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Global Supply Chains, Value Added and Production Intensity

Case Semiconductors

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Abstract

Semiconductor chips and their production are foundational for future innovation, future developments of digitalization, and economic prosperity. However, the role of production when discussing who is creating and capturing value across different industrial supply chains has often been underestimated. In this report, we analyze the distribution of the value added in the semiconductor supply chain. Value added analysis is insufficient on its own to understand the importance of production; therefore, we also examine the share of operating profits that has been reinvested in the growth of tangible and intangible assets. Based on value added and reinvesting cycle analysis, we discuss production intensity, and we draw conclusion regarding how important production is for different supply chains and industries.

Tiivistelmä

Globaalit toimitusketjut, jalostusarvo ja tuotannon merkitys: Case puolijohdeteollisuus

Puolijohteista valmistetut sirut ovat perusta digitalisaation edistymiselle, monille tulevaisuuden innovaatioille ja siten myös talouskehitykselle. Toisaalta viimeaikaisessa keskustelussa valmistuksen roolia arvonlisän tuottajana on usein aliarvioitu, eikä sitä kuvaavaa arvoketjuanalyysiä puolijohdeteollisuudesta ole aikaisemmin toteutettu. Tässä raportissa analysoimme arvonlisän jakautumista puolijohdeteollisuuden toimitusketjussa eri toimijoiden kesken. On huomioitava, että arvonlisä ei yksinään riitä kuvaamaan valmistuksen merkitystä. Osoittaaksemme valmistuksen merkitystä laskemme arvonlisän lisäksi, kuinka suuri osa ja kuinka nopeasti yritysten liikevoitoista investoidaan takaisin yrityksen aineellisen ja aineettoman pääoman kasvuun. Edellä mainittujen laskelmien pohjalta teemme johtopäätöksiä valmistuksen merkityksestä arvoketjun eri toimijoiden osalta ja laajemmin puolijohdeteollisuudessa.

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Keywords: Semiconductor industry, Value chain, Value added, Value creation, Manufacturing, Tangible assets

Avainsanat: Puolijohdeteollisuus, Arvoketju, Jalostusarvo, Arvonluonti, Valmistus, Aineellinen pääoma

JEL: L16, L22, L23, L63

Contents

Introduction

The semiconductor industry is booming. The market capitalizations of listed semiconductor firms currently exceed $4 trn, with increased demand for chips as work moved online and consumers were locked down at home during the COVID pandemic. The car industry and 5G network rollouts are expected to further drive demand, justifying a recent increase in capital spending. Samsung Electronics from South Korea announced that it will invest more than $100 bn over ten years in its memory and foundry businesses while TSMC recently announced capital expenditures of $100 bn over the next three years. (Economist, 2021; TSMC, 2021)

Rapid improvements in semiconductor technology have spurred the ongoing information and communication technology (ICT) revolution and enabled the digitalization of society. Ever more products rely on semiconductor chips, highlighting their foundational function for future innovation and economic prosperity. Their critical role in the economy is further evidenced by recent chip shortages forcing automobile manufacturers to temporarily shut their plants. Moreover, a resilient and secure supply chain is imperative for the state-of-the-art semiconductors used in communications infrastructure and defense applications to ensure national security.

The industry has seen significant changes in recent decades. First, Taiwanese contract manufacturers and US chip designers emerged in the 1990s enabled by computerized design and communication tools. This new partnership between designers and fabricators has been successful in providing a shorter time-to-market and diversifying the risk of large capital expenditures across a broader product portfolio (Leachman & Leachman, 2004). In addition, vertically integrated manufacturers dominate commoditized memory markets, and Intel held a strong leadership position in complex microprocessors until recently. Second, physical limits to transistor scaling have dramatically increased the costs of staying at the leading edge in semiconductor technology since the start of the 2000s, leading to consolidation among equipment makers and integrated manufacturers.

In this article, we illustrate the following: 1) how value added is distributed between different participants in the semiconductor value chain; 2) what share of profits has been reinvested into tangible and intangible assets; and 3) based on the results of one and two, we conceptualize a method for understanding production intensity, i.e., the shape of a smiling curve.

Contextualizing the debate

The fragmentation of production globally can be seen in the growing trade of components and intermediate goods (Yeats, 2001). To understand this phenomenon, the concept of global value chains (GVCs) has emerged to aid the characterization of international trade patterns and global production networks (Gereffi et al., 2015). “Upgrading” and “governance” are core concepts of GVC theory in international business management literature. Upgrading is a deliberate effort for a firm or country to increase its share of the value creation in an entire value chain. For instance, firms that are initially involved in simple manufacturing can upgrade their capabilities to provide logistics, subassembly, and design services. Governance in GVCs is determined by the degree of explicit coordination and changing power asymmetry (Gereffi, Humphrey, & Sturgeon, 2005).

