their income, usually in the form of large reductions of corporate income tax or outright income-tax holidays.

The transfer mechanism of choice for supporting semiconductor firms appears to be tax concessions, either in the form of R&D tax credits, property-tax abatements, special reductions in rates of corporate income tax, investment tax credits, etc. Together, tax concessions made up 90% of the total USD 36 billion in budgetary support provided to the 21 firms in the sample over the period 2014-18. Most tax measures have the stated aims of either increasing R&D spending by private firms in the hope of encouraging innovation, or attracting capital investment to support local economic activity and job creation. Examples of investment tax incentives abound in the sample, though there can be differences in the extent to which jurisdictions are able to offer such concessions. EU state-aid rules have constrained the ability of Member States to provide targeted tax relief to attract semiconductor firms (Thomas, 2011[82]), but other forms of support (e.g. for industrial research) remain in use in Europe. Investment incentives benefitting semiconductor firms are not confined to OECD countries, however, as many can be found in China, Malaysia, the Philippines, Singapore, and Chinese Taipei.

The tax concessions that account for most budgetary support in the semiconductor value chain appear at times to benefit both domestic and foreign firms. This can be observed not just in OECD countries (e.g. the European Union, Israel, and the United States), but also in China, Singapore, and other Asian economies. In certain cases, the benefits may be even higher for foreign semiconductor firms, possibly in an attempt to encourage international transfers of technology (Thomas, 2011[82]; Fuller, 2016[37]).

3.3. Government support provided through the financial system

While, as noted above, tax concessions for the semiconductor industry can benefit both domestic and foreign firms, the situation is different in the case of support provided to companies through the financial system in the form of below-market financing. Local firms are, for example, often able to secure loans at favourable terms that are generally not accessible by foreign enterprises. In what follows, this section presents evidence indicating that below-market debt and equity can constitute crucial channels of government support in the semiconductor value chain, particularly in countries where the state exercises significant control over the allocation of capital in the economy.

3.3.1. Below-market borrowings

Unlike on-budget measures such as grants and tax concessions that are normally provided to companies by governments themselves, the provision of below-market finance often happens using state-owned financial institutions as intermediaries (Sapienza, 2004[83]).[78] This points to the dual role that state enterprises can play as both recipients and providers of support, such as where a state bank is instructed by the authorities to issue below-market loans to another state enterprise deemed strategic.[79] The presence of intermediaries along that chain further complicates efforts to identify and estimate the support ultimately conferred by governments. It also suggests that below-market finance is more prevalent in economies where the state plays a strong role in the allocation of productive resources.

Below-market borrowings consist of the issuance of loans at contractual terms that are more favourable than can be obtained from commercial lenders in the market. This generally includes lower interest rates, longer repayment periods, longer grace periods, etc. The practice becomes problematic from a competition standpoint where favourable lending terms originate in non-commercial behaviour by financial institutions that are owned or otherwise influenced by the state, or where they result from government guarantees (explicit or implicit) that ease the terms and conditions of borrowings in the market. In the latter case, governments as guarantors "pass the risk

78 This includes development banks, export-credit agencies, and majority state-owned banks, among others.

79 The state bank in question might itself become a recipient of support if it is ultimately refinanced by the state in the event that the loans it made prove non-performing.

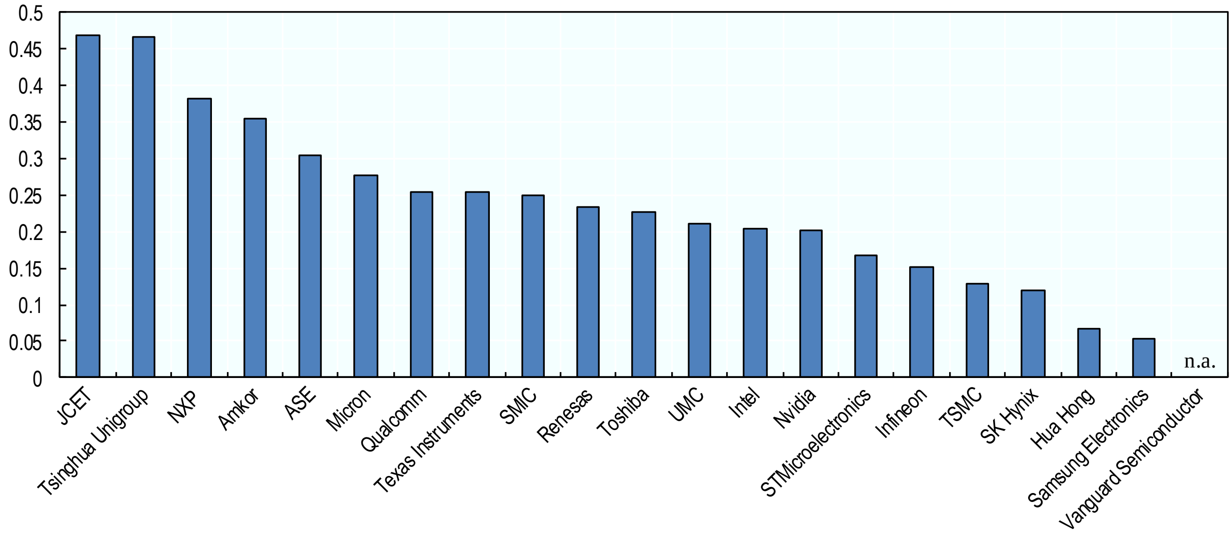
underlying [borrowings] to taxpayers, who inevitably become *de facto* equity-holders in the project" (OECD, 2018[84]). One example can be found in Mubadala's bond prospectus dated 29 April 2016, where the parent of contract foundry GlobalFoundries notes that its credit ratings "are the same ratings given to the Abu Dhabi sovereign and reflect the Group's strong strategic relationship with the Government."

One sign of the existence of below-market borrowings is the mismatch that can exist between firms' financial standing and their cost of debt. Commercial lenders typically analyse the financial well-being of borrowers when considering whether to extend a loan and at what terms and conditions. By examining various financial metrics and indicators, lenders evaluate, for instance, companies' funding structure, profitability, and solvency. This helps them determine the interest rate that should be charged on any particular loan, taking into account the risk profile of the borrower. The interest rate corresponds in that case to the opportunity cost for lenders – i.e. the foregone benefit that an alternative investment might have generated – as well as reflecting debtors' default risk, in order to compensate for the likelihood that borrowers may become unable to service their debt.

Most semiconductor firms in the sample seem to have sufficient ability to service their debt obligations. This is in part because most firms studied have relatively low leverage as measured by their debt-to-asset (D/A) ratios (Figure 3.3).[80] Generally, the higher the D/A ratio, the greater the relative level of debt held by a firm, and thus the more susceptible the firm is to the risk of default. The D/A ratio not only reflects firms' leverage and their ability to repay existing debt; it also helps lenders anticipate the likelihood that additional debt, should they provide it, will be repaid in full. While all firms in the sample carry a D/A ratio below 0.5, JCET, Tsinghua Unigroup, and NXP nonetheless appear relatively more leveraged than their peers. This might be due to all three companies having had to finance large acquisitions in the period covered by this report.

Figure 3.3. The firms studied appear to carry balanced D/A ratios

Average debt-to-asset ratio over the period 2014-18



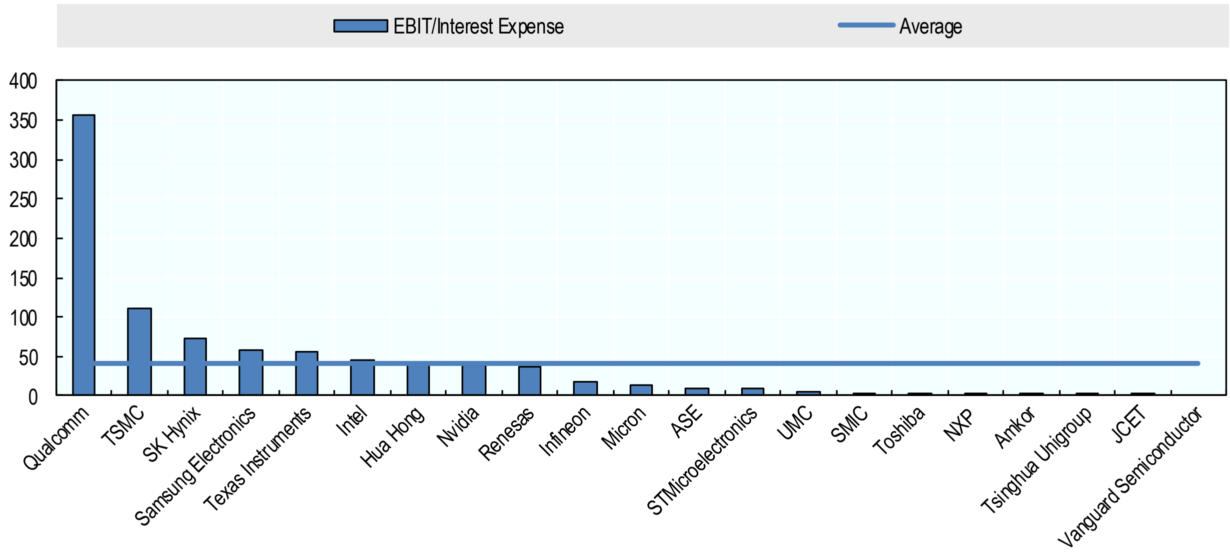
Note: Vanguard Semiconductor had no debt over the period studied. Data for Toshiba are for 2013-17.
Source: OECD calculations based on firms' financial statements and the FactSet database.

80 While an overall assessment of companies' financial standing would normally take into account a variety of indicators, e.g. profitability metrics (RoA and RoE), this report shows a selection of solvency indicators for illustrative purposes only.

The interest-coverage ratio tells a complementary story as it provides another indication of firms' ability to service their debt obligations. This is calculated by dividing a firm's earnings before interest and taxes (EBIT) by that firm's interest expenses for the same period. This serves to indicate whether a firm can utilise its own earnings to meet the required interest payments arising from its debt. Most firms in the sample have EBIT levels that are at least three times their interest expense (Figure 3.4). JCET is the only firm in the sample for which the interest coverage ratio is below one. It should be noted, however, that the data used here were obtained from firms' audited financials, and therefore do not account for the existence of support that might serve to lower interest payments or increase EBIT levels.

Figure 3.4. Most firms studied have EBIT levels that are at least three times their interest payments

Average interest-coverage ratio over the period 2014-18



Note: Data were obtained from firms' audited financials and therefore do not account for the existence of support that might serve to lower interest payments or increase EBIT levels. Vanguard Semiconductor had no debt and thus no interest payment over the period studied. Data for Toshiba are for 2013-17.
Source: OECD calculations based on firms' financial statements and the FactSet database.

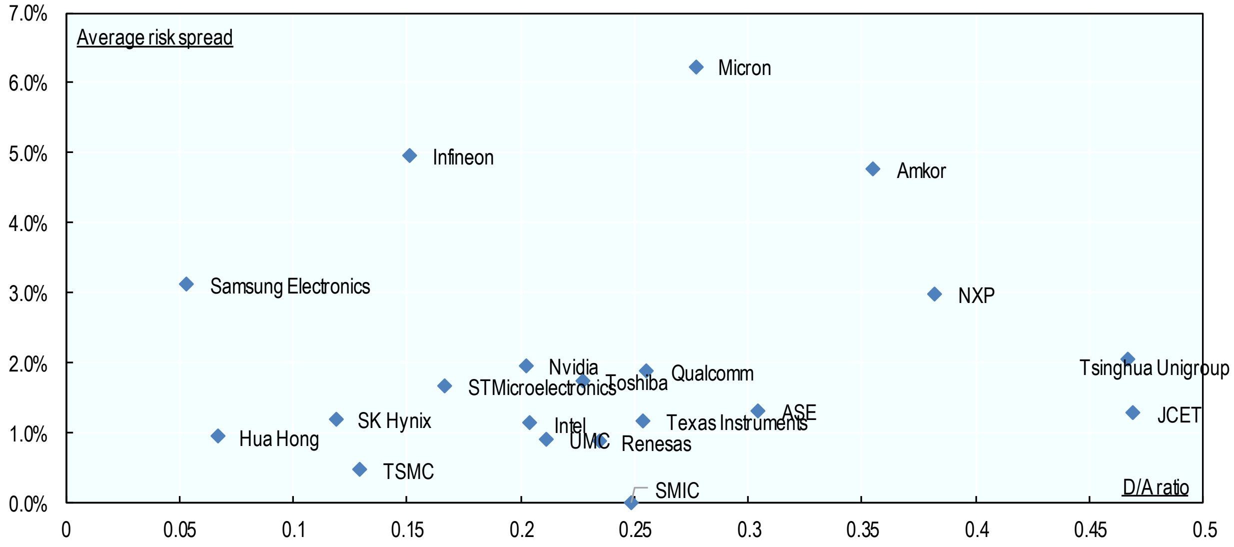
A higher leverage ratio and lower interest coverage can translate into higher risk premia charged on borrowings. Figure 3.5 shows the relationship between firms' D/A ratio and risk premia. Given their higher leverage and their lower interest-coverage ratio, Amkor and NXP, for instance, were on average charged higher risk premia than their semiconductor peers. Both JCET and Tsinghua Unigroup, which similarly displayed signs of higher leverage and lower interest-coverage over the period studied, appear nonetheless to face considerably lower risk premia. In the case of Tsinghua Unigroup, this may have to do with the "long-term relationship" the company maintains with China's policy banks (e.g. China Development Bank) and the 'big four' state-owned banks (e.g. Bank of China and China Construction Bank) (Tsinghua Unigroup, 2015[80]). SMIC has been charged below-benchmark rates on average owing to the large loans it has obtained from the China Development Bank and the Exim Bank of China at rates that vary between 1-3%.[81] Meanwhile, there are also firms in the sample for which risk premia conditional on leverage have exceeded the

81 The People's Bank of China risk-free benchmark lending rate varied between 4-5% over the same period.

average. This concerns notably Micron, but also NXP and Amkor to a lesser extent, and may have to do with these firms relying more on corporate bonds to finance themselves.

Figure 3.5. Some companies have lower risk premia despite weaker financial ratios

Average debt-to-asset ratios and risk spreads over the period 2014-18



Note: Data for Toshiba are for 2013-17.

Source: OECD calculations based on firms' financial statements and the FactSet database.

Methodology

Bearing in mind the positive relationship that exists between interest rates and default risks, the report next attempts to estimate the amount of support attributable to below-market borrowings for all semiconductor firms in the sample. Calculating the support equivalent of below-market borrowings is far from straightforward, however. There is no internationally recognised method for doing so, with practices differing widely (Jones and Steenblik, 2010[85]). Consistent with earlier OECD work on the aluminium value chain (OECD, 2019[1]), this report chooses to compare the actual interest rates charged to firms against a hypothetical benchmark rate of interest that could have been charged in a private market, conditional on borrowers' characteristics.

To do this, the analysis collects information on interest rates charged to semiconductor firms using firms' own financial statements, which indicate the interest rates that companies pay on their borrowings.[82] Calculating the benchmark rate of interest that could have been charged in a private market then requires estimates of risk-free base rates and the additional risk spreads that might be applied on corporate debt. This is done based on the information provided in financial statements, such as firms' actual amount of borrowings, their tenor (short-term and long-term), the currencies in which companies borrow, and their credit ratings, where available. Credit ratings assigned by international rating agencies (Fitch, Moody's, and S&P) provide useful information about firms'

82 Wherever a firm discloses individual interest rates applied on each single loan, or some weighted average of interest rates incurred throughout the year, those rates are taken into account. Where such numbers are not publicly available, the analysis calculates instead implicit interest rates by dividing interest payments in any given year (t) by the average debt outstanding in the same year (t) and the previous year (t-1).

creditworthiness, or their likelihood of default.[83] There is therefore a strong correlation between risk spreads and credit ratings, which one can use to back-out from credit ratings the corresponding spread (OECD, 2018[84]).[84]

Benchmark rates are established by combining two components, namely the risk-free base rate and additional spreads corresponding to different credit-risk levels on corporate debt. Risk-free base rates vary by currency and include: interbank rates (e.g. the London Inter-bank Offered Rate [LIBOR] and the Euro Interbank Offered Rate [Euribor]), which are applied in the case of variable-rate loans; government bond yields for fixed-rate and long-term financing; and other commonly used base rates reflecting country-specific circumstances (e.g. the base rates published by the People's Bank of China [PBOC], which apply in case a loan is denominated in Chinese RMB). In all cases, rates are selected to match the currency and tenor of a weighted-average life of transactions where information is available.

