# OEM vs module supplier knowledge in the smartphone industry: the impact on the market satisfaction

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**Abstract**

**Purpose** – *The purpose of this study is to identify and characterize the role of both original equipment manufacturer (OEM) and module supplier (MS) knowledge in the smartphone industry. In particular, this study aims to evaluate which of the two actors possesses the knowledge that has the greatest impact on the market satisfaction.*

**Design/methodology/approach** – *This study explores and combines the concepts of modularity and knowledge management by investigating the patent portfolio of 16 leading smartphone OEMs and 144 MSs. The applied methodology is based on the content analysis of patent data to extract information on both OEM's and MS's component knowledge.*

**Findings** – *The results show that, although its components are purchased from external MSs, the OEM should preserve both a general and specific concentration of component knowledge, as well as on the end product, to achieve a greater market satisfaction. Moreover, a positive direct relationship was found for the MS between the general concentration of component knowledge and the market satisfaction.*

**Originality/value** – *The novelty of this study is to segment the knowledge of both the OEM and the MS on multiple levels. To the best of the authors' knowledge, this is one of the first studies that investigates the end product and component knowledge of both actors by filtering patent data using text-mining techniques. The originality of this work is to intercept the relationship between the different shades of knowledge of each actor and the market satisfaction.*

**Keywords** *Smartphone, Knowledge management, Modularity, Patent, OEM, Supplier innovation*

**Paper type** *Research paper*

Received 13 December 2021
Revised 17 March 2022
Accepted 11 April 2022



## 1. Introduction

High-tech industries are featured by a constantly evolving market where technological revolutions and consumer tastes change rapidly. Among the various high-tech sectors, the smartphone industry has raised some interest. Since 2013, the smartphone market has been hugely successful by selling billions of devices (Dedrick and Kraemer, 2016). Scholars have focused their attention on this highly technological product for several reasons, such as: the complexity of the product (Sun and Zhong, 2020), the technological knowledge management (Im *et al.*, 2016; Martín-de Castro, 2015) and its degree of modularity (Sun and Zhong, 2020). These combined factors are interesting for studying the strategic choices of companies operating in the sector to achieve a competitive advantage (Im *et al.*, 2016; Martín-de Castro, 2015).

The exponential growth of functionality and innovation of high-tech products created specific issues for knowledge management (Wu *et al.*, 2014). In particular, technological knowledge is the knowledge necessary for the production of new products with innovative features (Bohn, 1997). Since Henderson and Clark (1990), technological knowledge can be divided into component and end product knowledge. Both the end product and component knowledge are hardly entirely possessed by a single actor within the supply chain (Damanpour and Daniel Wischnevsky, 2006; Smals and Smits, 2012). The technological knowledge of the original equipment manufacturer (OEM), considered essential to carry out the improvements on the end product, may not be sufficient (Zhou *et al.*, 2019). More players on the network can affect the innovative performance of the product, such as module suppliers (MSs) of innovative components and original design manufacturers.

Many researchers assessed the importance of external knowledge from MSs (Gomes *et al.*, 2021; Lin *et al.*, 2020). In particular, they considered the benefits of collaborating according to open innovation theories and creating co-value for the end product (Pihlajamaa *et al.*, 2017). It is important for the OEM to know how to manage external knowledge, as shared suppliers and customers could reveal important information to competitors (Parente *et al.*, 2020; Sun and Zhong, 2020).

In particular, scholars focused their interest mainly on the end product knowledge and less on the modules (Takeishi, 2002). They also identified the relationships between knowledge and the market performance of the end product (Alegre *et al.*, 2013). However, little has been discussed and investigated on what knowledge and which degree of knowledge concentration matters for the OEM and the MS. For example, some researchers have found that a high degree of end product knowledge for the OEM improves the internal knowledge exchange on various technological fields and allows to find new product combinations and achieve radical innovation (Carnabuci and Operti, 2013; Chen *et al.*, 2020). However, excessively high degrees of knowledge concentration on the end product could reduce the innovation developments (Yoon *et al.*, 2017). On the contrary, a low degree of end product knowledge implies that the companies should carry out an internal investigation on its end product features and subsequently interface with MS for components purchased (Srivastava and Gnyawali, 2011). Regarding MSs, Chang (2017) highlights the importance of knowledge concentration for high-tech suppliers, as they are increasingly under pressure to develop and renew knowledge to adapt on new product development. However, the degree of knowledge concentration on the high-tech components supplied by MS seems unexplored. Therefore, the importance of knowledge of each actor has not been well-defined and quantified.

In addition, the purpose of this study is to investigate the linkage among the concepts of modularity, knowledge management and market satisfaction. Market satisfaction can be considered as a market performance indicator. In particular, market performance measurement methods can be divided into two groups: one that uses financial criteria (i.e. market share, revenues and net profit) and the other that uses qualitative non-financial criteria (Ferraresi *et al.*, 2012). Among the qualitative non-financial criteria, the research has shown that there is a positive relationship between market satisfaction and product sales (Lemon and Verhoef, 2016; Shah *et al.*, 2017). One of the ways to collect the market satisfaction information is by capturing the online feedbacks, scores and comments on the web (Safi and Yu, 2017). Therefore, this study uses the online scores of the most reviewed smartphones to measure market satisfaction.