An established view is that intangible assets contribute to value creation in GVCs at an accelerating pace, highlighting the role of knowledge-intensive industries in current and future wealth creation (Mudambi, 2008). Previous literature has postulated that value creation has, as a consequence, become increasingly concentrated at the upstream and downstream ends of the value chain. A study suggested that repetitive manufacturing and logistics in the middle of the value chain contribute far less to value creation and capture (Mudambi, 2007). This pattern, first introduced by Stan Shih of Acer (1996) and then later appropriated by international business scholars, became known as the “smiling curve of value creation”. Smile curves have been measured and mapped using input-output trade statistics to better understand the roles of countries and industries in GVCs (Ye, Meng & Wei, 2015). Studies focusing on the distribution of the value creation in commodity mobile device manufacturing found that Asian suppliers captured a larger share of the value creation over time (Larsen, Seppälä & Ali-Yrkkö, 2018), and it has long been known that the owners of a handful of key components were able to capture most of the overall value (Linden, Kraemer, & Dedrick, 2009). These key components are often semiconductor chips that are used across several GVCs to enable a large variety of electronics and other products.

Despite the centrality of semiconductors in multiple GVCs, research on value creation in the semiconductor industry is limited. Interest in examining who captures the most value in the global semiconductor industry by comparing fabless design companies and contract chip manufacturers has been expressed previously (Shin, Kramer, & Dedrick, 2012). Brown, Linden, and Macher (2005) provide an account of how offshoring led to disintegration into the current semiconductor value chain. They see the development as positive with lower costs and increased flexibility helping fabless designers maintain competitiveness. Macher and Mowery (2007) describe how innovation-related activities largely have remained in the home countries of large semiconductor firms, even as design and production have been unbundled and product demand has shifted. With data from Taiwan's semiconductor industry, Sher and Yang (2005) examined how R&D clustering influences the relationship between innovative capability and firm performance through technology and knowledge spillovers. West (2002) provides a knowledge creation perspective, contrasting how semiconductor firms rely on local institutions for talent and research while sources for new technology and markets have spread internationally.

Successfully designing chips and operating a semiconductor fabrication plant requires substantial investments in human expertise, much of which is learning-by-doing (see Hatch and Mowery, 1998). Excellent commercial knowledge is furthermore necessary to successfully recuperate the massive capital expenditures for a cutting-edge facility. Nevertheless, the importance of production in semiconductor value creation needs to be underscored. There is also a long-running concern that transitioning out of manufacturing into services will jeopardize the ability to capture value in the future (see, for instance, Cohen & Zysman, 1987). We suggest that the traditional value chain literature, as exemplified by the Shih/Mudambi smiling curve, should be modified by our understanding of the role of production in the semiconductor value chain.