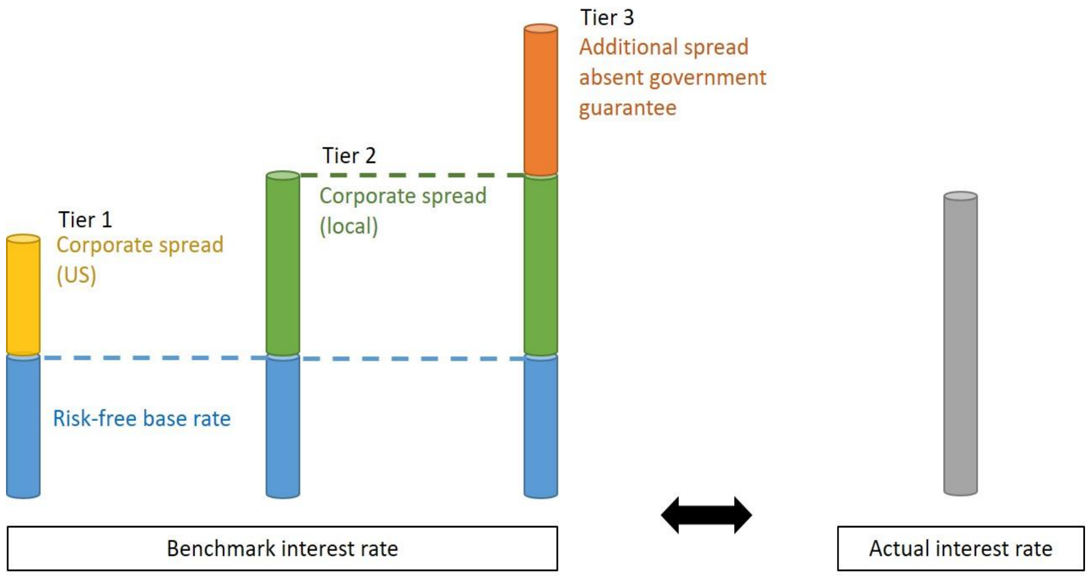
The second component, i.e. risk-adjusted spreads, consists of three tiers that are applied incrementally in the analysis (Figure 3.6). The use of incremental tiers for risk-adjusted spreads is to account for the sensitivity of the results to the assumptions made and for potential data-quality concerns. The three tiers are specified as follows:

- *Tier 1*: These are risk-adjusted spreads that are established based on the average spread to Treasury bond yields of US corporate bonds for a relevant industry (e.g. the electronics technology sector). Spreads are differentiated by credit ratings and maturities (to match the weighted-average life of transactions). In other words, Tier 1 spreads apply uniform risk-adjusted spreads regardless of the currency or location of transactions.
- *Tier 2*: These spreads account for additional factors attributed to local bond markets or practices. For instance, for debts denominated in Chinese RMB, Tier 2 spreads represent the difference between the credit spreads of corporate bonds denominated in Chinese RMB and bonds denominated in the US dollar.
- *Tier 3*: These correspond to the additional spreads that would have otherwise been charged absent government guarantees. Accredited credit-rating agencies usually base their stand-alone credit ratings for firms on their financial performance, before then adjusting the ratings further to account for additional external factors, including ties to the government and expected government support in case of financial distress. Considering such information, Tier 3 spreads represent the increase in interest rate that would occur absent such government support.

83 The use of credit ratings assigned by the largest international rating agencies is also preferable in the Chinese context for reasons explained in recent research by the Bank for International Settlements (Jiang and Packer, 2017[72]).

84 One would ideally use the credit rating that is specific to the project being financed. Absent such information, firms' credit rating or the rating of similar debt instruments can serve as useful proxies.

Figure 3.6. Estimating below-market borrowings: The OECD approach



Results and discussion

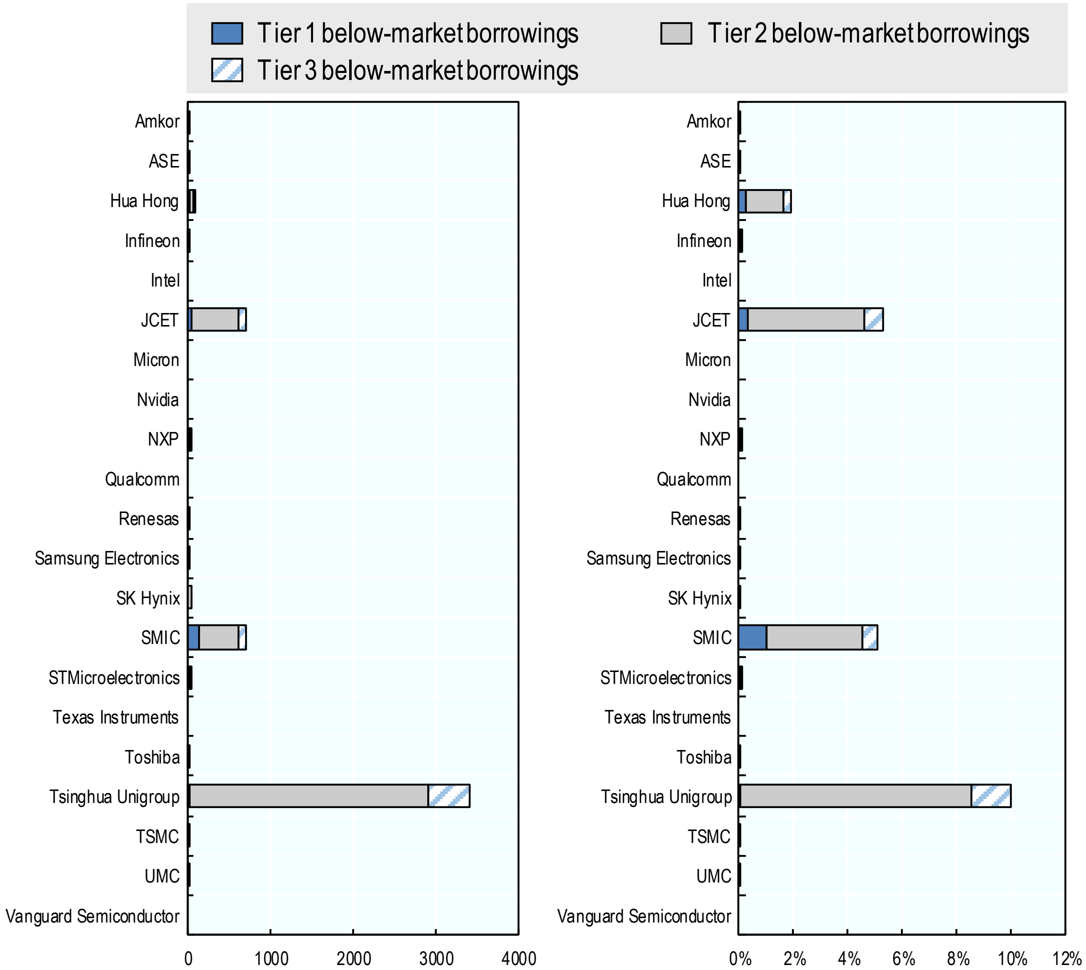
Tier 1 estimates suggest that the benefits conferred through below-market borrowings to the semiconductor firms in the sample amounted to USD 232 million over 2014-18. Tier 2 estimates represented an additional USD 4 billion while Tier 3 estimates added USD 676 million when removing the implicit government guarantee from which certain state-invested firms benefitted (Figure 3.7). Unlike budgetary support that benefitted all firms studied, below-market borrowings concerned only six firms in the period 2014-18. The three largest recipients were Tsinghua Unigroup (USD 3.4 billion), SMIC (USD 695 million), and JCET (USD 688 million), notably for the loans they received from Chinese state banks such as the Bank of China, the China Development Bank, and the China Construction Bank.[85] Hua Hong (USD 71 million) is another firm that obtained support from Chinese state banks, albeit in a lower proportion due to that firm's lower borrowings).

While smaller in volume, the analysis also identified specific instances of loans that were provided through policy-driven banks outside China. Below-market borrowings benefitting SK Hynix (USD 34 million) were mainly related to long-term loans it obtained in the early 2000s from creditor banks, including the Korea Development Bank. STMicroelectronics has received loans from the European Investment Bank (USD 24 million) that are explicitly tied to R&D activities in conformity with the European Union's state-aid rules.

85 In the case of SMIC, the company explicitly mentions in its annual report for 2018 that it benefits from lower interest rates, which are partly recognised as "government funding for specific intended use" in its financials.

Figure 3.7. Below-market borrowings appear concentrated among few firms

Left: Support by firm, 2014-18, USDmn, current
Right: Support by firm, 2014-18, % of firm revenue



Note: Data for Toshiba are for 2013-17.
Source: OECD calculations.

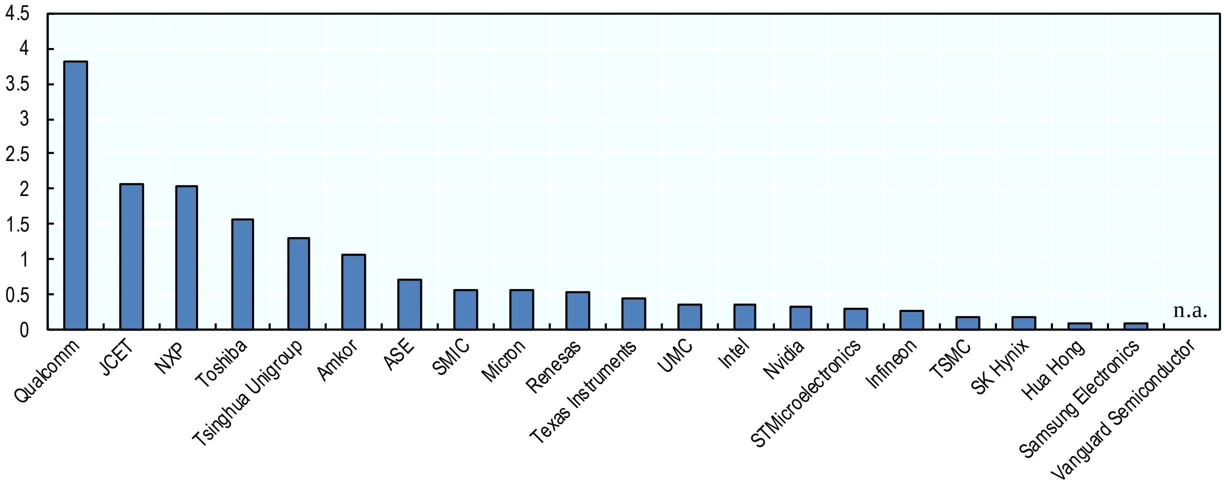
The overwhelming majority of all below-market borrowings that this report has identified over the period 2014-18 originate from the Chinese financial system. This is consistent with China's own 2014 IC Guideline, which instructs "domestic development banks and commercial banks to continually provide financial support to the integrated circuit industry." The results are also in keeping with the economic literature that generally finds Chinese SOEs and politically connected firms to enjoy preferential access to credit at favourable terms (Hsieh, Bai and Song, 2019[76]; Ru, 2018[70]; Harrison et al., 2019[69]; Tan, Huang and Woo, 2016[75]). In the specific context of China's semiconductor industry, low-cost financing from Chinese state banks has been a recurring feature of the country's efforts to build new semiconductor-manufacturing capacity. Tsinghua Unigroup, for example, obtained loans for USD 1 billion from the Exim Bank of China and the China Development Bank in 2014, which were then complemented in 2017 by an additional USD 14 billion from the China Development Bank and a further USD 7 billion committed by the China Construction Bank. These loans were specifically intended to help finance the construction of a memory fab in Wuhan, i.e. Yangtze Memory Technologies Co., Ltd. ("YMTC"). The provision of finance at lower cost is particularly important for semiconductors given the industry's high capital intensity, which usually requires large amounts of debt and equity capital to be raised from investors.

3.3.2. Provision of below-market equity

Debt is not the only way for companies to finance their activities. In fact, nearly three-quarters of the 21 semiconductor firms in the sample appear to have relied more heavily on equity as a source of finance, judging by their debt-to-equity ratios (Figure 3.8).As with debt finance, equity finance need not be an issue for competition where it stems from the normal operation of market forces. Equity finance becomes a problem, however, where it involves governments injecting capital into firms that the market would not deem worthy of equity investment given the expected level of returns. Below-market equity is in that sense not a question of government ownership strictly speaking, but more one of how governments behave as investors and shareholders. This echoes the discussion above in Section 2.4, where it was noted that state ownership is not in itself a problem for competition, but can become one where it serves to confer undue support and advantages to local firms.

Figure 3.8. Most firms in the sample finance themselves through equity

Average debt-to-equity ratio over the period 2014-18



Note: Vanguard Semiconductor had no debt over the period studied. Qualcomm's higher debt-to-equity ratio comes predominantly from the large share buybacks that the company undertook over the period. Data for Toshiba are for 2013-17.
Source: OECD calculations based on firms' financial statements and the FactSet database.

Government provision of equity finance to the semiconductor industry appears to be largely a Chinese phenomenon, and one that has intensified in recent times. One reason is China's unique reliance on equity funding as the country's main instrument for supporting R&D (OECD, 2014[12]). Another is the sheer size of the semiconductor funds that China has established starting in 2014 (see discussion in Section 2.4). Taken together, China's National IC Fund and its sister funds at the provincial and municipal levels envisage investing more than USD 100 billion into Chinese semiconductor firms by 2020 (Credit Suisse, 2017[42]). This amount is aspirational, however. For the four Chinese firms covered by this study (Hua Hong Semiconductor, JCET, SMIC, Tsinghua Unigroup), government funds have committed equity funding of about USD 22 billion in total to date, with the largest share benefitting SMIC and Tsinghua Unigroup, and their subsidiaries.

Looking only at China's National IC Fund, these four firms have together attracted equity funding of about USD 10 billion, which represents slightly less than half of the National IC Fund's first round of funding (roughly USD 23 billion).

Given the scale at which Chinese authorities are investing in domestic semiconductor firms, the question arises as to whether these equity infusions proceed from a "market-oriented operation" as stated in China's 2014 *Guideline for the Promotion of the Development of the National Integrated Circuit Industry*. In other words, do these investments obey a market logic, whereby government funds act as regular investors seeking to share in the risks and rewards of market-driven semiconductor firms, or do they reflect a disguised form of government support aiming to promote actively the consolidation and development of the local semiconductor industry? On the one hand, China asserts in the 2014 *Guideline* that it intends to "make full use of market mechanisms in their role of guiding and promoting integrated circuit industry mergers and regroupings." The WTO's seventh *Trade Policy Review of China* likewise notes that "the authorities state that the [National IC] Fund is a private equity fund, and the goal of the Fund is to deliver profits for shareholders; investment decisions are accountable to shareholders" (WTO, 2018[86]).

Other statements by Chinese authorities, however, give rise to questions about the extent to which the National IC Fund's investment decisions are market-based.[86] The Ministry of Finance, for example, stated in September 2015 that the fund "takes into account the government's guidance of industrial development and the commercial interests of private investors."[87] In addition, some experts such as Ernst (2015[3]) argue that China's new semiconductor policy (including the National IC Fund) "resorts to investment rather than subsidy as the tool of industrial policy", possibly in an attempt "to avoid being accused of violating WTO anti-subsidy agreements." Noble (2018[87]) adds that "market discipline on [China's] guidance funds is weak, as they […] are subject to heavy government intervention in their operations." The considerable opacity that surrounds the National IC Fund's operations further complicates efforts to determine whether its investments are consistent with market principles.