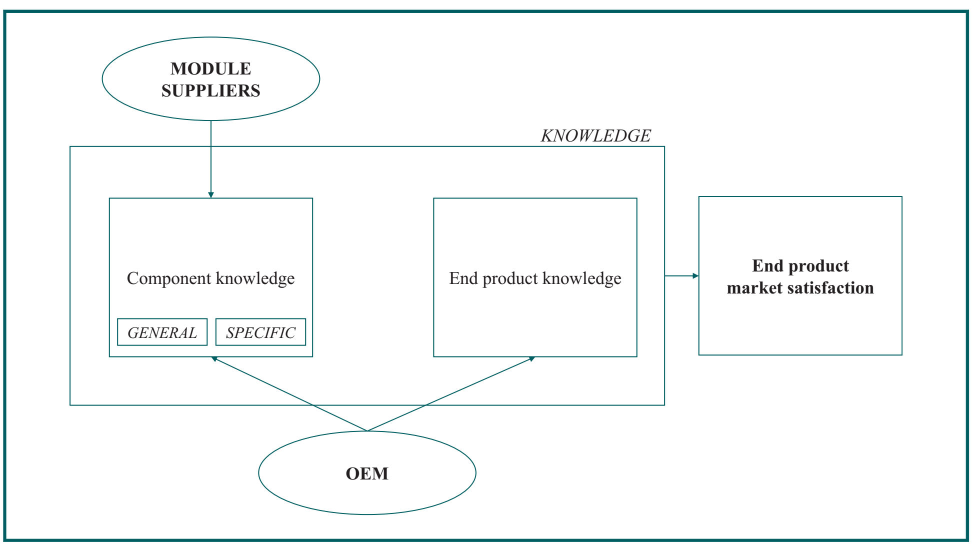
In the past, research has widely recognized the positive effect of knowledge on innovation performance (Buenechea-Elberdin *et al.*, 2018; Zia, 2020). Recently, some scholars, through surveys, have investigated what specific combinations of knowledge management and innovation performance can be associated with better market performance (Cabrilo and Dahms, 2018; Hussinki *et al.*, 2017). For example, the research results of Darroch (2005) show that companies that use knowledge management strategies achieve better innovation and market performance. However, Ferraresi *et al.* (2012) have highlighted how knowledge management has no direct effects on companies' market performance, but this relationship becomes statistically significant when mediated by strategic orientation and innovation.

Therefore, starting from these linkages, the following research questions were considered: *Does the market satisfaction of the end product depend only on the OEM knowledge*? *Does it depend only on the supplier knowledge? Or does it depend on a combined contribution of both actors?* In addition to these research questions, literature has a research gap on how the knowledge of these two actors is composed. Specifically, the component knowledge could be possessed by both actors (Chen *et al.*, 2020; Park, 2018; Yoon *et al.*, 2017; Zhou *et al.*, 2019). Therefore, it is interesting to investigate which degree of knowledge concentration of both actors makes the difference to obtain a better performance on the final market. Finally, component knowledge can be further segmented into a general component knowledge – for instance, the knowledge concerning a display module can be used into various products such as tablets and PCs – and a more specific component knowledge linked to a peculiar end product, for example, the specific knowledge on the display for its integration on smartphone applications. Therefore, *what level of component knowledge (general vs specific) is significant for the two actors to improve the market satisfaction?*

Hence, the purpose of the article is to investigate what knowledge of which actor (OEM or MS) has an impact on the final market, analysing: 1) which degree of knowledge concentration is essential and 2) which level of component knowledge (general vs specific) is relevant for the two players, to gain better market satisfaction. Figure 1 shows a conceptual schematization of the proposed framework.

To achieve the scope of the work, the applied methodology is based on the content analysis of patent data, as patents are proxies of the company's technological knowledge (Cammarano *et al.*, 2020). The smartphone industry has been analysed because the MSs of the sector are autonomous in product development and often the OEMs follow their innovations (Dedrick and Kraemer, 2016; Shi *et al.*, 2019). Moreover, in this work, the analysis is conducted only for the relationships between OEM and MS where the component is developed by the external supplier. Through this analysis, it is possible to investigate the knowledge dynamics of each player within the smartphone industry related to the effects on the final market. The use of patent data allows to filter and identify the various types of knowledge of interest to detect the relationships that have an association on the final market.

**Figure 1** Representation of original equipment manufacturer and module supplier knowledge and relationship with the market satisfaction of the end product



The following sections present a theoretical background on knowledge management and modularity issues for OEMs and MSs. In particular, the internal and external knowledge strategies are compared. Thereafter, the patent-based methodology for identifying raw technologies with specific end products and components is defined and the sets used to characterize knowledge are identified. After the results description, discussions on theoretical, methodological and practical implications are presented. Finally, the conclusions close the work.

## 2. Theoretical background

### *2.1 The importance of original equipment manufacturer knowledge*

The use of knowledge in technological innovation is part of a recombinant process that involves various types of sources to generate different valuable innovation ideas (Schumpeter, 1947). Companies drive innovation through their stock of accumulated knowledge (Brusoni, 2001; Yoon *et al.*, 2017). In high-tech industry, OEMs are seen as an important source of knowledge (Hsiao *et al.*, 2020; Pihlajamaa *et al.*, 2019). Smartphone OEMs accumulate and hold knowledge on the design of the smartphone and in some components, as in the case of the Samsung display (Lee *et al.*, 2020). The knowledge that the OEM should have to control the innovation of its end product is crucial (J. Lee and Veloso, 2008). Many companies have considered and evaluated their internal knowledge capacity to improve their ability to produce innovative product (Ernst, 2005). This knowledge is embedded in several entities, such as organizational culture, work routines, information systems, documents and R&D personnel (Alavi and Leidner, 2001). The ability of companies in creating, sharing and using knowledge is the main factor that impacts on competitiveness (Carlsson *et al.*, 1996).