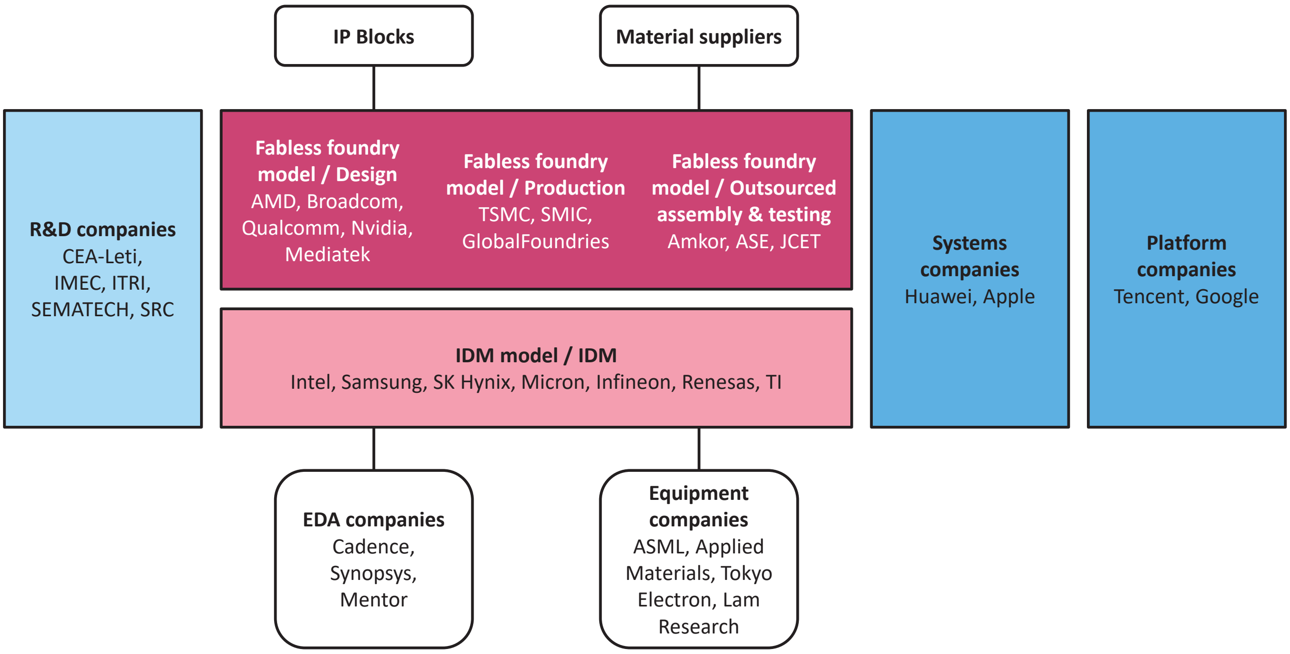
Semiconductor value chain

Producing semiconductor chips is extremely knowledge intensive, and fabricators are supported by highly capable suppliers. All segments of the value chain are dominated by a small number of specialized firms located in the US, South Korea, Taiwan, Japan, Europe, and China. The industry has considerable barriers to entry in the form of first mover technology advantages, intellectual property, and extremely high fixed costs (King, 2003); and it is characterized by rapid technological advances, global markets, and strategically designed industrial policy (Flamm, 2010). GVC upgrading in Asian nations, changing product demands and outsourcing/offshoring have led to the emergence of specialized layers in terms of designers, fabricators and assemblers in an industry that had traditionally been dominated by vertically integrated corporations.

At this time, there are two parallel strategies of specialization and integration in the industry, and these are the foundation for the value-added analysis. The traditional integrated device manufacturer (IDM) value chain that vertically integrates design, fabrication, testing, and assembly is contrasted with the newer fabless foundry model in which specialized firms engage in a design-production partnership. The distinction allows for assessing the differences between specialization and integration in terms of financial performance. The semiconductor value chain is presented in Figure 1.

The IDM, foundry, design, equipment, electronic design automation (EDA), and outsourced assembly and test (OSAT) segments were defined based on our previous research of the semiconductor industry (Holmström & Seppälä, 2020). The main suppliers for semiconductor design and fabrication can be categorized into three groups. First, companies in the materials segment provide high purity silicon wafers and chemicals (e.g., photoresist). Second, firms provide equipment used in the lithography, photomask development, etching and metallization phases. Third, the OSAT segment provides services for packaging and testing ICs. In addition, there is the EDA segment that provides the tools used for IC design. Due to a lack of publicly available information, it was decided to exclude providers of intellectual property blocks (such as ARM).

Figure 1 The semiconductor value chain: central stakeholders



Source: Holmström & Seppälä (2020).

Calculating value added

Value added is defined as the sum of the in-house labor costs, depreciations, amortizations and profits for any company in the value chain (Ali-Yrkkö et al., 2011; Seppälä, Kenney, & Ali-Yrkkö, 2014; Larsen, Seppälä, & Ali-Yrkkö, 2018). Previous studies have had access to detailed intrafirm data, but this analysis uses publicly available firm-level data. We calculate the value added for a single firm as the sum of its EBIT, cost of employees, depreciations, and amortizations. Most semiconductor firms have large R&D expenses, which are at least partly included in the cost of employees measure we use.

Firm-level data are weighted with their share of the value added to calculate aggregated figures for each segment. Depreciations and amortizations (reported as one line are in the income statement) are split into two components based on balance sheet information. The contribution of depreciations (tangibles) to value added is calculated by dividing the company's tangible assets by the total tangible and intangible assets. The contribution of amortizations (intangibles) is the company's intangible assets divided by the total tangible and intangible assets.

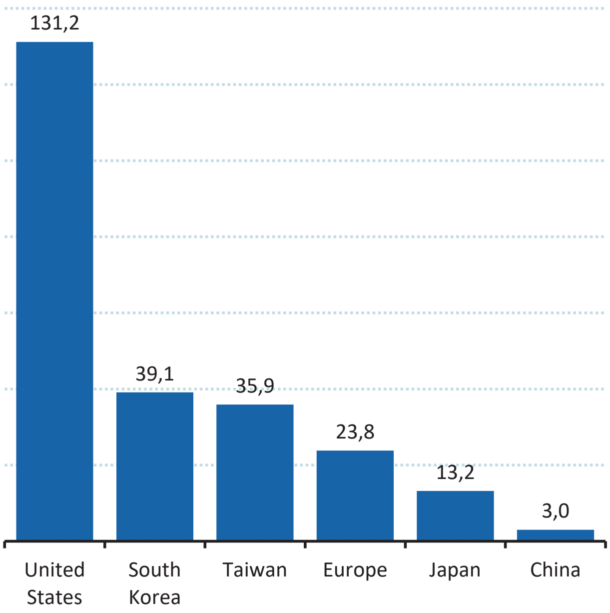
Unfortunately, our approach has some limitations. A lack of granularity in the publicly available data makes it impossible to distinguish between direct labor, R&D, and SG&A in employee expenses. It is also not possible to account for value-adding activities spread across several countries on the firm level. Furthermore, most governments provide a range of incentives for domestic semiconductor firms (OECD, 2019), which is not accounted for in this study. The aggregate nature of the analysis means that the results depict an approximation rather than an exact flow of goods and services between firms in the semiconductor GVC. Finally, the cost of employees for 23 Japanese, South Korean and American companies were estimated based on peer group analysis (see Appendix for more details).