Whichever view is correct, there appears to be a direct connection between equity injections by China's government funds and the construction of new semiconductor foundries or 'fabs' in the country (Box 3.1). Hua Hong Semiconductor states, for example, in its annual report for the year 2018 that "the proceeds from subscription shares approximately USD 400 000 000 […] were invested into HH-Wuxi for the setup of 300mm production line", and that these funds were additional to "USD 565.0 million of equity injection to HH-Wuxi." Both capital injections were made by China's National IC Fund in support of the construction of Hua Hong's new fab venture in Wuxi (Jiangsu). They also came on top of equity provided by the local Wuxi government (USD 360 million).

Government equity has also at times been injected to support the acquisition of foreign semiconductor firms by Chinese companies. This was the case in October 2015 when OSAT company JCET obtained USD 390 million from both China's National IC Fund and SMIC – which itself also received equity funding from the National IC Fund – in order to finance its USD 780 million acquisition of Singaporean OSAT company STATSChipPAC.

[86] As already mentioned in Section 2.3, the National IC Fund is majority owned by China's Ministry of Finance and large state enterprises, including the China Development Bank.

[87] See www.gov.cn/xinwen/2015-09/11/content_2929586.htm (in Mandarin Chinese, accessed on 3 October 2019).

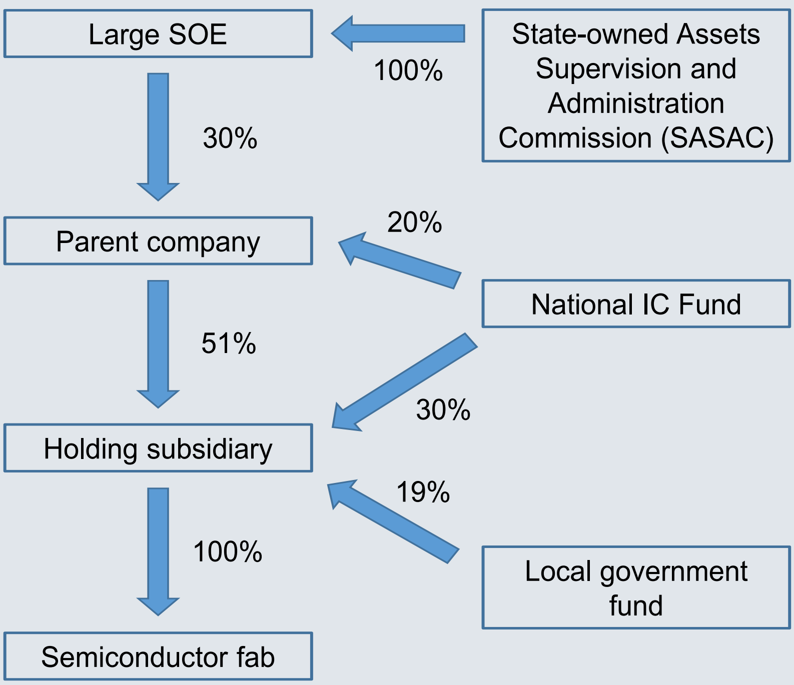
Box 3.1. Equity injections by government funds and the construction of new semiconductor fabs in China

Semiconductor foundries or 'fabs' are highly capital-intensive ventures, with state-of-the-art facilities (e.g. using 5 nm process nodes) costing more than USD 20 billion each. More than half of all capital expenditure for fabs goes into semiconductor manufacturing equipment, while the remainder serves to acquire land, facilities, etc. Other production costs include operating expenses such as labour and utilities and intermediate inputs like silicon wafers, chemicals, specialty gases, and maintenance.

The Chinese Government has since 2014 played a decisive role in co-financing through equity injections the construction of new semiconductor fabs in the country. This usually happens through complex ownership structures that involve local and central government funds as well as certain SOEs (Figure 3.9). Some industry participants estimate that government-financed fabs in China could number 60 or more by 2023. If accurate, this would more than double China's semiconductor-manufacturing capacity. Prominent examples that involve companies in the sample include:

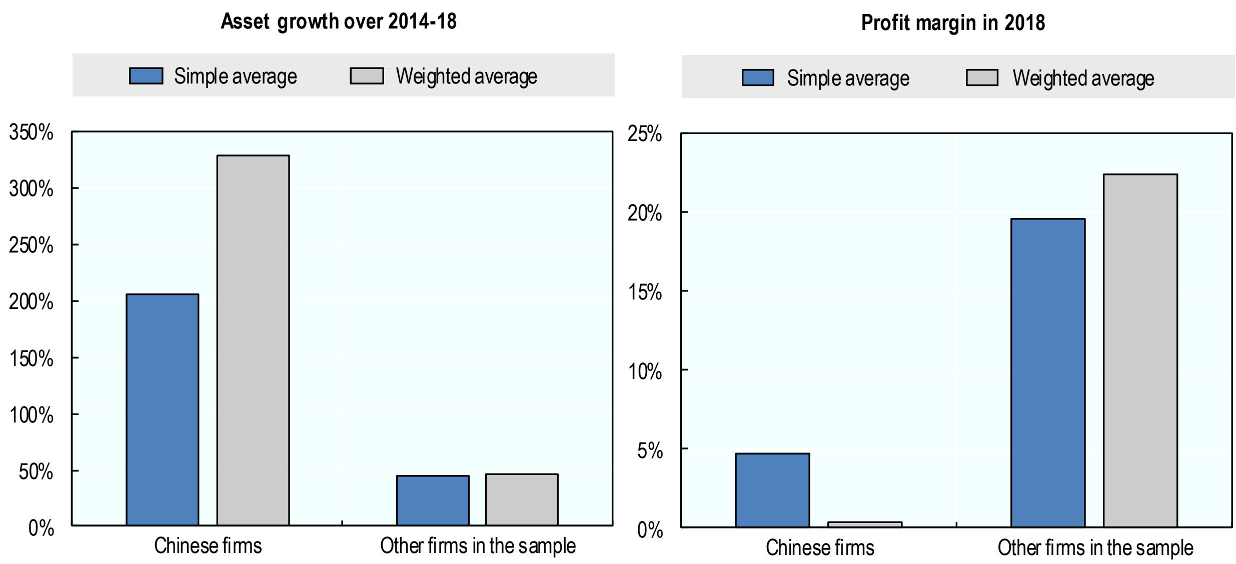
- Yangtze Memory Technologies Co., Ltd. ("YMTC"): a memory fab specialised in 3D-NAND chips and located in Wuhan, Hubei. The investment, which amounts so far to USD 7.5 billion, was announced in 2016 and has already benefitted from a USD 1.35 billion injection from China's National IC Fund and additional equity (USD 667 million) provided by the local Hubei IC Fund, which exclusively supports YMTC. Government equity in the project totals 74%. It is managed by Tsinghua Unigroup, YMTC's ultimate parent.
- SMIC North: a logic fab located in Beijing that was completed in 2018. The investment, which may amount to USD 7 billion in total, has already benefitted from a USD 1.5 billion injection from China's National IC Fund and additional equity (USD 432 million) provided by the local Beijing IC Manufacturing Fund. Government equity in the project exceeds 57%. It is managed by SMIC, SMIC North's parent.
- Shanghai Huali: a logic fab located in Shanghai that is nearing completion. The investment, which may amount to USD 5.9 billion in total, has already benefitted from a USD 1.8 billion injection from China's National IC Fund and additional equity (USD 316 million) provided by the Shanghai IC Manufacturing Fund. Government equity in the project exceeds 95% since Shanghai Huali's parents are the Shanghai SASAC and the state-owned Hua Hong group.

Figure 3.9. Stylised ownership structure of new semiconductor fabs in China, % of shares



Government equity injections have had discernible effects on the financial performance of the Chinese semiconductor producers studied here. Large investments in the construction of new fabs have notably translated into steep increases in the book value of firms' assets, which are yet unmatched by any corresponding increases in profitability (Figure 3.10). Not only has the profitability of Chinese semiconductor firms stagnated or decreased in most cases, but it has also remained consistently below the profitability of firms operating elsewhere (in Europe, Japan, Korea, Chinese Taipei, and the United States). There are only two exceptions in the sample: Hua Hong appears to have performed better than its Chinese peers and a few non-Chinese firms, while European firm STMicroelectronics has had profit margins in the low single digits that are below those reported by other non-Chinese firms.[88] It is possible that the lower profitability of Chinese semiconductor firms is due partly to a multi-year lag between increases in asset value and higher profits. The discussion above has shown nevertheless that recent Chinese semiconductor investments are the direct result of government intervention, which raises concerns that these investments may not have been undertaken for purely commercial reasons.

Figure 3.10. Government equity injections in China have translated into steep increases in firms' assets but profits remain relatively low



Note: Data for Toshiba are for 2013-17. Weights are based on 2018 asset value (left) and revenue (right).
Source: OECD calculations based on corporate financials.

Determining empirically whether the state is acting like a regular private investor or shareholder is a difficult exercise. Where the state does not invest consistently with market principles, or where there is limited transparency or public or institutional oversight of such investments, quantifying the support that this generates is even more challenging. Article 14(a) of the WTO's Subsidies and Countervailing Measures (SCM) agreement – which stipulates the methods for calculating the "benefit" conferred to the recipient – states that "government provision of equity capital shall not be considered as conferring a benefit, unless the investment decision can be regarded as inconsistent with the usual investment practice (including for the provision of risk capital) of private investors."

88 Toshiba's losses over the period were entirely due to non-semiconductor-related activities (e.g. nuclear power generation).

Yet WTO cases that might serve as precedent in this matter are few, with one such case noting that "Article 14(a) of the SCM Agreement does not provide a precise method for calculating benefit."[89]

The use of companies' stock prices as market benchmarks for estimating the support conferred through equity injections is problematic too, as not all semiconductor firms are publicly listed (e.g. Tsinghua Unigroup). That said, even where they are, the limited available evidence suggests that there does not appear to be a significant difference between prices observed on the stock exchange and what governments paid for acquiring shares in semiconductor firms.[90] Adding to this is the likelihood that stock prices reflect investors' expectations of future government assistance in cases where policy announcements signal that authorities regard a sector favourably. There have also been instances of governments intervening in the stock exchange to support the value of stocks, which may invalidate the use of market prices as benchmark. More generally, there does not seem to be a clear consensus among countries on how best to estimate the benefit or support conferred through equity injections. These difficulties notwithstanding, the remainder of this section offers one possible way of estimating the support conferred through below-market equity, before then applying this method to government-invested firms covered by this study.

Methodology

To quantify government support conferred through the provision of below-market equity to semiconductor firms, the OECD has worked in collaboration with Professor Deborah Lucas, Director of the Golub Center for Finance and Policy at the Massachusetts Institute of Technology (MIT). The methodological discussion that follows borrows heavily from Professor Lucas's own work, as reflected in Lucas (2014[88]) and other forthcoming papers, as well as from exchanges the OECD Secretariat has had with Professor Lucas over the past year.

The approach used here departs in important ways from earlier attempts to estimate the support conferred through equity injections in a trade context. For one, the approach relies on an *ex post* assessment of the financial returns of government investments rather than on an *ex ante* determination of whether such investments were consistent with market behaviour at the time they were made. In a 2011 WTO case, the Appellate Body noted that "Article 14(a) [of the SCM] focuses the inquiry on the 'investment decision'. This reflects an *ex ante* approach to assessing the equity investment by comparing the decision, based on the costs and expected returns of the transaction, to the usual investment practice of private investors at the moment the decision to invest is undertaken."[91] Instead of trying to predict the expected future returns of the transaction at the time the investment is made, this report chooses to look at the observed financial performance of government-invested firms for a period of several years following the transaction. While both

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89 Panel Report, *European Communities — Countervailing Measures on Dynamic Random Access Memory Chips from Korea*, para. 7.211, WT/DS299/R (17 June 2005).

90 When Hua Hong entered into a Subscription Agreement with China's National IC Fund on 3 January 2018 to issue new shares worth HKD 12.90, the market price of existing shares was HKD 15.84 on that day and HKD 16.04 on the previous day. One day before the subscription took place on 7 November 2018, shares traded at HKD 14.98. At the time of the first Share Purchase Agreement between SMIC and China's National IC Fund on 12 February 2015, shares traded around HKD 0.7, while the agreed subscription price was HKD 0.6593. In the weeks before the new shares were issued on 8 June 2015, SMIC's shares traded above HKD 0.8.

91 Appellate Body Report, *European Communities and Certain member States — Measures Affecting Trade in Large Civil Aircraft*, para. 999, WT/DS316/AB/R (18 May 2011).

approaches are valid, they measure different things and have different policy implications as explained later in the report.

Another important difference is that the approach used in this report does not focus on equity injections themselves as one-off, discrete events. Instead, given its focus on quantifying government support, this report seeks to assess the recurring benefits that equity injections and government investments more generally can confer to semiconductor firms over time. These benefits take the form of financing costs that are below the cost of capital wherever government-invested firms fail to generate a fair return[92] on equity for taxpayers in addition to covering their interest costs. This stems from the basic notion that a company's cost of capital is a weighted average of the cost of its debt and the cost of its equity, and that taxpayers and the general public are the ultimate equity holders of government investments. As with below-market borrowings, measurement here relies on a comparison between a firm's actual financial returns and the estimated full cost of capital that private semiconductor firms face in financial markets.

Judgment and a number of assumptions are unavoidably necessary for estimating the full cost of capital that private semiconductor firms face in the market. This is because the financial statements of firms do not provide all the requisite information for calculating their full cost of capital: "they treat interest payments on borrowed funds as an expense, but make no mention of the required return to equity capital" (Lucas, 2014[88]). In what follows, the calculation of the benchmark cost of capital is based on the capital asset pricing model (CAPM). The CAPM is a workhorse of financial economics, having been used widely for decades for estimating the cost of capital for firms (Fama and French, 2004[89]). At the heart of the basic model is the relationship between returns and risk. Although the model performs poorly in predictive terms (ibid.)[93], it provides a reasonable approximation for what market participants might view as an adequate return on capital. It has been used, for example, by regulators for setting utility rates, and remains used today by the Government of Norway for setting the required rate of return it expects its own SOEs to achieve.[94] At a minimum, using the CAPM as benchmark helps avoid the trappings of subjective valuations and *ad hoc* asset-pricing models. In that sense, the CAPM provides a transparent, simple, and replicable formula for calculating firms' cost of capital. In the words of Professor Aswath Damodaran from the Stern School of Business at New York University, CAPM "works as well as the next best alternative in most cases."[95]

The basic formula for calculating the benchmark cost of capital is as follows:

$$RRR = r_f + (\beta \times ERP)$$

RRR is the required rate of return on assets, r_f is a risk-free rate, β is the asset beta for the global semiconductor industry (i.e. a measure of the correlation between semiconductor stocks and the

[92] This refers to the financial concept of 'fair value'. The fair value of an asset represents the price that would be paid for that asset under competitive market conditions (excluding forced liquidation and fire sales).

[93] One critique of the model is that it assumes an overly steep relationship between firm-level betas (a measure of risk) and average returns. This problem does not affect our results significantly since we rely on the same industry-wide asset beta for all 21 firms in the sample. Section 3.4 on caveats, limitations, and data gaps discusses briefly possible alternatives to the CAPM.

[94] See www.regjeringen.no/globalassets/upload/nhd/statenseierberetning/pdf/engelsk/the_governments_ownership_policy_2008.pdf (accessed on 16 September 2019).

[95] See Professor Damodaran's teaching material at http://pages.stern.nyu.edu/~adamodar/ (accessed on 28 August 2019).

overall market)[96], and *ERP* is the overall equity risk premium, i.e. the premium investors receive for holding equity as opposed to risk-free assets. Risk-free rates are proxied using the yield on one-year government bonds. Semiconductor asset betas were obtained from the website of Professor Aswath Damodaran at the Stern School of Business, New York University. They are averaged globally and are based on a large sample of listed semiconductor firms extending beyond the 21 companies studied in this report. Finally, the analysis assumes a central value of 6.5% per annum for the equity risk premium in line with the existing literature, with a range of ± 1 percentage point (Lucas, 2014[88]; Jordà, Schularick and Taylor, 2019[90]; Fernandez, 2019[91]).