For this reason, according to knowledge-based view theories, knowledge can be considered as the most strategic resource available for a company (Alegre *et al.*, 2013; Grant, 1996). Effective knowledge management can improve performance in various business processes such as problem-solving or new product development (Marsh and Stock, 2006; Palacios *et al.*, 2009). In high-tech industries where the market is changing constantly, knowledge is essential for achieving high market performance (Alegre *et al.*, 2013). Especially when the end product is complex, the OEM should accumulate high levels of knowledge. However, it is not obvious that the OEM is perfectly familiar with both the end product and the single modules. Takeishi (2002) found that it is important to preserve OEM knowledge about specific components to properly integrate them into their end product. Additionally, OEMs may be interested in preserving component knowledge internally to better manage the risks arising from purchasing strategies (Burton and Galvin, 2018; Lee *et al.*, 2020). Through modularization, OEMs could use black-box integration for some components and preserve its knowledge only on standard interfaces to facilitate the integration of the component into the final product (Howard and Squire, 2007).

However, as the smartphone is a complex product, it is difficult to understand if the OEM is the only actor preserving the knowledge to satisfy its final customers. Indeed, the component knowledge that the OEM should retain on single modules to have an effect on market satisfaction was little investigated.

### *2.2 The role of external knowledge from suppliers*

An important role for knowledge management is played by external actors, such as suppliers of materials, components and equipment (Liao and Barnes, 2015; Simao and Franco, 2018). Many studies confirmed that the integration of suppliers within the production process is a crucial factor for improving product quality and product innovation for the OEM (Makkonen *et al.*, 2018). One of the main reasons concerns the strategic importance of external knowledge on technological innovations (Cruz-González *et al.*, 2014;

Vrontis *et al.*, 2017; Yu and Chen, 2020). External knowledge management is recognized as the process of acquiring, developing, sharing and using external knowledge (Chyi Lee and Yang, 2000).

OEMs should diversify their external knowledge to absorb more domains of technological knowledge (Lin and Patel, 2019; Papazoglou and Spanos, 2018). Some researchers found that the exchange of external knowledge need to be accepted with only a part of partners to avoid opportunistic behaviour from other competitors (Homfeldt *et al.*, 2019). Regarding the dilemma between internal and external knowledge, Rosenkopf and Nerkar (2001) found that internal knowledge has less impact on subsequent technological evolution than the knowledge acquired outside the company. Laursen and Salter (2006) found that, in general, external knowledge can significantly improve the innovative performance of the firm.

In high-tech industries, it is necessary to carry out new products to market quickly, with innovative features and lower costs through the contribution of external actors who support product innovations and provide external resources and knowledge (Chang, 2017). Suppliers are seen as an important source of knowledge (Bozdogan *et al.*, 1998; Solesvik and Westhead, 2010), and suppliers integration is critical for product innovation performance, as the manufacturer can incorporate their complementary knowledge (Chang, 2017). Companies are increasingly forced to rely on partners' core competencies to improve the ability to develop better products (Emden *et al.*, 2006). Access to external knowledge allows to add new ideas that renew the knowledge of the company (Chesbrough *et al.*, 2008). Firms can connect with each other to ensure the acquisition of knowledge that creates a competitive advantage: sharing knowledge among supply chain partners is an important resource of innovation that allows companies to acquire skills (Varriale *et al.*, 2021a; Sun *et al.*, 2020).

As the smartphone is a product composed by hundreds of components, (Li, 2012) modularization and knowledge management strategies could be combined (Sanchez and Mahoney, 1996). The OEMs provide the architecture of the modular product, coordinate supplier innovation and module design and ultimately integrate these modules within the end product (Linden *et al.*, 2009; Sanchez and Mahoney, 1996). Modularization allows MSs to be innovative by experimenting with new projects until they do not deviate from the established parameters (Pil and Cohen, 2006). In particular, using black-box integration, the supplier has the task of developing and producing innovative components that will be integrated into the end product via standard interfaces (Patrucco *et al.*, 2017). In this case, knowledge is embedded into the innovative component produced by the supplier, and consequently, the OEM acquires it indirectly (Howard and Squire, 2007).

However, a high level of OEM knowledge on the component could underestimate the external knowledge of the partners, and the importance of external resources could be ignored (Chen *et al.*, 2020). A highly specific component knowledge can increase the overlapping of knowledge between the OEM and its suppliers, leading to a loss of flexibility on the components purchasing and, consequently, managing high production costs (Zhou *et al.*, 2019). A high level of end product knowledge allows to effectively combine external knowledge from external components, improving the efficiency of the integration of components in the basic end product (Chen *et al.*, 2020; Zhou *et al.*, 2019).

The role of suppliers is often obscure regarding the knowledge dynamics of the final market. The market recognizes the OEM as a promoter of knowledge and innovation. Previous studies have assessed how supplier knowledge can impact on the OEM performance (Laursen and Salter, 2006; Rosenkopf and Nerkar, 2001). This study differs from these because it investigates on what knowledge of OEMs and MSs has an impact on the final market. As literature affirms the importance of knowledge for both OEMs and MSs, what knowledge of which actor contributes significantly to the final market? This study, combining the effects of modularity and knowledge of both the OEM and the MS, tries to explore what knowledge and which level of knowledge concentration on which component of which actor has an impact on the final market. Moreover, the study detects which level of component knowledge (general vs specific) is relevant for the two players to achieve better market satisfaction.

## 3. Methodology

The suggested methodology supports the evaluation of high-tech components for the smartphone industry. In this market, the performance of the end product strongly depends on the value of each component and how it is integrated within the end product. To study the technological knowledge of OEMs and MSs, it is necessary to identify data on products and components that can be associated with these two players. The use of patent data allows to associate the relationships among the end product, the component and the component applied to a specific end product for the considered players. In particular, literature has widely recognized the value of patent data for knowledge management issues in high-tech industries (Lee *et al.*, 2020). Several researchers state that indicators based on patent data can provide measures of the knowledge possessed by the company and evaluate its impacts on the final market (Cammarano *et al.*, 2020; Jaffe and Trajtenberg, 2002; Liu *et al.*, 2021). To stratify knowledge, the patent data will be analysed with a specific original data filter procedure.