Data description

The basis for our analysis is the financial data of 35 public semiconductor companies, which were obtained from the Orbis Bureau van Dijk database. The firms in our dataset have combined revenues of $420 billion while the revenues of the global semiconductor industry are estimated at $500-600 billion. Since each segment is dominated by a handful of companies, we argue that this selection of leading firms is representative of semiconductor GVCs. The consolidated profit and loss statement used to calculate value added and the consolidated balance sheet for each segment are presented in Table 1.

The geographical distribution of the value added by company headquarters is presented in Figure 2. However, since most large semiconductor firms have internationally distributed operations, the figure only serves to describe the data. The predominance of leading US semi-

Figure 2 **Geographical distribution of the value added by firm headquarters, USD bill.**



Source: Authors' data.

Table 1 **Description of data**

Value chain segments	Equipment	EDA	Foundries	IDM	Material suppliers	OSAT	Design
Firms	ASML, Applied Materials, Lam Research, Tokyo Electron	Cadence, Synopsys, Mentor	TSMC, GloFo, SMIC, UMC	Intel, Samsung Electronics, SK Hynix, Micron, Infineon, STMicroelectronics, NXP, Renesas, TI	Globalwafers, JSR corporation Shin-Etsu Handotai, Siltronic, SK Siltron, Sumco, TOK	Amkor, ASE, JCET	AMD Broadcom, Qualcomm, Nvidia, Mediatek
Number of companies	4	3	4	9	7	3	5
Consolidated profit and loss, 2019, $ bn							
Net sales	48,3	7,8	48,9	216,1	12,4	21,2	68,0
Cost of employees	10,4	2,5	5,5	64,4	2,4	3,8	13,6
Amortizations	1,1	0,0	0,2	10,1	0,1	0,5	7,1
Depreciations	0,7	0,1	12,7	21,2	1,1	2,2	1,2
EBIT	11,3	1,2	12,9	43,2	2,6	1,1	11,6
Value added	23,5	4,7	31,4	138,8	6,5	7,6	33,6
Consolidated balance sheet, 2019, $ bn							
Total noncurrent assets	29,0	9,4	68,2	276,2	10,8	17,9	85,2
Tangible assets	6,6	1,0	60,4	164,7	8,4	13,0	9,9
Intangible assets	13,3	5,9	1,0	79,1	0,5	3,0	66,2

Source: Orbis Bureau van Dijk database, author's calculations.

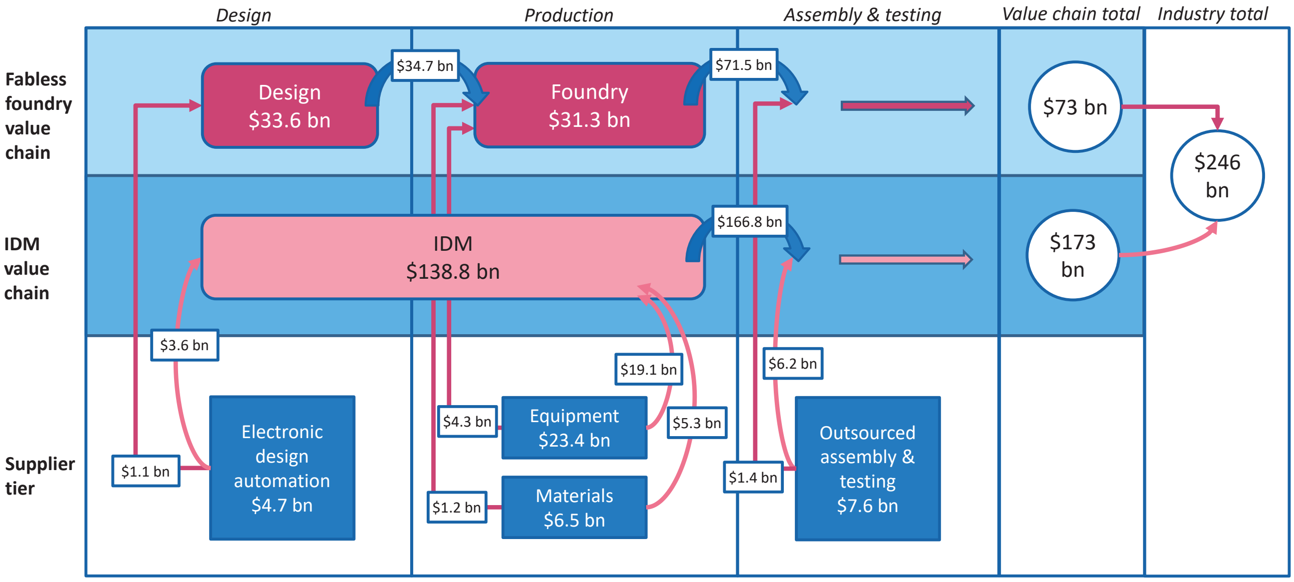
conductor firms in the dataset is clearly visible. However, the American lead is being challenged by firms from Taiwan and South Korea, currently leading state-of-the-art semiconductor mass manufacturing.