Using the required rate of return estimated above, the analysis then proceeds to calculate monetary equivalents of below-market equity returns for all 21 firms in the sample. Although below-market equity returns are only a potential concern for competition where governments are investors in companies, this report looks consistently for evidence of below-market equity returns in all 21 firms in the sample regardless of their ownership structure. This enables the analysis to assess empirically the validity of the benchmark cost of capital in the context of all firms covered by the study. The implications of below-market equity returns are different, however, for firms in which governments have significant stakes. Whereas the market price of equity in a private firm will fall when private shareholders sell shares in anticipation of a below-market rate of return, government-invested firms could in principle benefit from prolonged leniency of their state shareholders where the latter do not act in a manner consistent with market principles. Should below-market equity returns be more persistent and frequent in government-invested firms, then this could indicate that these firms have obtained support from state investors in the form of financing costs that are on average below their full cost of capital.

The calculation for annual monetary equivalents of below-market equity is performed for each firm as follows:

$$BME_{i,t} = \left(RRR_t \times 0.5\left(assets_{i,t} + assets_{i,t-1}\right)\right) - BMB_{i,t} - profit_{i,t}$$

$BME_{i,t}$ is the annual monetary equivalent of the below-market equity return for firm *i* in year *t* (‘below-market equity’ for short), *RRR* is the required rate of return calculated as above for every year, *assets* is the book value of firm *i*’s assets in year *t*, *profit* stands for firm *i*’s net operating profit after tax in year *t*, and $BMB_{i,t}$ is below-market borrowings for firm *i* in year *t* as estimated earlier in this report. The first term ($RRR \times assets$) corresponds to the benchmark cost of capital in monetary terms. The required return to equity holders is obtained by deducting below-market borrowings (*BMB*) and actual interest payments (a part of net operating profit after tax) from the first term ($RRR \times assets$). Profits are the portion of firm earnings that accrue to equity holders. When profits on average fall short of the required return to equity holders, the firm has incurred financing costs that are below its cost of capital. Where that difference is negative on average, the firm has instead delivered returns in excess of its cost of equity.

The sum of below-market equity, below market borrowings, and budgetary support together represents total government support. Grants and tax concessions increase after-tax profit, and they are partially returned to the government through retained earnings or dividends. Summing the three components thus correctly accounts for that netting effect.

96 Formally defined as the covariance between semiconductor stock returns and overall market returns divided by the variance of overall market returns. Using the asset beta (or unlevered beta) instead of the equity beta corrects for the effects that leverage has on the capital structure of firms and corresponding variations in financial risk. The risk that remains is essentially a business risk associated with a company’s assets, which results in a lower asset beta than the equity beta for a firm with debt.

The calculation above is performed every year for each firm and aggregated over the period 2014-18 to be consistent with other support estimates presented in this report. Aggregating over five years also helps address the volatility of realised profits. A firm may perform unusually badly or well in a given year due to unforeseen market circumstances (e.g. sudden falls or increases in the price of semiconductors). The numbers shown and discussed in the remainder of this section are therefore obtained as follows:

$$BME_{i,.} = \sum_{t=2014}^{2018} BME_{i,t}$$

Just as below-market borrowings are divided into three incremental tiers, the analysis seeks to account for the imprecision of some of the parameters by dividing below-market equity into three incremental sets of estimates: a low estimate, a middle estimate, and a high estimate. Each set of estimates is characterised by different parameter values used in calculating the required rate of return, with the medium estimate serving as the central value used for the purposes of this report. Table 3.3 shows how parameters vary in the three different sets of estimates.

Table 3.3. Each set of estimates for below-market equity is characterised by different parameter values

	Risk-free rate (r_f)	Semiconductor asset beta (β)	Equity risk premium (ERP)
High estimate	1-year local government bond	Global average	7.50%
Middle estimate	1-year local government bond	Global average	6.50%
Low estimate	1-year US Treasury bond *	Global average	5.50%

Note: * The yield on 1-year US Treasury bonds is only used for the low estimate in cases where local government bonds have higher yields than US Treasury yields.

Results and discussion

Although volatility in profits tends to be the norm in markets, applying the method described above to all firms in the sample reveals important differences in the extent to which the companies studied have earned enough profit to cover their full cost of capital (Table 3.4). Some companies such as Infineon, Intel, Nvidia, Texas Instruments, and TSMC appear to have consistently obtained returns that exceeded their full cost of capital in all years between 2014 and 2018. Several others have achieved high-enough returns throughout the period, with the exception of one bad year during which profits fell or stagnated in the face of adverse business developments, causing one isolated bout of below-market equity returns. This concerns private companies such as Micron, NXP, or SK Hynix.

Results for all other firms in the sample indicate the presence of below-market equity returns for at least two years out of the five years covered by this study. These firms include, notably, all three OSAT companies in the sample (Amkor, ASE, and JCET), which might be due to that segment's thinner margins compared with other parts of the semiconductor value chain. This could suggest that the benchmark cost of capital ought to be adjusted in the particular case of OSAT firms (e.g. a different asset beta). The particular cases of Qualcomm, Samsung Electronics, and Toshiba – all private firms – deserve, meanwhile, more explanation:

- In Qualcomm's case, estimates of below-market equity arose mainly in 2018, during which year Qualcomm's revenue was negatively affected by a dispute over licensing practices with Apple, which has historically been the firm's largest customer.
- Samsung Electronics failed for two consecutive years (2015-16) to achieve high-enough returns due to low operating profits in business segments such as consumer electronics (e.g. digital TVs) and display panels (e.g. LCD screens). The company's semiconductor

segment was, however, the most profitable, contributing more than proportionally to the group's overall net income.

- Toshiba incurred unprecedentedly large losses that were not semiconductor-related, stemming instead from its nuclear-power business segment (Westinghouse).[97] As a result, Toshiba underwent months of negotiations and restructuring and eventually sold its lucrative memory-chip unit to a consortium led by Bain Capital Private Equity in 2018.

With the exception of Renesas, the firms that remain all feature persistent below-market equity returns over the period 2014-18. They are also all government-invested apart from UMC.[98]

Table 3.4. There are important differences in the extent to which firms in the sample have earned enough profit to cover their full cost of capital

Red indicates the presence of below-market equity returns for that year under the parameter values for the middle estimate

Firms	2018	2017	2016	2015	2014
Amkor	■	■	■	■	■
ASE	■	■	■	■	■
Hua Hong	■	■	■	■	■
Infineon					
Intel					
JCET	■	■	■	■	■
Micron			■		
Nvidia					
NXP			■		
Qualcomm	■	■			
Renesas	■		■		
Samsung Electronics*			■	■	
SK Hynix			■		
SMIC	■	■	■	■	■
STMicroelectronics		■	■	■	■
Texas Instruments					
Toshiba*	■	■	■	■	■
Tsinghua Unigroup	■	■	■	■	■
TSMC					
UMC	■	■	■	■	■
Vanguard Semiconductor					

Note: Estimates of below-market equity that represent less than 1% of firm revenue are treated in this table as rounding errors and ignored given the assumptions used and the imprecision of some parameter values. Data for Toshiba are for the period 2013-17. * Most reported below-market equity returns for Toshiba and Samsung Electronics arises from non-semiconductor-related activities (e.g. nuclear power generation for Toshiba).
Source: OECD calculations.

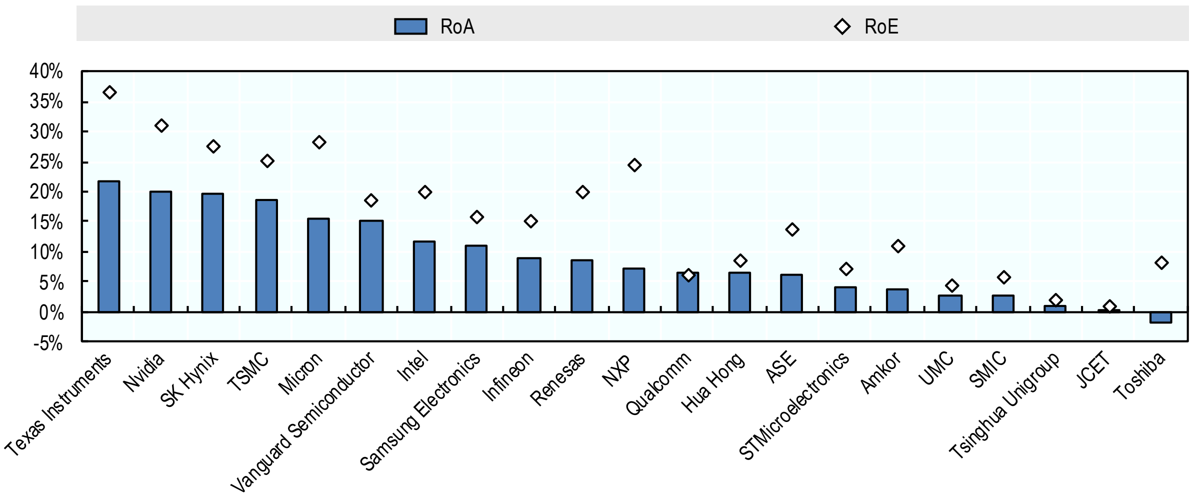
97 As indicated earlier in Section 3.1, as much as 92% of Toshiba's net income for FY2016/17 came from semiconductor-related activities, which indicates that semiconductors were the only sizable source of profits for the company.

98 The analysis is unable to explain why UMC, a private contract foundry, failed to achieve returns that are high enough to meet its full cost of capital. This contrasts with other contract foundries from Chinese Taipei (TSMC and Vanguard Semiconductor) that display above-average returns.

The results in Table 3.4 reflect the fact that those firms in the sample in which governments have invested as shareholders generally tend to have lower returns on assets (Figure 3.11). Save for privately owned Toshiba, three of the four firms that have the lowest RoA in the sample are Chinese government-invested firms. This result is consistent with other studies that have found Chinese SOEs to have consistently lower returns than their private counterparts (Harrison et al., 2019[69]; Song, 2018[74]; Rosen, Leutert and Guo, 2018[79]), which also suggests that the low profitability of the Chinese companies in the sample is not solely the result of their recent large investments in new fabs. The finding that state enterprises exhibit a lower performance on average is not limited to China, however. The OECD's latest *Business and Finance Outlook* likewise notes that SOEs have lower profitability than private firms in most of the countries analysed (OECD, 2019[92]).[99]

Figure 3.11. Government-invested firms in the sample tend to have lower RoA and RoE than their peers

Average return on assets (RoA) and return on equity (RoE) over the period 2014-18



Note: Data for Toshiba are for 2013-17.
Source: OECD calculations based on corporate financials.

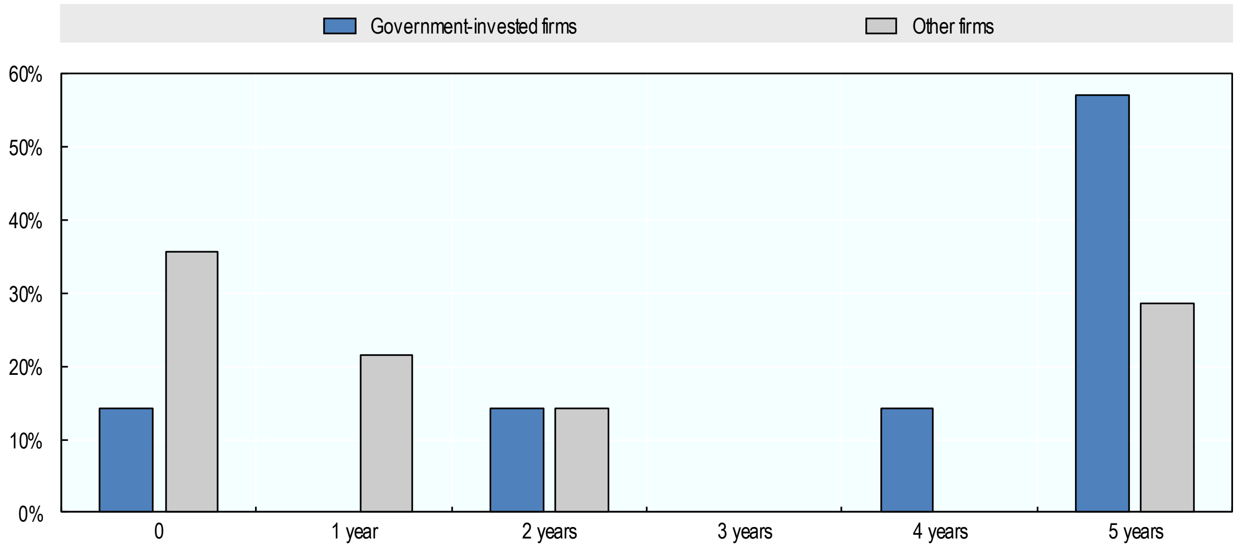
While this report finds occurrences of below-market equity returns for both government-invested firms and private firms, the two cases have fundamentally different implications for competition. Below-market equity cannot rightfully be considered government support in the case of fully private firms, given the absence of any government intervention through the equity channel. Although private firms also experience below-market equity returns (albeit to a lesser extent, and possibly reflecting normal volatility in profits), the 'support' thus conferred does not come from government authorities, but instead from private market participants that may be willing to earn below-market returns now in the expectation that they will earn significant returns in the future.

[99] The countries analysed include China, Hungary, Indonesia, Lithuania, Malaysia, the Russian Federation, Saudi Arabia, Slovenia, and Viet Nam.

Importantly, the analysis shows below-market equity returns to be considerably more persistent and frequent in the case of government-invested firms (Figure 3.12).[100] This suggests that one important difference between government-invested firms and private ones lies in the behaviour of their shareholders as regards investment decisions. Private investors might be willing to forego a fair return on assets for a few years if they expect to be compensated later in the form of higher returns. Alternatively, investors could sell shares that they think will generate below-market returns, driving down the price until the expected return is commensurate with the risk. NXP, for instance, performed poorly in 2016 after it acquired Freescale Semiconductor, but the company quickly resumed higher returns in the following years. The same consideration applies where companies face unexpected market developments that affect their performance (e.g. Qualcomm). The finding that private firms sometimes earn below-market returns does not invalidate the approach used in this report, but rather reflects the difficulty of predicting profits. Government equity holders, on the other hand, may forego fair returns in the pursuit of non-market, policy objectives. The persistence of below-market equity returns over the period 2014-18 in the case of government-invested firms therefore provides some useful indication that governments are behaving differently than private investors.

Figure 3.12. Below-market equity returns are more frequent and persistent for government-invested firms

Number of years for which results indicate below-market equity returns, % of firms



Note: The graph above refers to below-market equity returns calculated using the parameter values corresponding to the middle estimate. Government-invested firms in the sample include (in alphabetical order): Hua Hong, JCET, Renesas, SMIC, STMicroelectronics, Tsinghua Unigroup, and Vanguard Semiconductor. Private firms that have not had high-enough returns for all five years considered are Toshiba, UMC, and two OSAT companies (Amkor and ASE). Data for Toshiba are for 2013-17.
Source: OECD calculations.

[100] The contrast is especially strong once it is recognised that private firms in the sample for which the analysis finds more frequent or persistent below-market equity include Qualcomm, Samsung, and Toshiba. As explained earlier, below-market equity for these firms stems from either one-off business events (e.g. Qualcomm) or a weaker performance in non-semiconductor-related segments. Interestingly, the only government-invested firm that did not benefit from below-market equity, Vanguard International Semiconductors, also had a comparatively small share of government shareholding at around 17%.

While there are known instances of private investors choosing to forego fair returns on their investments for extended periods of time ('patient capital'), this generally does not concern large and mature firms that produce semiconductors. Venture capitalists and other investors often acquire stakes in loss-making companies that would most certainly fail the CAPM test (e.g. Uber, Tesla, Lyft, and WeWork have all sustained large losses over the past years). These cases, however, are not the subject of this report since they do not stem from government action. The recipients of these investments also tend to be young firms in their growth phase that could later prove to be successful financial bets. By contrast, government-invested semiconductor firms are usually mature companies that use well-proven technologies, including some that are behind competitors as measured by process nodes (Box 2.3). The payback time for investors is also different as foundries typically enter production in their third year after construction began, with profits expected soon after.