### *3.1 Data collection*

The methodology acquires information about a specific component/end product, providing an accurate tool to examine knowledge of both OEMs and MSs. This study analyses patent data to detect which knowledge between OEM and MS affects the market satisfaction. The analysis is based on data extracted from industry analysis providing disassembly reports outlining the list of components to be assembled into the final product (Linden *et al.*, 2009; Soosay *et al.*, 2008). In particular, the analysis was conducted on a sample of 168 smartphones launched from 2003 to 2017, considering the best performing products on the market for the following OEMs: Alphabet, Apple, AsusTek Computer, BBK Electronics, HTC, Huawei Technologies, Lenovo, LG Electronics, Motorola, Nokia, Research in Motion, Samsung, Sony, Sony Ericsson, Xiaomi and ZTE. For these smartphones, 11 main components were analysed: accelerometer, application processor, camera module, DRAM, GPS chip, HDI PCB, image sensor, power amplifier, proximity sensor, touchscreen controller and WiFi/Bluetooth chip. The choice of these components is based on their higher market value and their potential impact on market satisfaction. Moreover, all the components considered were outsourced to a MS. From the analysis of disassembly reports, 144 different MSs were identified (Appendix).

The information on the technological knowledge of each component and product was obtained from the analysis of patents by downloading data from the PATSTAT database version October 2018. The patent portfolio was extracted for each actor, considering the patents filed with the US Patent and Trademark Office (USPTO), European Patent Office (EPO) or World Intellectual Property Organization (WIPO). Only the first granted patent application of each patent family was considered for the protection of a specific technological knowledge (Harhoff *et al.*, 2003; Johnstone *et al.*, 2012). Therefore, the overall patent portfolio is a starting point for the analysis of the whole stock of knowledge. It consists of the list of patent applications filed before the launch date (*t*) of the smartphone on which the component is assembled. Furthermore, in consideration of the rapid development and technological obsolescence that characterizes the smartphone industry, patents filed before five years from the launch date (*t-5*) were excluded, conceptually following the theories on organizational learning and on knowledge management (Cammarano *et al.*, 2019; Harlow, 2019).

Recently, one of the most used methodologies to analyse patent data is content analysis which is more accurate than the analysis of International Patent Classification codes, as confirmed by literature (Jun and Park, 2013; Tseng *et al.*, 2007; Yoon and Park, 2007). Through content analysis, a list of keywords is extracted from the patent portfolio of the analysed companies, with information on their frequency of occurrence. Following various scholars, the content analysis is performed on the abstract field of a patent application (Aaldering and Song, 2019; Kim *et al.*, 2019; Xie and Miyazaki, 2013). For each patent, the array of keywords extracted from the abstract field was generated using T-Lab.

The main problem with this methodology is the selection of the keywords (Costantini *et al.*, 2015; Valverde *et al.*, 2017). The search conditions for defining the keyword list of a component must come from experts in the relevant technology sector, who are asked to identify them (Jeon *et al.*, 2011). Hence, a team of ten experts in the field of hardware and electronics technology was involved for two months. Table 1 shows an example of keywords selection related to the WiFi/Bluetooth chip. Table 2 presents the keywords associated with the smartphone.

The robustness of the instrument was verified by comparing it to other previous studies (Bessen and Hunt, 2007; Haaker *et al.*, 2021; Hall and MacGarvie, 2010; Layne-Farrar, 2012; Varriale *et al.*, 2021b).

As shown in Figure 2, after detecting the keywords for the smartphone and the components, the methodology uses filters to associate patents with the smartphone and its components starting from the companies' stock of knowledge. A first filter identifies the technologies that can be associated with a component for both the OEM and the MS, regardless the end product on which this technology can be integrated ($OEM_{comp}$ and $SUPPLIER_{comp}$). In this set, there are component technologies that could be useful for different products such as: PCs, tablets, TVs and even smartphones. In this case, the patents that have at least one keyword referring to the component within the patent abstract are included.

Subsequently, the methodology applies a second filter including the set of technologies that can potentially be integrated into the smartphone. This filter is applied to patent portfolio of

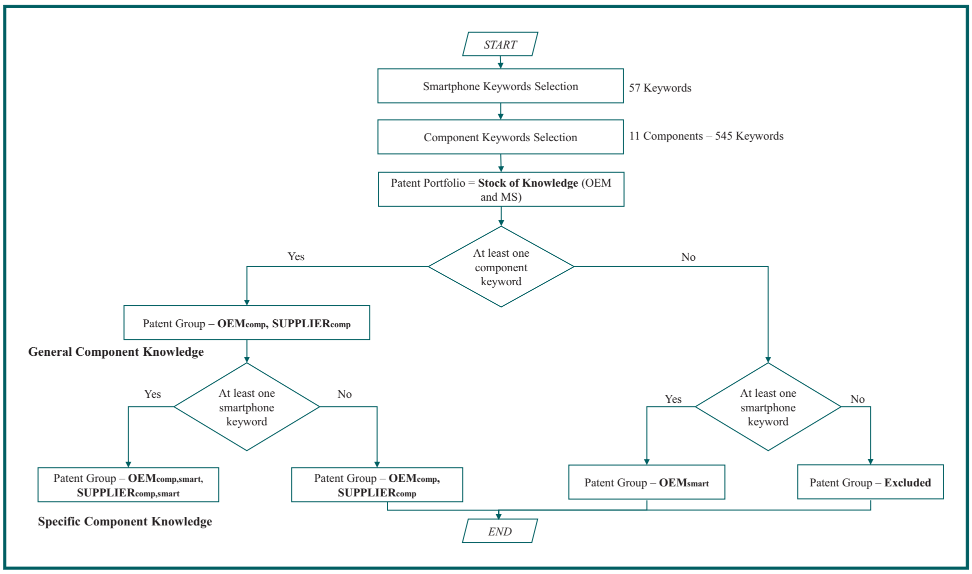
**Table 1** List of keywords associated to the WiFi/Bluetooth chip