Results

The sample of 35 companies had a combined total value added of $246 billion in 2019. Figure 3 breaks down how value was distributed across the value chain segments. First, the fabless foundry value chain generated a total of $73 bn in value added. Second, the traditional vertically integrated IDM value chain generated $173 bn in value added. The value added contributions from the supplier tier to design and production were approximated as the fraction of fabless and foundry revenues to IDM revenues (24% and 18%, respectively). IDMs, design firms, and foundries constitute over 80% of the total value added in semiconductor GVCs. From the value-added perspective, equipment makers, followed by OSAT, materials, and EDA, are the most important customer segment.

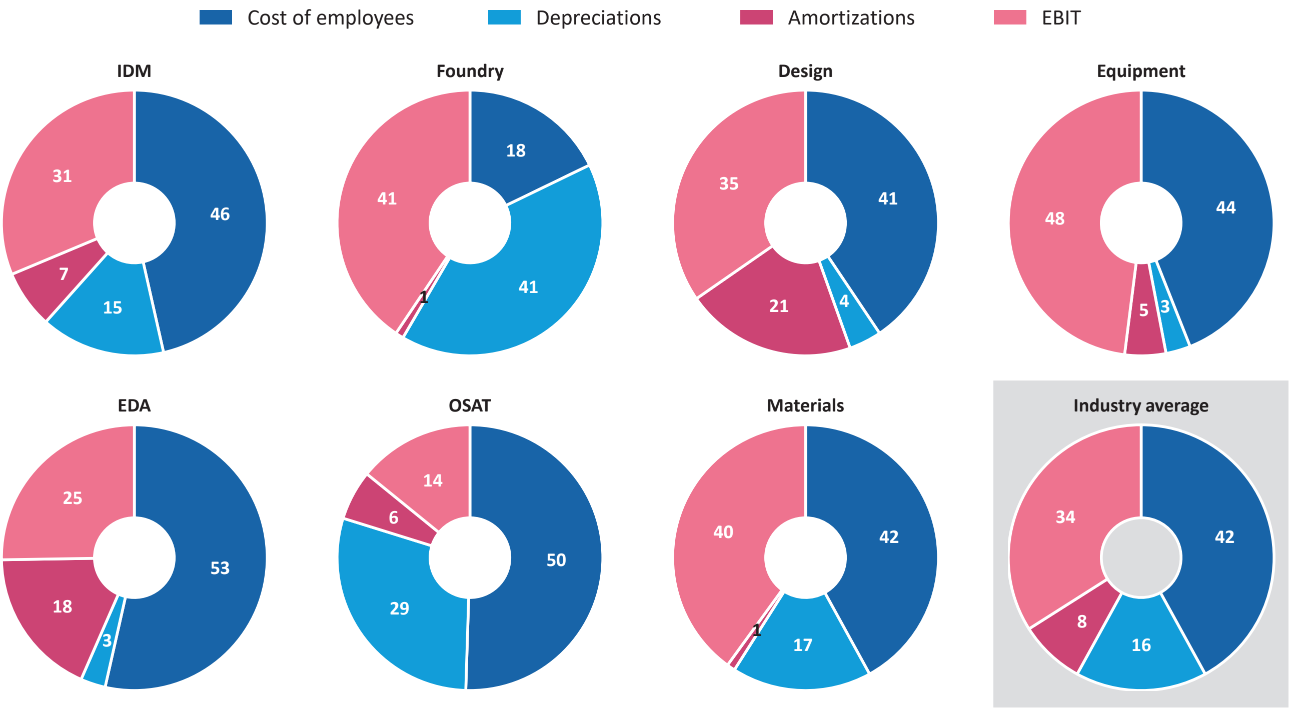
Figure 4 depicts the composition of the value added in the different segments. The cost of employees is the major component in most segments, contributing 41–53% to the value added. The exception is the foundry segment where employee expenses account for only 18% of the value added, for which one explanation is a high degree of automation in foundry production. It needs to be reiterated that the cost of employees includes direct labor, R&D and SG&A expenses. With this in mind, we hypothesize that design, equipment, and EDA companies spend large shares of employee expenses on R&D while OSAT and materials spend more on direct labor in production. Unfortunately, we are not able to determine what share of employee expenses are directed into R&D using public data. IDMs can be found somewhere in the middle having employee expenses in both R&D and production. Depreciations contribute greatly to value added in the foundry and OSAT segments while making smaller but still significant additions to value creation in IDMs and materials firms. In stark contrast, equipment, design, and EDA companies gain little value added from depreciations. In addition, the design and EDA segments expectedly have the highest share of the value added from intangible asset amortization. Operating profits are finally a large contributor to the value added in all segments excluding OSAT. The segments contributing most to value added (IDM, foundry, design, and equipment) have weighted operating margins in the range of 15–29% according to our data.