The discussion above has shown that government investors in semiconductor firms are often more willing to accept persistently lower returns than private investors. This therefore suggests that the companies in question might have benefitted from government support in the form of a lower cost of equity. For this reason, the remainder of this section looks in more depth at those firms in the sample that are government-invested. This includes the following firms: Hua Hong (China), JCET (China), Renesas (Japan), SMIC (China), STMicroelectronics (Europe[101]), Tsinghua Unigroup (China), and Vanguard Semiconductor (Chinese Taipei). While none of these firms is fully government owned, state investors generally possess the largest proportion of shares[102], thereby potentially giving them significant influence over corporate decision-making. In that sense, a company does not need to be fully owned by the state for it to benefit from government support in the form of below-market equity.

All of the Chinese companies in the sample benefitted from below-market equity, and they did so in every single year between 2014 and 2018 (Table 3.4). This suggests that past investments by China's National IC Fund and other local funds have not yet delivered fair returns for their government investors, which implies significant support for recipient companies. Tsinghua Unigroup, for example, indicates on its webpage that the China IC Investment Fund has continuously supported Tsinghua Unigroup's development since the fund's inception in 2014.[103] Growing restrictions placed on the autonomy of local governments in China to provide budgetary support and loans to local companies have also been said to have spurred the recent proliferation of sub-national "government guidance funds" in semiconductors (Noble, 2018[87]). These could arguably provide an alternative means for serving other objectives such as local employment and regional development through investment decisions by these funds.

Because it often conflates financial as well as policy objectives, the conflicting incentive structure of government-invested firms can prevent them from earning a fair return on assets (Rosen, Leutert and Guo, 2018[79]; Harrison et al., 2019[69]; Noble, 2018[87]). This may not be problematic for trade where this arises because such firms provide essential public goods and other non-commercial services (e.g. certain local utilities), but it does raise trade concerns where these firms operate in internationally competitive markets like semiconductors. In this case, the lower returns put these

101 The company is headquartered in Switzerland, but state investors are from France and Italy.

102 This can be stakes that are below the 50% ownership threshold.

103 See www.unigroup.com.cn/newscenter/jtxw/2018/0913/370.html (in Mandarin Chinese, accessed 6 September 2019). Other company sources state that "[t]he Ministry of Finance […] provides continuous support to Tsinghua Holdings", the parent company of Tsinghua Unigroup (Tsinghua Unigroup, 2015[80]).

firms at a competitive advantage by exempting them from having to meet their full cost of capital, thus relaxing the market discipline that otherwise constrains their competitors. This can in turn enable these firms to invest more than market conditions would normally warrant, be it in new semiconductor fabs or R&D projects. As documented above (Box 3.1), there is a direct connection between some of the equity that Chinese authorities have injected in domestic semiconductor firms and the construction of new semiconductor fabs by these same firms. This therefore suggests that the decision to invest was likely influenced by government action and that the investments might not have proceeded absent government equity injections, in particular given their poor profitability to date.[104]

Crucially, the government-invested firms in the sample cannot be considered young firms in need of upfront capital. All of them are mature companies that are past their growth phase, having already reached an important size in terms of assets and revenue. Hua Hong has its roots in China's semiconductor plans of the 1990s.[105] Tsinghua Unigroup (Ziguang) was created in the late 1980s as an IT conglomerate before it acquired semiconductor assets in 2013. The creation of JCET goes back to the 1970s. SMIC was established in 2000 as a contract foundry. Renesas has existed since 2003 as a joint venture between Hitachi and Mitsubishi Electric, before government-owned INCJ became the company's largest shareholder. STMicroelectronics was established in 1987 through the merger of France's Thomson Semiconducteurs and Italy's SGS Microelettronica.

Government support conferred through below-market equity reached between USD 5-15 billion, depending on the assumptions made, for six of the seven firms in the sample that are government invested (Figure 3.13).[106] This amount of support is additional to that received through other channels, namely budgetary support and below-market borrowings. Counting together below-market borrowings and below-market equity, support provided through the financial system appears to be an important source of government support in semiconductors (Figure 3.14). Support provided through the financial system represented between 70%-80% of all the support received by government-invested firms in the sample (under the low and high estimate, respectively), while accounting for 22%-35% of total support when looking at the complete firm sample, private firms included (budgetary support makes up the rest).

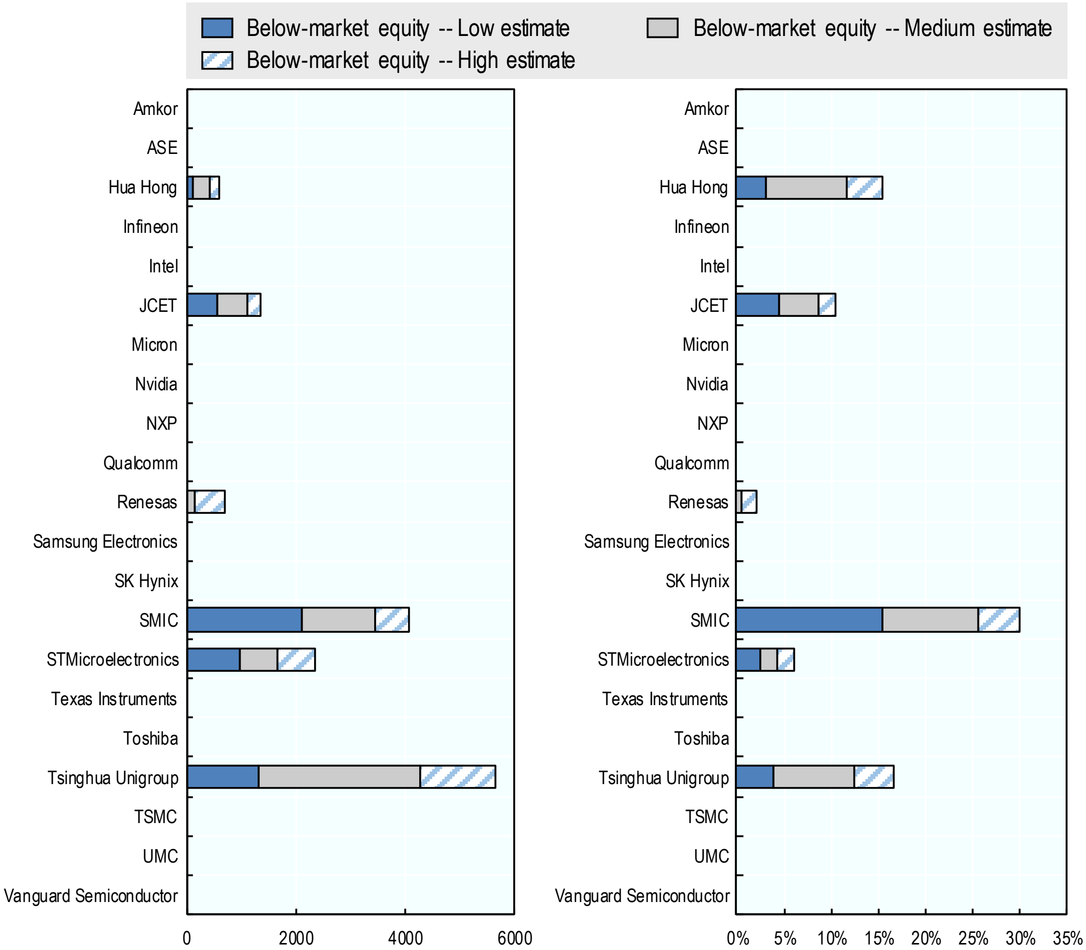
104 Noble (2018[87]) notes that the typical time horizon of government guidance funds in China is between seven and ten years. Some of the government investments analysed in this report took place as early as 2014 and have yet to yield above-average returns to compensate for the lack of profitability in early years.

105 Box 2.8 provides more background on the Chinese semiconductor firms that are in the sample.

106 As explained before, Vanguard International Semiconductors (17% owned by the National Fund of Chinese Taipei) did not benefit from any below-market equity.

Figure 3.13. Government support conferred through below-market equity reached between USD 5-15 billion, depending on the assumptions made

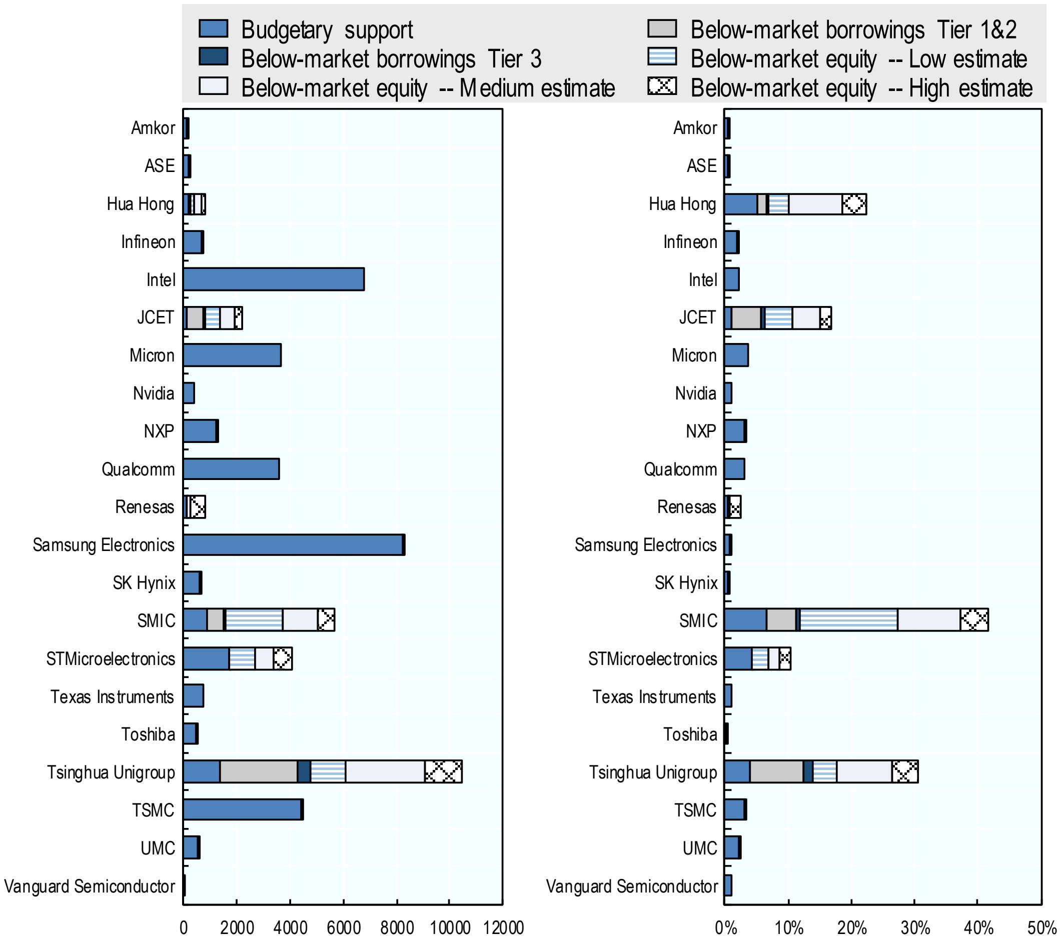
Left: Support by firm, 2014-18, USDmn, current
Right: Support by firm, 2014-18, % of firm revenue



Note: Data for Toshiba are for 2013-17.
Source: OECD calculations.

Figure 3.14. Below-market equity added another USD 5-15 billion to total government support over the period 2014-18

Left: Total support by firm, 2014-18, USDmn, current
Right: Total support by firm, 2014-18, % of firm revenue



Note: Data for Toshiba are for 2013-17.
Source: OECD calculations.

Government support provided through the equity channel benefitted overwhelmingly Chinese firms, both in absolute terms and as a share of revenue. The amount of equity support received by the four Chinese firms in the sample amounted to about 86% of all equity support measured here under the middle estimate. The remainder was divided up between Renesas (2%) and STMicroelectronics (11%). The picture is even more stark when government support is expressed as a share of annual firm revenue. Moreover, there are important differences in the underlying drivers of the estimates of support derived from below-market equity. While estimates for all four Chinese firms are primarily driven by a very fast build-up of assets over the period (+228%), numbers for Renesas and STMicroelectronics largely stem from stagnating or depressed profits that have failed to meet market expectations, even as assets barely increased in book value (+20% and +18%, respectively). In the case of STMicroelectronics, the lack of sufficient profits might have had to do with disagreements among state shareholders over the fate of certain loss-making units.[107] This suggests that below-market equity in China took the form of large government equity injections for investing in new production facilities, whereas it arose elsewhere from government shareholders supporting companies with weaker financials.

The conflicting objectives of certain government-invested firms raise the question of whether government investments cause these firms' poor performance, or whether governments invest in these firms because they perform poorly in the first place (e.g. a bailout through an equity injection). A related issue is the possibility that risk-averse governments may not necessarily be the best stewards of mature, technology-intensive companies that face short product cycles and disruptive innovation breakthroughs.

It is important to stress that the estimates reported above aim to measure benefits to recipients (that is, firms) as opposed to the cost to governments.[108] The nuance matters for delineating the scope of what to count since governments do not fully own the six firms for which the analysis has identified support through below-market equity. If the exercise were concerned with the foregone returns that governments failed to earn through their investments, then account should be taken of the proportion of shares effectively owned by the state. However, the focus of this exercise is consistently on the benefits to the recipients, e.g. the net impact tax concessions are having on firms' profits rather than the net fiscal cost of these measures for the government (expressed as tax revenue foregone). To the extent that minority private shareholders have also 'subsidised' those firms through below-market equity, this arguably resulted from decisions that were presumably influenced by the largest shareholder, namely the state.

3.4. Important data gaps and limitations

It is important to note that the support estimates presented in this report, both budgetary and financial, are likely a lower bound. The reasons for this are twofold. One is that the analysis does not capture all possible forms of support due to lack of transparency and data availability. Another reason is that the analysis uses conservative assumptions regarding market benchmarks and parameter values, both as concerns below-market borrowings and below-market equity. The resulting numbers are also subject to important caveats that warrant some discussion.

3.4.1. Important data gaps remain

One potential channel of government support that this report did not analyse is the *provision of land at below-market prices*. Although land is not a central input in the semiconductor value chain, semiconductor foundries do require considerable space. In the discussion below, China is used as an illustration owing to the great number of new foundries that are being constructed there, and which often require large tracts of land. The provision of land at below-market prices as a form of investment incentive exists, however, in other jurisdictions. Israel, for instance, also has land-related incentives (e.g. a subsidy for land development and an "exemption from a land tender") that

[107] See www.bloomberg.com/opinion/articles/2016-01-27/stmicro-hamstrung-by-france-and-italy (accessed on 13 September 2019).