| | | |
|---|---|---|
| BLUETOOTH | NETWORK | WIRELESS_DEVICE |
| BLUETOOTH_COMMUNICATION | NETWORK_COMMUNICATION | WIRELESS_DEVICES |
| BLUETOOTH_COMMUNICATIONS | NETWORK_COMMUNICATION_ASSOCIATIONS | WIRELESS_HANDSET |
| BLUETOOTH_CONNECTION | NETWORK_COMMUNICATIONS | WIRELESS_HANDSET |
| BLUETOOTH_DEVICE | NETWORK_CONNECTION | WIRELESS_INTERNET |
| BLUETOOTH_DEVICES | NETWORK_CONNECTIONS | WIRELESS_LAN |
| BLUETOOTH_HEADSET | NETWORK-CONNECTED | WIRELESS_MOBILE |
| BLUETOOTH_RADIO | NETWORK-CONNECTING | WIRELESS_NETWORK |
| BLUETOOTH_SIGNALS | PORTABLE_INTERNET | WIRELESS_NETWORK |
| BLUETOOTH_SYSTEM | WI-FI_CONNECTION | WIRELESS_NETWORK_DEVICE |
| BLUETOOTH_TRANSMISSION | WI-FI_NETWORK | WIRELESS_PHONE |
| BLUETOOTH_TRANSMISSIONS | WI-FI_RADIO | WIRELESS_PHONE_SYSTEM |
| BLUETOOTH-CONNECTED | WI-FI_SIGNAL | WIRELESS_TRANSCEIVER |
| BLUETOOTH-CONNECTION | WIFI | WIRELESS_WI-FI |
| CELLULAR_INTERNET | WIFI_CONNECTION | WIRELESS-COMMUNICATING |
| CELLULAR_NETWORK | WIFI_NETWORK | WIRELESS-COMMUNICATING_UNIT |
| CELLULAR_WIRELESS | WIRELESS | WIRELESS-CONNECTION |
| CELLULAR-TELEPHONE_NETWORK | WIRELESS_ANTENNA | WIRELESS-TELEPHONE |
| HANDHELD_WIRELESS | WIRELESS_CELLULAR | WIRELESSCOMMUNICATION |
| INTERNET | WIRELESS_CHANNEL | WIRELESSNETWORK |
| INTERNET_NETWORK | WIRELESS_COMMUNICATING | WLAN |
| INTERNET_PHONE | WIRELESS_COMMUNICATION | WLAN_NETWORK |
| INTERNETPHONE | WIRELESS_COMMUNICATION_SYSTEM | WLAN-NETWORK |
| MOBILE_WIRELESS | WIRELESS_COMMUNICATIONS | |
| MOBILE_WIRELESS_DEVICE | WIRELESS_CONNECTION | |

**Table 2** List of keywords associated to smartphone

| | | | |
|---|---|---|---|
| CELL_PHONE | HAND-PHONE | MOBILE-TELEPHONE | SMARTPHONE |
| CELL_PHONES | HANDPHONE | PHONE | SMARTPHONES |
| CELL-PHONE | HANDSET | PHONE_DEVICES | TELEPHONE |
| CELL-PHONES | IPHONE | PORTABLE_CELLULAR_TELEPHONE | TELEPHONES |
| CELLULAR | MEDIA_DEVICE | PORTABLE_DEVICE | WIRELESS_CELLULAR |
| CELLULAR_PHONE | MEDIA_DEVICES | PORTABLE_DEVICES | WIRELESS_DEVICE |
| CELLULAR_PHONES | MOBILE | PORTABLE_ELECTRONIC_DEVICE | WIRELESS_DEVICES |
| CELLULAR_TELEPHONE | MOBILE_DEVICE | PORTABLE_HANDSET | WIRELESS_HANDSET |
| CELLULAR_TELEPHONES | MOBILE_HANDSET | PORTABLE_PHONE | WIRELESS_PHONE |
| CELLULAR-TELEPHONE | MOBILE_HANDSETS | PORTABLE_TELEPHONE | WIRELESS_TELEPHONE |
| COMMUNICATION_DEVICE | MOBILE_PHONE | SMART_DEVICES | WIRELESS_TELEPHONES |
| COMMUNICATION_DEVICES | MOBILE_PHONES | SMART_PHONE | WIRELESS-TELEPHONE |
| COMMUNICATION-DEVICE | MOBILE_TELEPHONE | SMART-DEVICE | |
| ELECTRONIC_DEVICE | MOBILE_TELEPHONES | SMART-PHONE | |
| ELECTRONIC_DEVICES | MOBILE-PHONE | SMARTMOBILE | |

**Figure 2** Patent classification using text mining




both the OEM and the MS ($OEM_{comp,smart}$ and $SUPPLIER_{comp,smart}$). This set includes the patents that have within the abstract at least one keyword related to the component and one associated to the smartphone. In this way, two levels of knowledge are identified: a general one, concerning the component *per se*, and a more specific one, related to the component applications for smartphones. This segmentation allows to quantify the accumulation of knowledge on the focal component by the OEM and the MS.