Figure 3 **Distribution of semiconductor value added in 2019**



Source: Authors' data.

Figure 4 Constitution of the value added in the semiconductor industry, %

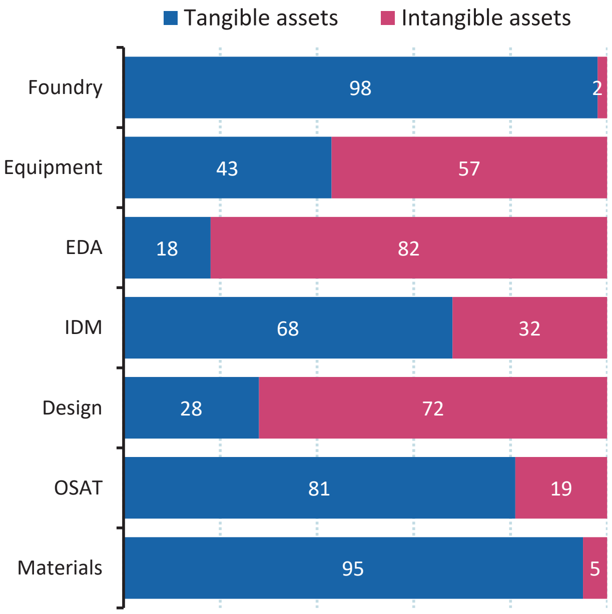


Source: Authors' data.

The distribution of assets weighted by firm-level value added is presented in Figure 5[1]. When interpreting the value added components above, it is important to consider how large the share of tangible and intangible assets is in relation to all noncurrent assets within the segment. Tangible assets form the largest share of noncurrent assets in the IDM, foundry, OSAT, and materials segments. These segments also rely the most on tangible assets in value creation. For the purpose of disclosure, the firms' total noncurrent assets include, for instance, deferred income tax assets, refundable deposits, and other noncurrent assets such as stock in other companies or advances made for acquisitions of tangible assets, which are not included in the analysis.

The value-added methodology alone does not provide an adequate picture of the importance of production in the semiconductor GVC. A good indicator to understand the status of production is what share of profits is reinvested in tangible manufacturing assets – a measure we call the production intensity. A prominent role for pro-

Figure 5 Noncurrent asset distribution for all segments weighted by value added, 2019, %



Source: Authors' data.

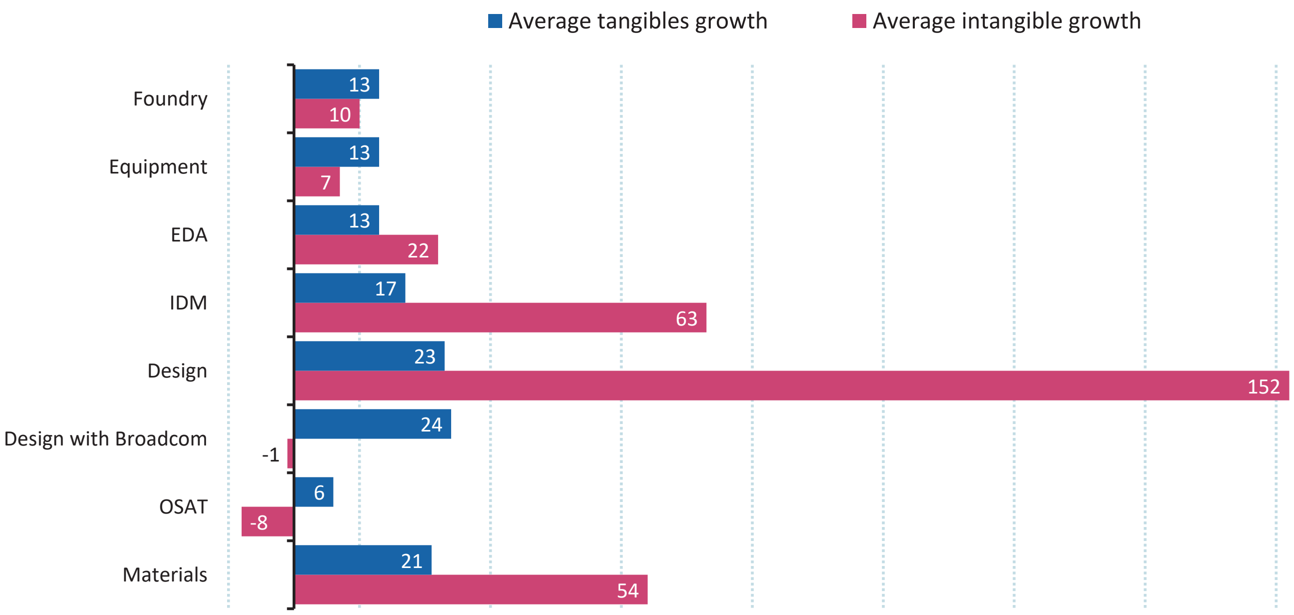
duction in a value chain can be established if a high value-added activity also has a high production intensity. Additionally, such a situation represents a value chain with a flattened smile curve that looks more like a smirk (see Rehnberg & Ponte, 2018).