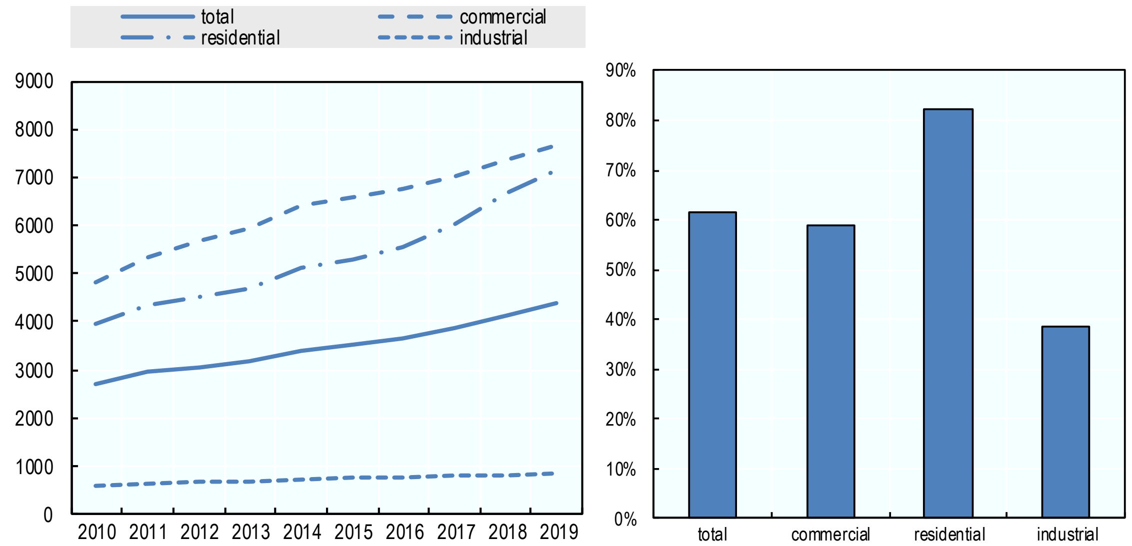
[108] Benefits do not refer here to the legal concept of 'benefit' under the WTO's SCM agreement (Article 1.2).

result in cheaper land prices.[109] Intel reportedly benefitted from this exemption by obtaining land allocated from the government.[110]

Official data from the Chinese Ministry of Natural Resources show that industrial land in China is significantly cheaper than land sold for commercial or residential purposes. While this might be due to qualitative differences between land types, empirical studies have found industrial land to remain cheaper even after controlling for factors such as distance from the city centre, suggesting the unexplained difference to potentially be an "implied subsidy" (Hsieh, Bai and Song, 2019[76]). Starting from that lower base, industrial land prices also increased by much less than prices for other land types over the period 2010-19 (Figure 3.15). Some analysts again suggest that this lesser price increase might be related to the practice of local governments offering "industrial land at subsidized prices to support local industries" (Liu and Xiong, 2018[93]). Tsinghua Unigroup, for instance, purchased land for its foundry in Chengdu for CNY 240 per m^2, while the official average price for industrial land in second-tier cities was CNY 724 per m^2. Even considering possible quality effects, the price gap is sizable. Unlike below-market financing, however, land sold at preferential terms tends to be available to domestic as well as foreign companies in China. Nevertheless, it might still be of concern for its effects on resource allocation.

Figure 3.15. Industrial land prices in China increased much less than prices for other land types over the period 2010-19

Left: Land prices in 105 major Chinese cities in CNY per m^2, by year and use
Right: Increase in land prices from 2010 to 2019, by use



Note: Prices refer to the first quarter values of each year.
Source: OECD based on data from the Ministry of Natural Resources of the People's Republic of China.

109 See https://investinisrael.gov.il/HowWeHelp/downloads/ADVANCED%20MANUFACTURING.pdf (accessed 24 September 2019).

110 See www.jpost.com/Israel-News/Intel-to-invest-a-further-11-billion-in-Israel-operations-578973 (accessed 24 September 2019).

Another potential channel of government support that this report does not cover is the *provision of water and electricity at below-market tariffs by state utilities*. Prior OECD work has shown support through below-market energy to be significant in the aluminium value chain (OECD, 2019[1]). While semiconductor production arguably is relatively less energy-intensive than aluminium smelting, it still "uses extensive amounts of electricity and fresh water" according to TSMC's annual report for 2018. A study by consulting group McKinsey has found that "[e]nergy costs can account for 5% to 30% of fab operating expenses".[111] The OECD estimates, for instance, that TSMC alone accounted for 7.7% of the total industrial electricity consumption in Chinese Taipei in 2017. Electricity consumption of foundries is reportedly set to increase further with the deployment of extreme ultra-violet (EUV) production technology. Water is mainly used in the form of ultra-pure water in the semiconductor manufacturing process. While companies tend to publish their water and electricity consumption in their corporate social responsibility reports, it is not always clear what rates these firms paid. This report has therefore not attempted to quantify systematically the support that might be conferred through this channel.

While this report has identified several subsidies tied to capital expenditure, it does not cover support that might be conferred through the *provision in kind of semiconductor manufacturing equipment* itself, which makes up more than half of a foundry's capital expenditure. One potential way for companies to lower their costs is to lease machinery instead of buying it. In 2017 and 2018, SMIC and Sino IC Leasing, for instance, entered into several sale and leaseback agreements for a total valuation of USD 1.2 billion, under which SMIC sold production equipment to Sino IC Leasing and leased it back subsequently (according to SMIC's annual report for 2018). Such transactions are not unique and would not raise concerns were they undertaken by private actors. Sino IC Leasing's owners, however, include China's National IC Fund (32%) as well as the Shanghai IC Fund and the China Development Bank (each 4.5%), giving the state a substantial stake in the company. While it is possible that firms obtain government support through this channel, further information about these transactions would be necessary to undertake an assessment.

A further data gap relates to the *companies that could not be covered by this report due to data limitations*. This mainly concerns GlobalFoundries and Huawei's chip design subsidiary HiSilicon.

- The limited information that is available on GlobalFoundries does not cover the period analysed in this report, but shows that the firm received an aggregate USD 327 million in subsidies and incentives over the period 2013-15, representing 2.4% of its revenue during that time.[112] GlobalFoundries' parent, the Mubadala fund, has the same credit rating as its sole shareholder, the government of Abu Dhabi, and enjoys its "consistent backing" and "continuing support".[113] In line with this report's finding that government-invested firms tend to benefit more from below-market equity than private companies, preliminary estimates suggest that state-owned GlobalFoundries also benefitted substantially from below-market equity in the years 2013-17, possibly reaching between 50% and 60% of its revenue. Mubadala has also contributed USD 22 billion to GlobalFoundries between 2009 and 2015, including the USD 1.9 billion acquisition of Chartered Semiconductor Manufacturing Ltd. by Mubadala and its subsequent transfer to GlobalFoundries. While this limited information does not provide a

[111] See www.mckinsey.com/~/media/mckinsey/dotcom/client_service/operations/pdfs/bringing_fabenergyefficiency.ashx (accessed on 16 September 2019).

[112] The information was obtained from a bond prospectus of Mubadala Development Company PJSC dated 29 April 2016.

[113] See www.mubadala.com/en/investors (accessed on 16 September 2019).

complete picture, it hints at least at the considerable support that GlobalFoundries might have obtained.

- Information on HiSilicon, on the other hand, are much scarcer, making even a rough assessment practically unfeasible. Although Huawei does publish annual reports, the information they contain about HiSilicon is mostly limited to the statement of the unit being wholly owned by Huawei. HiSilicon also makes up only a comparatively low percentage of Huawei's total operations, which would make any analysis of the Huawei group difficult in the context of a study of semiconductors.

Finally, this report did not attempt to examine comprehensively the *support provided by governments prior to the period 2014-18*. Some of today's large market players may have benefitted previously from support that helped them in their development and contributed to their success. A comparison of support across different periods, however, is inherently challenging for at least two reasons. While some instances of support, such as earlier R&D grants provided by DARPA, are noted in the report, it is substantially more difficult to obtain comprehensive information on policies from earlier decades. At the same time, even where data are available, the question of comparability remains. Current support takes place in a considerably different international market environment than support provided several decades ago, when the number of firms and countries involved in semiconductor manufacturing was more limited than today. This arguably might have an influence on the effects of government support on competition and international trade.

3.4.2. Several other caveats and limitations apply to the analysis

Not all types of support identified in this report are equally precise when it comes to quantitative estimates (Figure 3.16). *Grants* are by far the most precise as their exact amount is reported in primary sources (by governments or companies) and can be considered support from the government in their entirety. Although measuring *tax concessions* often involves a comparison between a benchmark tax rate and a preferential tax rate, the calculated amounts are reasonably accurate, provided the benchmark tax rate is selected correctly and the tax base is sufficiently precise.[114] *Below-market borrowings*, however, are entirely estimated by the OECD, which required assumptions at many stages to fill in the gaps left by missing information. As far as *below-market equity* is concerned, the range of choices, the assumptions, and unpredictable future elements that can affect calculations all make it the least precise form of government support identified in this report. The analysis has attempted nevertheless to quantify government support conferred through below-market equity on a best-efforts basis, using assumptions and models grounded in economic theory and the literature.

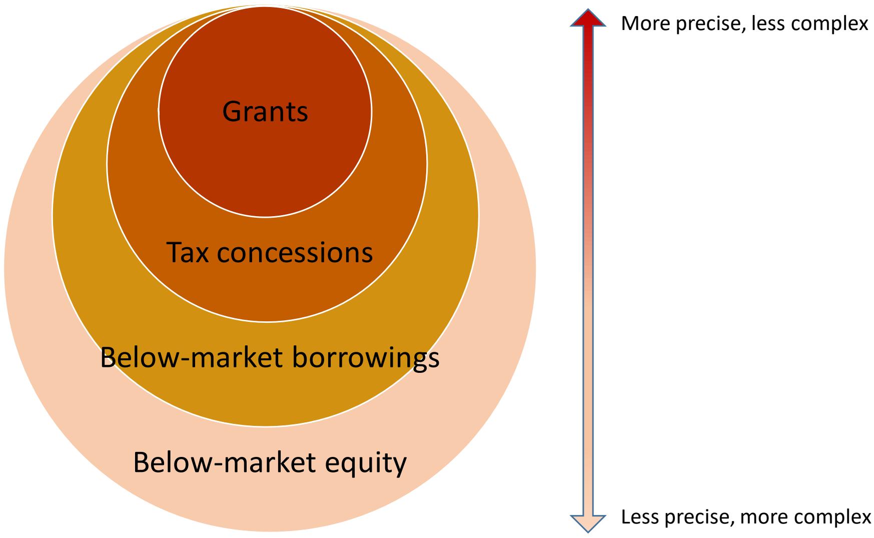
This study has made conservative choices whenever assumptions and judgments were necessary; this implies that the estimates of below-market borrowings and equity presented in this report should be considered lower-bound numbers that likely under-estimate the true amount of support. For below-market equity in particular, the analysis has selected values for the equity risk premium (ERP) that are based on mature markets, i.e. the United States, and an industry beta at the global level. The true ERP may, however, be higher in the case of emerging economies (Salomons and Grootveld, 2003[94]). The same applies to the parameter values used for the industry beta. One alternative might be to use a country-specific industry beta.[115] However, not all markets have many

[114] Complications might arise in the case of more complex tax concessions such as accelerated depreciation schemes or the expensing of certain capital expenditure.

[115] Using country-specific beta values would likely increase this report's estimates of below-market equity by less than a third in the case of the four government-invested firms in the sample that are from China.

semiconductor companies that are publicly traded, a necessary condition for constructing a reliable beta. Even where such a publicly traded market exists, the beta may still not represent the true stock volatility in relation to the entire market if semiconductors account for a disproportionately large portion of the total market in the country in question. The analysis therefore choses to use the same ERP of a mature market and a global-average beta for all companies studied.

Figure 3.16. The degree of certainty and precision varies among types of support



Another caveat of the analysis concerns the *possibility that a firm's consolidated financial statements do not cover all of that firm's business*. In theory, the consolidated financial statements should reflect all business conducted by a group's entities, be they subsidiaries, associate companies, or other invested companies. At the same time, however, different accounting methods may apply depending on the size of equity stakes, which could possibly alter the level of information retrievable from the financial statements. This concern is further aggravated for firms whose business structures involve multiple layers of subsidiaries or other forms of companies co-owned by other parties like state institutions (e.g. Box 3.1). While the report has attempted to collect as much information as possible from firms' financial statements, together with a variety of publicly available sources, it is not certain that the consolidated financial statements of the firms studied entirely reflect all of their projects, including small foundries or semiconductor-related investments.

Finally, although the *capital asset pricing model* (CAPM) is widely used for considering or evaluating investments, there are valid concerns that a single variable (that is, the beta) is not sufficient to assess future risks and returns in financial markets. Many other factors help explain financial returns and would need to be carefully reflected in calculations to arrive at more realistic expected rates of return. One such alternative to CAPM is the so-called multi-factor pricing models (or arbitrage-pricing theory), which take into account various systematic risk factors and assets' (or portfolios') sensitivity to them. One important characteristic of multi-factor models, however, is that they do not specify how many and which systematic factors to include; rather, it is part of the model's calculations to analyse and select risk factors that best apply to a particular asset or portfolio, and how they are influenced. This particular aspect of the models make them ill-suited to the type of exercise pursued in this report as it implies models that are less transparent, comparable, and replicable than CAPM. The exercise would also become more time-consuming since it would require identifying all relevant factors to consider in the model and decide their numbers through careful statistical analysis.

Policy implications: The good, the bad, and the ugly

This final section of the report attempts to draw preliminary policy implications based on the results obtained and discussed in previous sections. Where possible, insights relevant for trade rules are drawn in order to help support present and future discussions in the WTO and other trade-policy fora. The discussion that follows is organised around general policy questions that have proven recurrent throughout the analysis.

Support for R&D should not always get a free pass

Government support as described in the OECD matrix of support measures (Table 3.1) comprises a broad range of policies that can differ greatly in how distortive they are. Some forms of support might prove relatively benign for international competition, especially where they serve to correct market failures that would otherwise dampen innovation efforts and productivity growth. Other forms of support may prove, however, more damaging for trade and investment, indicating a possible need for tighter scrutiny and disciplines around the use of such policies by governments.

The issue of how distortive government support is matters greatly in the context of the semiconductor value chain given the industry's massive spending on R&D (Section 1) and this report's finding that most budgetary support targets R&D activities (Section 3.2). As discussed in Section 2.1 of the report, economic theory provides compelling arguments in favour of public support for R&D, especially where it can be shown that private actors left to their own devices would underinvest in R&D. Market failures are not systematic, however. R&D encompasses many different activities that vary in how close they are to commercial application, how product specific they are, and whether they involve pushing out the technological frontier as opposed to simply catching up with competitors. These characteristics will in turn affect the extent to which R&D benefits society as a whole (i.e. R&D as a public good) and how market-distortive government support for R&D may turn out to be.

One concern in that regard relates to the short product cycles that characterise the semiconductor industry and the increasingly blurry distinction between pre-competitive R&D and applied R&D of a more strategic nature. The economic literature has noted the role that R&D subsidies can play in helping domestic firms capture a larger market share internationally at the expense of foreign competitors (Spencer and Brander, 1983[95]; Bloom, Schankerman and Reenen, 2013[96]). The phenomenon, known as 'product market rivalry', serves to illustrate that R&D cannot be considered unambiguously benign for competition, but that much depends on policy design and the technological proximity of competitors. Empirical studies tend nevertheless to find that R&D generates net overall benefits for society on average, with social returns on R&D often exceeding private returns by a large margin (Bloom, Schankerman and Reenen, 2013[96]; Lucking, Bloom and Van Reenen, 2018[46]).

In this context, it is important for governments to design support measures for R&D in a manner that maximises societal benefits (i.e. innovation efforts that can increase productivity and well-being) while minimising costs (i.e. competitive distortions). The experience of the semiconductor industry suggests this to be more likely where support targets upstream research projects rather than companies themselves. This can involve, for instance, support destined for pre-competitive research collaborations involving firms, universities, and public research agencies (e.g. national laboratories) working together. Empirical studies for small high-tech firms also show early-stage R&D grants to have proven effective in enabling new technologies to go forward and start-up companies to attract venture capital and evolve into profitable businesses (Howell, 2017[97]). The effects appear especially pronounced for young hardware firms that face substantial constraints in raising upfront capital. Taken together, this would indicate that R&D support measures ought to be transparent (e.g. research grants awarded through an open competitive process), non-discriminatory (available to domestic and foreign-established firms equally), and targeted towards either young firms that face financing constraints or pre-competitive research collaborations that undertake basic, fundamental R&D. By contrast, support measures for R&D that take the form of blanket subsidies benefitting large incumbents or domestic firms only are at greater risk of distorting markets, trade, and capital allocation.

Investment incentives continue to be an issue and one that may gain in importance

Beyond support for R&D, much of the budgetary support that this study has identified falls into the broad category of investment incentives. This includes preferential tax regimes that lower income-tax rates for semiconductor firms, outright tax holidays for attracting foreign investment, investment tax credits, specific grants that are conditional on jobs created and capital invested, or local authorities providing property-tax abatements to attract large factories. The measures identified in this report can be found in most jurisdictions where the firms studied operate: China, Ireland, Israel, Italy, Korea, Malaysia, the Philippines, Singapore, Chinese Taipei, and the United States to name a few. This has led some observers to argue that "the semiconductor industry is one where companies demand incentives and will not invest without them" (Thomas, 2011$_{[82]}$).