Finally, a last filter was used to create a control variable indicating the OEM's knowledge on the end product ($OEM_{smart}$). This filter is needed only for the OEM, it being the primary owner of the end product. This set includes patents abstracts that have at least one keyword related to the smartphone and none related to the component. Patents excluded have neither a smartphone keyword nor a component keyword at the same time.

### 3.2 Independent variables

The statistical unit is the couple smartphone-component of each smartphone produced by the OEM. The groups identified previously were used to create variables that highlight the OEM and MS knowledge features. Starting from the patent portfolio (STOCK), four variables were identified to evaluate the component knowledge of each player.

Regarding the OEM:

- $OEM_{comp}$ indicates the knowledge accumulated by the company on the component without considering its integration within a specific end product. This variable is estimated as the number of patents owned by the OEM related to component knowledge.
- $OEM_{comp,smart}$ indicates the knowledge that the OEM has on the components related to the end product on which they are integrated. The variable measures the knowledge accumulated on component technologies specifically developed for smartphone applications. It is estimated as the number of patents owned by the OEM related to component knowledge for the specific end product.
- $OEM_{focal}$ is defined as the ratio between $OEM_{comp}$ and STOCK and corresponds to the concentration of knowledge on the focal component regardless its integration in a specific end product application.
- $OEM_{spec}$ is defined as the ratio between $OEM_{comp,smart}$ and $OEM_{comp}$ that defines the concentration of knowledge on the focal component integrated on the specific end product.

In a similar way, four variables were considered for MSs, starting from their patent portfolio. In this case, the variables define the technological capacity of the company. As in the data set the modules considered are always outsourced, these variables assess the value of the supplier's technological experience for the specific component:

- $SUPPLIER_{comp}$ implies the technological capacity of a MS in realizing the component without considering its final application.
- $SUPPLIER_{comp,smart}$ is the supplier's technological capacity in developing the component for the smartphone.
- $SUPPLIER_{focal}$ suggests the concentration of knowledge that the MS has for the component in general.
- $SUPPLIER_{spec}$ indicates the concentration of knowledge that the MS has for the component applications in a specific end product.

### 3.3 Dependent variable

A Total_score was collected by *alaTest.com* to assess market satisfaction for each smartphone analysed. alaTest.com is a service that helps consumers in their purchasing decisions, informing them about the product quality (e.g. electronics, computers, smartphone, photography, home and appliances). This website uses a complex sentiment analysis algorithm that collects product quality scores and reviews from several online shopping and specialized technology sites. Thereafter, these scores are standardized according to the age of the product and the experience of the users and developed into an impartial result named alaScore. The variable has a range from 0 to 100: for the purpose of this study, the collected variable was used as a proxy of the market satisfaction for the specific smartphone.

### 3.4 Control variables

As 11 components are analysed, 11 dummies are added, taking value 1 if the couple smartphone-component is related to the specific component and 0 otherwise. The use of dummy variables is essential to capture knowledge management peculiarities that can be associated with specific components.

In addition, four variables are considered to control the role of the OEM:

- STOCK corresponds to the size of the total patent portfolio owned by the OEM from *t* to *t – 5*, which is a proxy of its overall technological knowledge.
- $OEM_{smart}$ is the number of patents owned by the OEM whose abstract contains keywords directly associated with the smartphone. This variable is a proxy of the technological knowledge related to the smartphone.
- $OEM_{\%smart}$ is the ratio between $OEM_{smart}$ and STOCK, which highlights the concentration of R&D and experience of the OEM on improving its knowledge on the smartphone. For instance, if the company develops patents only in the smartphone industry, then it will have a percentage equal to 100%.
- %Market_share is the market share reached by the OEM in the smartphone market in the quarter preceding the one corresponding to the launch date of the smartphone, as a proxy of its market and brand reputation (Statista, 2021). The use of this variable is necessary because the market results obtained in the focal period could be a consequence of the OEM's previous reputation.

In Table 3, a synthesis of all the variables included in the work is reported.

**Table 3** Variables under investigation

| *Variable* | *Player* | *Investigated area* | *Level of analysis* | *Use in regression models* | *Definition* |
|---|---|---|---|---|---|
| $OEM_{comp}$ | OEM | Component | General | Independent | Number of OEM's patents filed from *t* – 5 to *t* including component-related keywords |
| $OEM_{comp,smart}$ | OEM | Component | Specific | Independent | Number of OEM's patents filed from *t* – 5 to *t* including both component-related and smartphone-related keywords |
| $OEM_{focal}$ | OEM | Component | General | Independent | Ratio of OEMcomp on STOCK |
| $OEM_{spec}$ | OEM | Component | Specific | Independent | Ratio of OEMcomp, smart on OEMcomp |
| $SUPPLIER_{comp}$ | MS | Component | General | Independent | Number of MS's patents filed from *t* – 5 to *t* including component-related keywords |
| $SUPPLIER_{comp,smart}$ | MS | Component | Specific | Independent | Number of MS's patents filed from *t* – 5 to *t* including both component-related and smartphone-related keywords |
| $SUPPLIER_{focal}$ | MS | Component | General | Independent | Ratio of SUPPLIERcomp on the MS's patent portfolio |
| $SUPPLIER_{spec}$ | MS | Component | Specific | Independent | Ratio of SUPPLIERcomp,smart on SUPPLIERcomp |
| Dummies | MS | Component | | Control for component | Value 1 if the statistical unit is related to the focal component and 0 otherwise |
| STOCK | OEM | Firm | General | Control for firm | Total number of OEM's patents filed from *t* – 5 to *t* |
| $OEM_{smart}$ | OEM | End product | Specific | Control for firm | Number of OEM's patents filed from *t* – 5 to *t* including smartphone-related keywords |
| $OEM_{\%smart}$ | OEM | End product | Specific | Control for firm | Ratio of OEMsmart on STOCK |
| %Market_share | OEM | Firm | | Control for firm | Market share reached in the quarter preceding the launch date of the smartphone |
| Total_score | OEM | End product | | Dependent | Market satisfaction collected from alaTest.com |