Due to not having investment data from the companies in our sample, we rely on balance sheet and P/L data to construct a simplified model to measure the production intensity. The proxy model assumes that the operating profits from the previous year are reinvested and that the reinvested profits are seen as an increase in assets in the next accounting period. For example, the operating profits from 2015 are compared with the growth in assets from 2015 to 2016 to approximate the production intensity for 2016. First, Figure 6 shows the average increase in assets during 2016–2019.

Having established an increase in assets, it is possible to examine what share of profits this increase would have required. The average share of operating profits being reinvested in tangible and intangible assets is shown in Figure 7. Foundries and IDMs reinvested approximately 40% of EBIT in the growth of tangible assets or, in other words, back into production. The OSAT and materials segment reinvested 64–65% of their operating profit into tangible assets, highlighting the production intensity of these segments. The same figure for equipment, EDA and design firms was only 6%, 12%, and 10%, respectively. The share of tangible asset growth in relation to profits in the OSAT and materials segments exceeding net income by over two times is proof of these companies having low profits relative to quite large expansions of tangible assets.

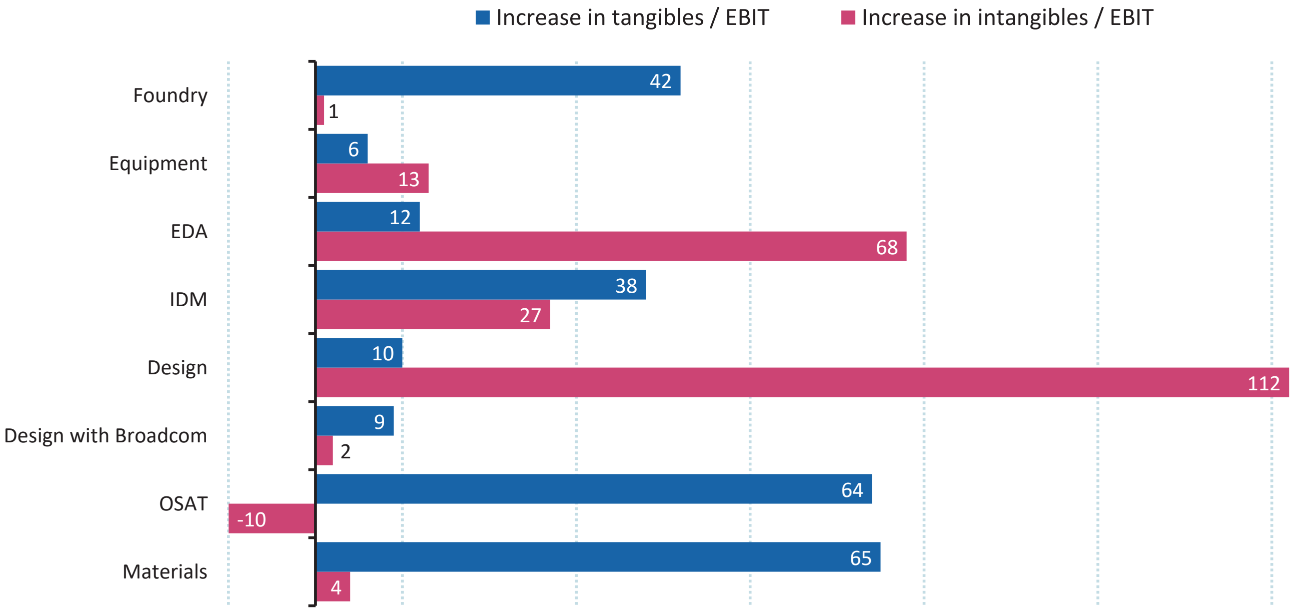
Additional comments on the reliability of the results: 1) Broadcom has grown through mergers and acquisitions and is therefore an outlier compared to the other design firms. The Broadcom-Avago merger in 2016 is seen in the massive growth of intangible assets in the design segment. To give a more balanced view, Design without Broadcom is included in Figures 6 and 7. And 2) For the OSAT segment a negative increase in assets makes sense in Figure 6. However, a negative share of profits reinvested in the increase in intangibles does not make sense in Figure 7. This is an artifact of decreasing intangible assets and having a limited sample. Moreover, it calls for an adjustment to the balance sheet analysis.