The fragmentation of production stages across different jurisdictions likely makes investment incentives more attractive for governments than traditional trade-policy tools such as import tariffs and quotas (Hoekman, 2016$_{[98]}$). The complexity and length of the semiconductor value chain is a case in point, as large vendors rely on operations that span multiple jurisdictions and trade numerous intermediate inputs and capital equipment. In this context, imposing trade restrictions at the border undermines countries' participation in semiconductor GVCs by raising local input costs. Instead, governments may resort to investment incentives in a bid to attract foreign capital into their jurisdictions and insert themselves into global production networks.

Although investment incentives can sometimes benefit both domestic and foreign firms[116], they may still distort trade and resource allocation by attracting capital to less efficient locations than would otherwise be the case. This investment diversion could impose economic harm on other countries that lose out through lower employment and exports. In the case of semiconductors, the loss may be significant as a single foundry can require investments in excess of USD 10 billion. Disciplining the undesirable spillovers that result may nevertheless require disciplines beyond those that currently exist since "local incentives to attract investment are not covered by WTO rules" (Hoekman, 2016$_{[98]}$).

Even where investment incentives do not distort trade greatly, they may generate sub-optimal outcomes and divert scarce fiscal resources away from other policy priorities. This is a particular concern where jurisdictions compete to attract capital locally (Chirinko and Wilson, 2008$_{[99]}$; Ossa, 2015$_{[100]}$). The poor effectiveness of some investment incentives in increasing local employment and investment only reinforces the potential gains from co-operation (Frish and Navon, 2009$_{[101]}$).[117] A number of the measures identified in this report show investment incentives for

[116] Some measures are in fact specifically designed to attract foreign firms in the hope of benefitting from international transfers of technology. See Section 2.3.

[117] The effectiveness of investment incentives is partly endogenous, being itself a function of the incentives being applied by other jurisdictions. In the words of Ossa (2015$_{[100]}$), "gaining at the expense of other states is much harder if all states try to do this at the same time." Investment incentives can also display decreasing

semiconductor firms to concern also sub-national jurisdictions, particularly certain US states and Chinese provinces and localities. States provided almost 15% of all support the analysis has identified for the United States, most of it in the form of property-tax abatements in states such as Maine, Oregon, and Texas. The sub-national competition to attract capital[118] is even fiercer between Chinese provinces, counties, and municipalities, owing to their important revenue needs (OECD, 2019[57]; Ru, 2018[70]) and to the criteria used by central authorities for evaluating the performance of local officials (Hsieh, Bai and Song, 2019[76]; McMahon, 2018[102]). Both factors contribute to local authorities in China favouring capital-intensive activities such as semiconductor foundries, especially where these activities receive explicit backing in national-level plans and guidelines (e.g. *Made in China 2025*).

Although the primary effect of sub-national investment incentives is to distort intra-national trade, they also distort international trade where they result in the establishment of more manufacturing capacity than market conditions would normally warrant. This concern is particularly prominent in the context of the numerous semiconductor funds that have been created by local authorities in China in the aftermath of the establishment of the National IC Fund in 2014 (Section 2.4 and Section 3.3). By injecting equity into local semiconductor firms, these funds aim to spur the construction of new semiconductor fabs with a view to promoting local development. Besides grants, tax concessions, and land subsidies, the proliferation of local IC funds in places like Nanjing (Jiangsu), Wuxi (Jiangsu), Xiamen (Fujian), and Hubei province constitutes in that regard a novel form of sub-national investment incentives that aim to secure a piece of the growing pie of China's semiconductor industry (Noble, 2018[87]). Protectionism between Chinese provinces only reinforces that local rivalry and fuels further the race to increase local manufacturing capacity (OECD, 2019[57]; Hsieh, Bai and Song, 2019[76]).

Support provided through the financial system plays a crucial role

The analysis in this report has shown that support provided through the financial system – particularly through the equity channel – is a significant contributor to total government support in the semiconductor value chain. While earlier OECD work on the aluminium value chain had stressed the important role played by below-market borrowings, this study has found below-market equity to be more important in semiconductors, reflecting the heavier reliance of semiconductor producers on equity for financing their activities. As with other forms of support, below-market equity can distort production and investment decisions by firms, particularly where it is tied directly to the construction of new semiconductor fabs. Unlike most other forms of support, however, government equity injections also expand the role of the state in the economy by increasing the proportion of assets that are government-owned and -controlled. As explained in Section 2.4, government provision of equity finance to the semiconductor industry appears largely concentrated in one particular jurisdiction. Recent investments by China's National IC Fund and its sister funds at local level have profoundly reshaped the ownership of Chinese semiconductor firms, giving the state more say over commercial decisions.

Not all support provided through the equity channel is necessarily harmful. As emphasised above, there are good reasons for governments to be supporting the R&D activities of firms, universities, and national laboratories. Government equity investments may in certain cases be preferred to alternative forms of support (e.g. tax breaks) since they enable the state, and eventually taxpayers,

returns as more firms relocate to where subsidies are the highest, which lowers the marginal benefits of each new establishment.

118 The phenomenon is known in China as '*zhaoshang yinzi*' ('investment promotion').

to share in the rewards of successful investments. The argument is most compelling in the context of support for early-stage innovation, where the public sector might compensate for a lack of private venture capital (Mazzucato, 2017[103]). Equity injections may even help reduce distortions where they obey market principles and replace more distortive forms of support such as input subsidies and output payments (Noble, 2018[87]).

Most of the support provided to semiconductor firms in the sample through the equity channel appears, however, to benefit mature companies that use proven technologies and to be explicitly tied to the construction of new manufacturing capacity. This suggests below-market equity in semiconductors to be a form of state support that is distortive for trade and competition. The analysis has also found below-market equity to come on top of other forms of support such as grants, tax breaks, and below-market borrowings, which implies that it did not serve to replace these other measures, but instead to complement them.

While government equity injections in the semiconductor value chain have implications for trade, what they mean for trade rules, and subsidy disciplines more specifically, warrants closer investigation. One fundamental issue is whether equity injections are only a one-off subsidy, or whether they are also a delivery mechanism for implicit support that arises from the non-market behaviour of state shareholders. This study has shown that equity injections, and government investments more generally, could be regarded as a delivery mechanism for below-market equity in cases where recipient firms do not earn enough returns to cover their full cost of capital.[119] Scrutiny of state investments should therefore be exercised beyond the point at which equity injections are made, and concern the ensuing behaviour of government-invested firms as well. This becomes even clearer when pointing out that today's state ownership may be yesterday's government equity injection, or equally, that today's injection is tomorrow's state ownership. Focussing only on contemporary injections therefore overlooks the possibility that ongoing state ownership (including as a result of past injections) may continue providing support to state enterprises in the form of below-market equity on a recurrent basis.

By its very nature, government support through the equity channel is probably among the hardest forms of support to identify and quantify. No consensus currently exists on how best to do this, which complicates efforts to discipline these measures, whether in the WTO or elsewhere. This could explain in part the recent proliferation of government funds investing in semiconductor firms, which may allow governments to continue supporting their domestic industry while limiting the risk of WTO challenges. There is little doubt that budgetary grants, tax concessions, or guaranteed prices are forms of government support. The questions that arise in a trade context are instead whether these measures are specific to a firm, sector, or group of firms, and whether they distort trade and harm competitors. With equity injections, however, it is not always clear whether they constitute government support. Part of the challenge is that identifying where equity injections confer government support already involves an assessment of the benefit they confer to firms. In other words, subsidy identification and measurement are inextricably linked in the case of equity injections. To a lesser extent, this is also true of below-market borrowings and below-market inputs.

Several existing approaches for identifying and measuring the support conferred through equity injections use *ex ante* assessments, which focus on the decision by the government to invest in a firm. This involves judging whether a private investor would have invested in that firm at the time the government did. That judgment is itself based in part on the future returns that market participants expected the firm to achieve at the time the government invested. There are obviously many different views of firms' future prospects, which makes any *ex ante* subsidy determination

119 In addition, the presence of below-market equity could serve to flag *ex post* that an equity injection may not have been market-based in the first place.

challenging. In the case of China's National IC Fund, authorities assert that the fund operates in a manner similar to a private equity fund and that its investments are market-based. If correct, this implies that the fund's managers (Sino IC Capital) view the firms in which the fund invests as valuable prospects, even though observed financial metrics (e.g. return on assets and equity) suggest they may be inferior relative to other investment options (Figure 3.11).

In light of these challenges, and of the fact that today's state ownership may be yesterday's equity injection, analysis in this report has sought to assess the performance of government-invested firms *ex post*, comparing their actual financial returns with the returns that market participants might reasonably expect semiconductor firms to achieve. While this approach has the benefit of using observable financial data, it only serves to flag behaviour that is not necessarily consistent with market principles years after government investments have taken place. This may prove too late in a trade context as any economic harm to competitors will have probably taken place already. The approach in this report also requires some interpretation of why below-market equity arose in the first place (e.g. capacity expansions, as in China, versus rescuing firms with weaker financials), which may require flexibility in its application. In the end, there does not seem to be one ultimate test of whether state investors behave like regular market participants, but instead a variety of approaches that each provide parts of an answer.

Methodological challenges and the fact that equity injections can be a delivery mechanism for government support together suggest that there will be challenges in disciplining support through the equity channel via subsidy rules only. Other instruments may therefore be necessary, beyond the focus on improving current subsidy rules, such as trade disciplines in relation to state enterprises. This analysis also underscores the need for a more nuanced re-examination of ways to address the issues surrounding state ownership of, or state investment in, firms. One option may be to move from models that discipline state investments based on the majority of the ownership, and consider government-invested firms more generally. Given that not all such investments are of concern, the focus would be on: (i) any legal and factual elements related to that investment that could contribute to the exercise of substantial influence by the government over the firms (e.g. majority or largest block of voting rights, veto power, or the power to appoint a majority of members of the board of directors); and (ii) on the behaviour of firms in the market (e.g. evidence of non-commercial decisions or practices effectively influenced by the government) on a case-by-case basis, as it is already attempted in certain trade agreements (Box 2.6). A first critical step is transparency, as discussed below.

Financial support only reinforces the need for transparency disciplines

As much support in the semiconductor value chain takes the form of below-market financing intermediated through state financial institutions (e.g. state funds and policy banks), the issue of subsidy transparency only becomes more pressing. This report shows the need for improved transparency to focus on two policy areas, namely (i) transparency about the extent to which governments own shares in semiconductor companies and their financial backers, and (ii) transparency about the support policies in place in different countries.

The evidence in this report shows the crucial and growing role of state enterprises as recipients of support, but also as providers themselves. China's National IC Fund is incorporated, for example, as a majority government-owned investment company. Significant amounts of below-market borrowings were provided to Chinese semiconductor firms through state banks such as the China Development Bank, which some view as "an extension of the government's fiscal function" that does not seek to maximise profits but to direct credit to strategic industries and underdeveloped areas of China (Ru, 2018[70]). A number of the venture-capital funds that have invested in semiconductor firms are also ultimately owned by local authorities such as the Shanghai SASAC.

This underlines the predominant role that China's state enterprises play in channelling capital towards those sectors and technologies that advance the country's industrial policy (Rosen, Leutert and Guo, 2018[79]). While this report has not explored in detail the question of whether government-invested semiconductor firms provide support to downstream electronics companies in the form of below-market chips, the growing involvement of the state in semiconductor production could eventually make this a valid trade concern.

Crucially, and unlike for other industrial sectors such as steel and aluminium (OECD, 2019[1]), it is not always evident which semiconductor firms are state enterprises or government-invested. Section 2.4 has shown that there is considerable opacity in the ownership structures of many Chinese semiconductor firms, which complicates efforts to discipline the provision of government support to and by state enterprises through trade rules. The problem is compounded where governments exert influence over companies that are not formally defined as SOEs by the countries themselves. This concerns several semiconductor firms studied in this report, for which government stakes often do not reach 50%. Moreover, those stakes are usually indirect as they result from a multitude of holdings and investment vehicles that are beneficially owned by local and central authorities.

One remedy could be to establish some form of transparency mechanism for government investments, past and present, in commercially active firms, building on existing plurilateral initiatives to disclose information on SOEs (e.g. CPTPP, USMCA, OECD *Guidelines On Corporate Governance of state-owned Enterprises*). This mechanism could cover, for instance, all government investments above a certain *de minimis* ownership threshold that would nonetheless be low enough to capture government participations under 50%. It would be distinct from existing transparency mechanisms on subsidies (e.g. WTO subsidy notifications) in order to avoid conflating state ownership and subsidies. To maximise effectiveness, it should also cover as many countries as possible.

Not only does this report underscore the lack of transparency that surrounds government stakes in semiconductor companies, but it also shows that information about the policies that confer support to semiconductor producers is alarmingly scarce and inadequate. In the course of the analysis, it has often proven hard to track down individual support measures and even harder to estimate their magnitude in monetary terms. The fact that information had to be collected at the level of individual firms only serves to show that much remains to be done to improve the transparency of support policies.

The lack of transparency is perhaps the most problematic in the case of support provided through the financial system, whether through below-market debt or below-market equity. This opacity stems in part from the assumptions that are necessary to both identify and estimate these measures, and which give governments considerable leeway in whether and how they choose to report that type of support. The necessary calculations also make it hard to assess how widespread or specific the measures are. In particular, below-market equity in the sense of this report[120] poses a formidable challenge to notification mechanisms given its lack of an internationally accepted definition (much less an estimation method). The consequences extend beyond trade and competition, however, as the lack of transparency on financial support undermines government accountability and public oversight (Lucas, 2014[88]).

[120] Below-market equity in the sense of this report differs from government equity injections, which are already covered by subsidy rules.

One possible conclusion from this report is that below-market equity is unlikely to be fully addressed through current subsidy rules only. The discussion above has already noted several reasons for this: severe methodological challenges; the lack of an internationally accepted definition, especially on what constitutes market behaviour; too much focus on current equity injections, which ignores the continued benefits that can come from past equity injections; and the opacity of firms' ownership structures. It is also unclear what changes to current subsidy rules would fully remedy these problems. Another option may therefore be to also address below-market equity outside of subsidy disciplines, e.g. through specific disciplines on state enterprises and government-invested firms. The discussion above has already noted the need for greater transparency on the proportion of shares that governments own in commercially active firms. This could be extended to a requirement that government-invested firms be audited independently (many already are) and that they be subject to required rates of return. Reform efforts would not need to start anew, but could build instead on pre-existing rules and guidelines at the national and international levels. By way of example, several OECD countries (e.g. Estonia, New Zealand, Norway, and Sweden) already have established rate-of-return requirements for their SOEs and subject their capital injections to a minimum expected rate-of-return on investment (OECD, 2018[104]).

Government support in a world of global value chains

One important implication of GVCs is that they make it difficult to determine the trade harm that might result from government support at any one point of the supply chain. With semiconductor firms interconnected through complex production networks, the impacts of any one measure may trickle down the value chain or instead affect companies upstream that provide crucial parts and components. An example was provided in earlier OECD work on the aluminium value chain, which found support at the smelting stage to benefit also downstream producers of semi-fabricated products of aluminium due to the presence of export restrictions on primary aluminium (OECD, 2019[1]).[121]

More generally, the fragmentation of production complicates efforts to determine the winners and losers of government support (Hoekman, 2016[98]), including in the context of applying trade-defence instruments. Whether a support measure affects the whole semiconductor value chain or only segments in that chain is eventually an empirical question, but one that has implications for trade rules. As semiconductor technology is imperfectly mobile between countries (Section 2.3), support measures that lead to the construction of new semiconductor fabs in country A may end up benefitting, for example, suppliers of lithography equipment located in country B, while at the same time harming competitors that manufacture chips in that same country B. This suggests that the benefits from government support in a value-chain world may not entirely accrue to those receiving the measures in the first place (Baldwin and Venables, 2015[105]).[122]

How effective is government support in semiconductors?