Figure 6 **Average yearly growth of tangible and intangible assets 2016–2019 weighted by assets, %**



Source: Authors' data.

Figure 7 **Average annual increase in assets relative to operating profits weighted by the intrasegment share of profits, %**



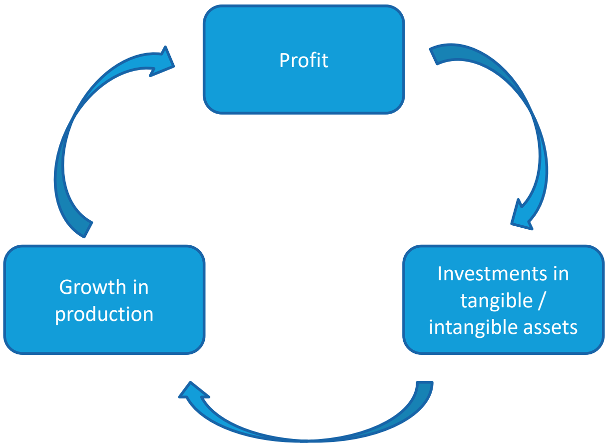
Source: Authors' data.

Concluding comments

The smile curve model has informed much of the literature on global business. However, the semiconductor industry demonstrates that it does not necessary fit to all other industries. Our analysis of the semiconductor value chain first examined the distribution of the value added, after which the importance of production was demonstrated by investigating what share of profits is reinvested back into manufacturing in the different value chain segments. The role of tangible assets in value creation is especially pronounced in production-intensive segments, where our model suggests that foundries and IDMs reinvested 40% of their operating profits in the growth of tangible assets during 2016–2019. With this in mind, we argue that, because the reinvesting cycle is faster in tangible assets and tangible assets are growing, in comparison to other industries the role of production is greater in the semiconductor industry than the international business literature suggests for GVCs in general. This might also be the case in other technology industries such as cloud computing and perhaps pharmaceuticals.

Sophisticated production can be highly profitable, though remaining on this leading edge is extremely difficult. TSMC, in particular, has been able to build global-class process expertise that allows it to generate enormous profits and has high returns on capital invested. Our results reinforce the idea of a cycle in which producers reinvest profits in production capability (i.e., tangible assets) to support growth (see Figure 8 for illustration).

Figure 8 **An Illustration of a reinvesting cycle**



To conclude, we wish to say that this is a preliminary interpretation based on a snapshot of semiconductor industry value creation in 2019. Hence, we call for a deeper investigation into a) the significance of production for value capture with more detailed data and b) the changing nature of semiconductor industry value creation with historical data.

Appendix: Description of approximated data

Japanese, South Korean and American corporations are not obliged to report their labor costs. They instead report the cost of goods sold, which includes both materials and direct employee costs. Thus, it was necessary to estimate the cost of employees for 23 out of 35 companies included in the sample. We make the approximation by simply taking the share of costs of employees to revenue in the peer group. However, this does not consider differing labor endowments across geographies or potential economies of scale. The companies for which the cost of employees was estimated and the segment-specific reference rate are presented in the Table 2.

Table 2 **Peer group analysis: labor cost**

Segment	Company	Cost of employees / revenue reference	Comment
Equipment	Applied Materials Lam Research Tokyo Electron	21 %	1 European equipment company (ASML) used as reference, however it has lower revenue / employee
EDA	Cadence Synopsys Mentor	–	We assume R&D expenses reported in Orbis represent these firms' cost of employees since EDA companies have little physical production
IDM	Intel Samsung Electronics SK Hynix Micron Renesas Texas Instruments	30 %	3 European IDMs (NXP, Infineon, ST) used as reference, however they have much lower revenue / employee
Material suppliers	JSR corporation Shin-Etsu Handotai SK Siltron Sumco TOK	22 %	1 Japanese and 1 European material supplier used for reference
OSAT	Amkor JCET	18 %	1 Taiwanese OSAT supplier (ASE) used for reference
Design	AMD Broadcom Qualcomm Nvidia	20 %	1 Taiwanese fabless design firm (Mediatek) used for reference

Source: Orbis database, author's calculations.

Endnote

[1] Weighted by value-added means that a weight for a firm within a segment is calculated with the following formula:

- Weight = VA_firm / VA_tot_segment

Then the asset distribution for a segment is derived from with the following formula:

- Segment_Tangible = Sum(Weight_i * Tangible_%_i) for all firms i=0...n within a segment
- Where Intangible_%_i = Tangible_i /(Tangible_i + Intangible_i)
- Segment_Intangible = Sum(Weight_i * Intangible_%_i) for all firms i=0...n within a segment
- Where Intangible_%_i = Intangible_i /(Tangible_i + Intangible_i)

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