At a broader level, this report also raises questions about the role and effectiveness of government support in R&D-intensive industries characterised by short product cycles. Success in the semiconductor industry appears to involve access to capital markets, human talent, sustained high

[121] Ru (2018[70]) has also found government credit from the China Development Bank to crowd in private investment in downstream industries. The paper's conclusions call on policy makers to "consider the different effects of government credit at different levels of the supply chain."

[122] That is to say, economic incidence and formal incidence are not identical.

R&D spending, and integration in global supply chains for accessing critical inputs and capital equipment. It is unclear whether and how government support helps these requirements. Even where support appears targeted toward R&D or capital financing, it does not necessarily follow that it is effective in stimulating innovation and firm productivity.

The cases of R&D support and investment incentives have been discussed above, but there are also questions as to whether below-market finance is conducive to productivity gains and competitiveness in the long term. Soft budget constraints[123] (including soft credit) can blur price signals for inputs and output, which may cause recipients of below-market financing to over-invest and tolerate weaker performance (Kornai, 1986[106]; Song, 2018[74]). This may in turn impede innovation and industrial upgrading (Fuller, 2016[37]), and eventually erode competitiveness. Evidence for China shows below-market borrowings to SOEs to have increased their assets but reduced their returns (Ru, 2018[70]). Moreover, this seems to have happened at the expense of SOEs' private competitors in China, who saw a decline in their investment, employment, and sales (ibid.). In other words, below-market financing can crowd out private investment and encourage instead the growth of SOEs that are generally less productive and profitable (Harrison et al., 2019[69]). Where SOE profitability did increase, this more often resulted from artificially low capital costs than from increased productivity (Berkowitz, Ma and Nishioka, 2017[107]).

The effectiveness of the support for semiconductors has a particular resonance for China, where, as this report has shown, support tends to be relatively large (Section 3). China is trailing in foundry technology (Box 2.3) and has adopted policies that explicitly seek to support the development of the domestic integrated-circuit industry. These current policy efforts to turn domestic semiconductor producers into leading global competitors are, however, but the latest in a long series of policy initiatives targeting the Chinese semiconductor industry. Lewis (2019[35]) notes that the 2014 IC Guideline marks China's fifth attempt to end its dependence on foreign chips, which remain to date China's largest import category as part of the global semiconductor GVC. Early Chinese semiconductor policies date back to the 1960s[124] and 1970s, though the most notable ones were adopted in the 1990s and early 2000s (Fuller, 2016[37]). While these initiatives may have differed in the instruments they used and the companies they supported, they all proceeded from the same objective to replace the country's imported chips with domestic ones. The aspirational targets that were adopted in the context of *Made in China 2025* similarly call on the country to achieve 40% self-sufficiency in chips by 2020 and 70% by 2025.

The historical record of import-substitution industrialisation (ISI) policies has typically been poor because they shelter domestic firms from international competition, which slows innovation and dynamism, while making it harder for these same firms to obtain crucial inputs from abroad (Cherif and Hasanov, 2019[108]). This matters especially for the semiconductor industry, which largely depends on global sourcing of inputs for its competitiveness (e.g. EDA software, specialty gases, and steppers). Attempts by countries to establish domestic semiconductor champions by way of subsidies and other trade-restricting policies may therefore fail to meet their objective while still distorting international markets. The recent provision of government equity on a large scale marks

123 Defined as a situation when "the strict relationship between expenditure and earnings has been relaxed, because excess expenditure over earnings will be paid by some other institution, typically by the State" (Kornai, 1986[106]).

124 The Huajing Group (originally Wuxi Factory No, 742) was established in 1960. By 1965, China had already created its first integrated circuit and was considered at the time to be more advanced in semiconductor technology than many foreign competitors were (Fuller, 2016[37]). See also www.scmp.com/tech/big-tech/article/3024687/how-china-still-paying-price-squandering-its-chance-build-home-grown (accessed on 16 September 2019).

nonetheless a qualitative and quantitative departure from earlier support policies. It is therefore an open question as to whether this form of support will prove more successful than its predecessors. Although this report does not provide an answer, the analysis of below-market financing in Section 3.3 suggests capital misallocation to be a possible future drag on productivity.

Yet however effective it is, the provision of large amounts of support by one country may still cause significant trade distortions that are a serious concern for others. The semiconductor industry relies today on a complex web of supply chains that span multiple jurisdictions, firms, and universities, and for which the ‘grease’ remains the cross-border movement of parts, machines, talent, and technology. This implies that any trade distortion will be magnified and transmitted across many companies and markets. It also makes it questionable for countries to try to locate the entire value chain domestically since competitive advantage lies precisely in the international production network (Lewis, 2019[35]; Semiconductor Industry Association and Nathan Associates, 2016[5]).

Policy should therefore focus on adopting the right set of measures that can best foster countries’ integration into the global semiconductor value chain. The possible rollout of new technologies such as 5G or machine learning offers, in that regard, opportunities for new entrants at the chip-design stage, where entry barriers are lower thanks to a smaller scale of physical assets but product sophistication and skill intensity remain high. Government support may be part of the policy package, but it needs to be designed in a way that maximises innovation and access to capital markets while minimising distortions to trade and competition.

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Annex A. Technical appendix

One possible goods classification for the semiconductor value chain

The following product list shows HS codes corresponding to this report's definition of semiconductor-related goods. Semiconductor-related goods included under the initial ITA appear in green while those in the ITA expansion appear in red. For other technology-related products, goods under the initial ITA appear in orange while those under the ITA expansion appear in blue.

	STEP 1	
Raw Material	Silicon high purity	280461
	Silicon carbide	284920
	Germanium	282560
Inputs	Photographic plates and film	370130
	Photographic plates and film	370199
	Photographic goods	370790
	Gallium Arsenide	811290
Equipment	Machines for the manufacture of semiconductor boules or wafers	848610 / 868640
	Parts and accessories	848690
	Instrument for measuring or checking semiconductor wafers or devices	903082
	Optical instruments for inspecting semiconductor wafers	903141
Outputs	Silicon wafers	381800
	STEP 2	
Raw Material	Silicon wafers	381800
Inputs	Sheets of semiconductor	900120
	Lenses for semiconductor	900190
	Objective lenses,	900219
	Optical filters	900220
	Mirrors	900290
	Electron microscopes for semiconductor inspection	901210
	Parts of electron microscopes	901290
	Instruments for measuring semiconductor devices	903082
	Optical instruments inspecting semiconductor devices,	903141
Equipment	Fans for cooling microprocessors,	841459
	Heat exchange units	841950
	Liquid filtering or purifying machinery	842129
	Filtering or purifying machinery and apparatus	842139
	Parts of filtering for semiconductor manufacturing	842199
	Machines for the manufacture of semiconductor	848620 / 848640
	Parts and accessories	848690
Outputs	Integrated circuits	8542
	Processors and controllers,	854231
	Memories	854232
	Amplifiers	854233
	Others	854239
	Micro assemblies	854290
	Non-volatile storage	852351
	Smart cards	852352
	Solid-state storage	852359
	Passive: Electrical capacitors	853290
	Passive: Electrical resistors	8533
	Printed circuits	8534

	STEP 3	
Material	Semiconductors (see Outputs above)	
Inputs	Tubes	8540
	Electrical apparatus; diodes	854110
	Electrical apparatus transistors	854121 / 854129
Output 1: Intermediate Industry	Automotive Ignition or starting equipment	851190
		852729
		854430
	Microscopes	901210 / 901290
	Navigational instruments	901490
	Machines accessories for those testing hardness	902490
	Microtomes	902790
	Meters	902890
	Meters and counters	902990
	Instruments, for measuring electrical quantities	903090
		903190
	Regulating or controlling instruments	903290
		903300
Output 2: Intermediate Consumer	Machinery; parts and accessories	8473
	Base stations	851761
	Communication apparatus	851762 / 851769
	Microphones, headphones, earphones, amplifier	851890
	Sound or video recording apparatus	852290
	Transmission apparatus	852990
	Photographic flashlight apparatus	900690
	STEP 4	
Inputs 1 and 2	(See Outputs 1 and 2 above)	
Output 1: Final Industry	**Computers and office**	
	Calculating machines	8470
	Automatic data processing machines	8471
	Office machines; not elsewhere classified	8472
	Industrial equipment	
	Radar apparatus, radio navigational	8526
	Navigational instruments	9014
		9022
	Gas or smoke analysis apparatus, for physical or chemical analysis	9027
	Meters; gas, supply	9028
	Meters and counters	9029
	Instruments for measuring or detecting ionising radiations	9030
Output 2: Final Consumer	Telephones for cellular networks or for other wireless networks	851712
	Telephone sets n.e.c. in item no. 8517.1	851718
	Apparatus for the transmission or reception of voice, images or other data, via	851770
	Microphones and stands therefor	85181
	Transmission apparatus for radio-broadcasting or television,	852580
	Monitors and projectors, not incorporating television reception apparatus;	8528
	Cameras, photographic	9006
	Games; video game consoles and machines	9504.30
		950450

Sample of companies covered in the M&A data

Semiconductor-related companies

ASE Technology Holding Co., Ltd. (Chinese Taipei); Advanced Micro Devices, Inc. (United States); Alphabet (United States); Amazon (United States); Amkor Technology, Inc. (United States); Analog Devices, Inc. (United States); Apple (United States); Broadcom Inc. (Singapore); ChipMOS Technologies (Chinese Taipei); Chipbond Technology Corporation (Chinese Taipei); DB HiTek (Korea); Facebook (United States); Hua Hong Semiconductor Ltd. (China); Huawei Investment & Holding Co. Ltd. (China); Infineon Technologies AG (Germany); Intel Corporation (United States); Jiangsu Changjiang Electronics Technology (China); MediaTek Inc (Chinese Taipei); Microchip Technology Incorporated (United States); Micron Technology, Inc. (United States); NVIDIA Corporation (United States); NXP Semiconductors NV (Netherlands); ON Semiconductor Corporation (United States); Powerchip Technology Corporation (Chinese Taipei); Powertech Technology (Chinese Taipei); QUALCOMM Incorporated (United States); Renesas Electronics Corporation (Japan); Rohm Co., Ltd. (Japan); SK Hynix Inc. (Korea); STMicroelectronics NV (Switzerland); Samsung Electronics Co., Ltd. (Korea); Semiconductor Manufacturing International Corp. (China); Skyworks Solutions, Inc. (United States); Sony Corporation (Japan); Taiwan Semiconductor Manufacturing Co., Ltd. (Chinese Taipei); Texas Instruments Incorporated (United States); Tianjin Zhonghuan Semiconductor Co., Ltd. Class A (China); Tianshui Huatian Technology (China); TongFu Microelectronics (China); Tower Semiconductor (Israel); Tsinghua Unigroup (China); UTAC Holdings (Singapore); United Microelectronics Corp. (Chinese Taipei); Western Digital (United States); X-FAB Silicon Foundries (Belgium).

Government-related funds and fund managers

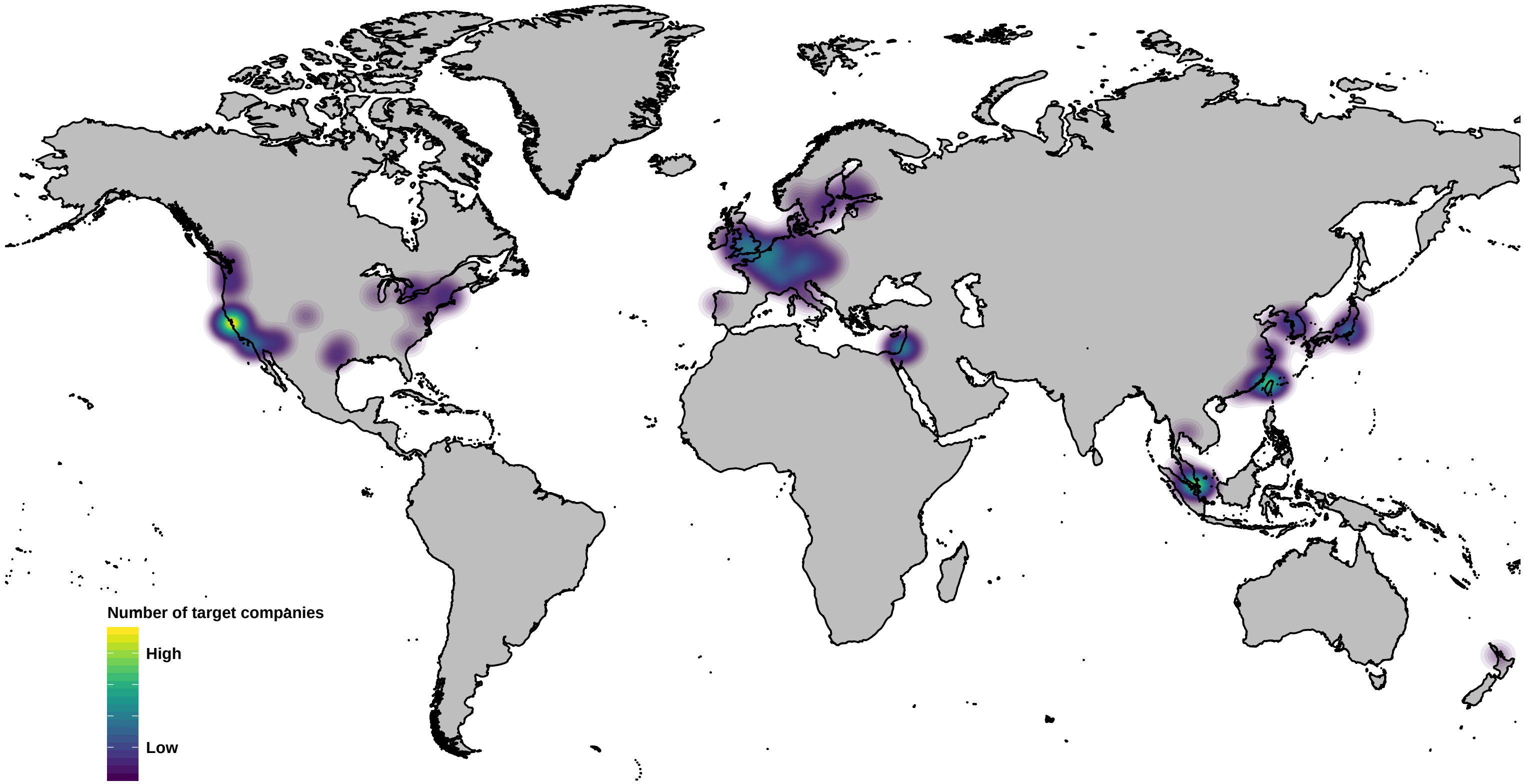
Beijing E-Town International Investment & Development Co. (China); China Integrated Circuit Industry Investment Fund Co. (China); GIC Pte Ltd (Singapore); Hua Capital Management Co., Ltd (China); Japan Investment Corp (Japan); Khazanah Nasional Bhd (Malaysia); Mubadala Technology Co. (United Arab Emirates); Public Investment Fund (Saudi Arabia); SB Investment Advisers (United Kingdom); Temasek Holdings Pte (Singapore).

List of FactSet industries considered in the analysis

FactSet identifier	FactSet sector	FactSet industry
1210	Producer Manufacturing	Industrial Machinery
1235	Producer Manufacturing	Electrical Products
1305	Electronic Technology	Semiconductors
1310	Electronic Technology	Electronic Components
1315	Electronic Technology	Electronic Equipment/Instruments
1320	Electronic Technology	Telecommunications Equipment
1330	Electronic Technology	Aerospace & Defence
1340	Electronic Technology	Computer Processing Hardware
1345	Electronic Technology	Computer Peripherals
1352	Electronic Technology	Computer Communications
1355	Electronic Technology	Electronic Production Equipment
1425	Consumer Durables	Electronics/Appliances
2210	Process Industries	Chemicals: Specialty
3305	Technology Services	Data Processing Services
3308	Technology Services	Information Technology Services
3310	Technology Services	Packaged Software
3320	Technology Services	Internet Software/Services
4900	Communications	Specialty Telecommunications

Figure A A.1. Location of target companies in semiconductor cross-border acquisitions

Number of targets by city, 1995-2018



Source: OECD based on FactSet.