## 4. Results

### *4.1 Descriptive statistics*

Table 4 shows the descriptive statistics for the variables under investigation. The average OEMs' portfolio includes 1,419 patents developed in the five years preceding the launch of the focal smartphone. Among these, 359 concern knowledge that can be associated with the smartphones ($OEM_{smart}$), with a knowledge concentration on smartphone applications of about 29% ($OEM_{\%smart}$). Knowledge focalization on components independently from their final application is on average 16% ($OEM_{focal}$), whereas knowledge specialization on components specifically developed for smartphones is 30% ($OEM_{spec}$). From this point of view, the OEM's accumulated knowledge focuses mainly on the product it markets and less on the components.

By comparing MSs and OEMs, the former are more focused on general component knowledge (24% $SUPPLIER_{focal}$ vs 16% $OEM_{focal}$); the latter have higher specific concentration on component knowledge specifically accumulated for the smartphone applications (30% $OEM_{spec}$ vs 10% $SUPPLIER_{spec}$).

Statistically significant differences are found as to the different components, with the highest focalization on general purpose component technologies on image sensors for OEMs (61% $OEM_{focal}$) and on power amplifiers for MSs (43% $SUPPLIER_{focal}$) and highest knowledge specialization on the development of components for smartphone applications on WiFi/Bluetooth chips for both OEMs and MSs (39% $OEM_{spec}$, 29% $SUPPLIER_{spec}$).

Finally, the Total_score has an average value of almost 88 on a theoretical maximum value of 100: the main reason for such a high value is because of the choice of the best top range and most reviewed top-tier smartphones.

### *4.2 Regression analysis*

Linear regression analyses were performed using the Total_score as the dependent variable and the different degrees of technological knowledge of the two actors as predictors. The analysis allows to evaluate which knowledge can influence the final market, distinguishing the role of OEMs and MSs. This tool highlights which levels of experience, knowledge and skills are necessary to satisfy the final market for each actor. Moreover, it is possible to understand if the relationship between OEM and MS component knowledge and market satisfaction is valid in general or only for some modules.

Table 5 shows five regression models. In M1, only the independent variables referring to the OEM and the MS and the dummies associated to the components are included, using WiFi/Bluetooth as the reference category. From M2 to M5, each firm-level control variable is added one by one. All regressions have adjuster R-square values ranging from 0.051 to 0.065, with statistical significance for the F-test higher than $10^{-3}$. Collinearity tests were performed, and all VIF values are lower than 5.

Interestingly, the focalization of the OEM on general purpose component knowledge ($OEM_{focal}$) has a positive effect in all regression models. This result highlights the importance for OEMs to accumulate general knowledge and experience on single components in general even if their development is outsourced to suppliers. This outcome underlines a general rule showing the importance of concentrating knowledge on all the high-value components, although purchased from external suppliers, to achieve a market advantage.

The variables $OEM_{comp,smart}$ and $OEM_{spec}$ have a positive effect on the final market in four of five models, being excluded only when $OEM_{smart}$ (M3) and $OEM_{\%smart}$ (M4) are included as controls. Therefore, the OEM's specific knowledge on components specifically developed for smartphones helps it to better perform on the market, despite the black-box integration strategy adopted.

**Table 4** Sample description

| Component | N | $OEM_{comp}$ | | $OEM_{comp,smart}$ | | $OEM_{focal}$ | | $OEM_{spec}$ | | $SUPPLIER_{comp}$ | | $SUPPLIER_{comp,smart}$ | | $SUPPLIER_{focal}$ | | $SUPPLIER_{spec}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | | |
| Accelerometer | 152 | 33 | 1.07 | 12 | 1.38 | 3% | 0.78 | 31% | 0.78 | 32 | 0.92 | 1 | 2.99 | 6% | 0.92 | 6% | 1.89 |
| Application processor | 154 | 249 | 1.47 | 51 | 1.28 | 15% | 0.64 | 27% | 0.82 | 255 | 1.42 | 7 | 2.84 | 9% | 0.63 | 3% | 2.44 |
| Camera | 84 | 85 | 1.46 | 23 | 1.36 | 58% | 2.24 | 24% | 0.76 | 205 | 0.73 | 23 | 0.84 | 20% | 0.78 | 12% | 0.56 |
| DRAM | 142 | 172 | 1.15 | 36 | 1.38 | 10% | 0.62 | 25% | 0.93 | 133 | 1.68 | 4 | 1.22 | 38% | 0.58 | 3% | 1.15 |
| GPS chip | 145 | 296 | 1.10 | 101 | 1.24 | 19% | 0.29 | 30% | 0.62 | 347 | 0.91 | 94 | 1.16 | 19% | 0.29 | 21% | 0.48 |
| HDI PCB | 140 | 22 | 1.27 | 9 | 1.76 | 1% | 0.67 | 35% | 0.96 | 6 | 1.09 | 0 | 3.08 | 24% | 1.16 | 3% | 3.59 |
| Image sensor | 111 | 171 | 1.07 | 44 | 1.13 | 61% | 1.59 | 31% | 0.81 | 224 | 0.53 | 18 | 0.95 | 29% | 0.76 | 7% | 0.74 |
| Power amplifier | 133 | 255 | 1.06 | 85 | 1.26 | 22% | 0.27 | 30% | 0.61 | 86 | 2.29 | 6 | 4.97 | 43% | 0.46 | 14% | 1.91 |
| Proximity sensor | 134 | 56 | 1.19 | 15 | 1.52 | 3% | 0.63 | 24% | 0.81 | 26 | 1.92 | 2 | 3.05 | 11% | 0.53 | 8% | 1.46 |
| Touchscreen controller | 121 | 141 | 1.17 | 48 | 1.37 | 11% | 0.54 | 30% | 0.54 | 74 | 0.70 | 3 | 1.22 | 39% | 0.72 | 5% | 1.10 |
| WiFi/Bluetooth chip | 133 | 350 | 1.83 | 124 | 1.35 | 21% | 0.51 | 39% | 0.54 | 263 | 1.18 | 84 | 1.30 | 21% | 0.50 | 29% | 0.25 |
| *Total* | *1,449* | *169* | *1.78* | *50* | *1.77* | *16%* | *2.53* | *30%* | *0.76* | *148* | *1.60* | *22* | *2.71* | *24%* | *0.89* | *10%* | *1.39* |
| Variance between | | 1,689,928 | | 199,318 | | 3 | | 0.26 | | 1,827,526 | | 161,416 | | 19,960 | | 8,815 | |
| Variance within | | 79,583 | | 6,597 | | 0 | | 0.05 | | 44,128 | | 2,490 | | 295 | | 123 | |
| F | | 21.24 | | 30.21 | | 22.41 | | 5.19 | | 41.41 | | 64.83 | | 67.64 | | 71.89 | |
| Significance | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |

| *Component* | *N* | STOCK | | $OEM_{smart}$ | | $OEM_{\%smart}$ | | % Market_share | | Total_score | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ | $\mu$ | $\sigma/\mu$ |
| Accelerometer | 152 | 1,353 | 1.33 | 295 | 1.21 | 26% | 0.61 | 10% | 0.93 | 87,72 | 0.03 |
| Application processor | 154 | 1,460 | 1.24 | 384 | 1.23 | 30% | 0.60 | 10% | 0.98 | 87,28 | 0.03 |
| Camera | 84 | 769 | 1.83 | 216 | 1.46 | 33% | 0.53 | 7% | 1.17 | 87,71 | 0.03 |
| DRAM | 142 | 1,532 | 1.22 | 412 | 1.17 | 31% | 0.56 | 9% | 1.04 | 87,38 | 0.03 |
| GPS chip | 145 | 1,520 | 1.20 | 392 | 1.21 | 28% | 0.61 | 11% | 0.87 | 87,54 | 0.03 |
| HDI PCB | 140 | 1,575 | 1.18 | 403 | 1.20 | 29% | 0.61 | 11% | 0.92 | 87,39 | 0.03 |
| Image sensor | 111 | 1,553 | 1.16 | 434 | 1.13 | 32% | 0.55 | 10% | 0.96 | 87,31 | 0.03 |
| Power amplifier | 133 | 1,229 | 1.00 | 356 | 1.31 | 28% | 0.60 | 11% | 0.85 | 87,53 | 0.03 |
| Proximity sensor | 134 | 1,476 | 1.26 | 313 | 1.09 | 26% | 0.59 | 11% | 0.93 | 87,89 | 0.03 |
| Touchscreen controller | 121 | 1,438 | 1.33 | 312 | 1.10 | 27% | 0.58 | 10% | 0.91 | 87,65 | 0.03 |
| WiFi/Bluetooth chip | 133 | 1,460 | 1.25 | 385 | 1.25 | 28% | 0.59 | 11% | 0.91 | 87,54 | 0.03 |
| *Total* | *1,449* | *1,419* | *1.25* | *359* | *1.22* | *29%* | *0.59* | *10%* | *0.94* | *87,53* | *0.03* |
| Variance between | | 5,065,696 | | 453,190 | | 665 | | 121 | | 5 | |
| Variance within | | 3,130,797 | | 191,119 | | 285 | | 92 | | 8 | |
| F | | 1.62 | | 2.37 | | 2.34 | | 1.32 | | 0.58 | |
| Significance | | 0.10 | | 0.01 | | 0.01 | | 0.22 | | 0.83 | |

**Table 5** Regression models

| *Model* | *M1* Adjusted $R^2$ | *M1* F | *M1* Significance | *M2* Adjusted $R^2$ | *M2* F | *M2* Significance | *M3* Adjusted $R^2$ | *M3* F | *M3* Significance | *M4* Adjusted $R^2$ | *M4* F | *M4* Significance | *M5* Adjusted $R^2$ | *M5* F | *M5* Significance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $OEM_{comp}$ | 0.000 | 0.362 | 3.108 | 0.000 | 0.336 | 4.090 | 0.000 | 0.481 | 3.117 | 0.000 | 0.274 | 3.200 | 0.000 | 0.382 | 3.232 |
| $OEM_{comp.smart}$ | 0.005 | 0.008 | 3.520 | 0.005 | 0.026 | 3.566 | 0.000 | 0.979 | 5.049 | 0.005 | 0.013 | 3.563 | 0.006 | 0.009 | 3.744 |
| $OEM_{focal}$ | 0.596 | 0.006 | 1.218 | 0.603 | 0.005 | 1.218 | 0.599 | 0.006 | 1.218 | 0.611 | 0.005 | 1.222 | 0.637 | 0.004 | 1.264 |
| $OEM_{spec}$ | 1.281 | 0.007 | 1.353 | 1.411 | 0.003 | 1.361 | 0.998 | 0.036 | 1.384 | 0.742 | 0.263 | 2.650 | 1.141 | 0.026 | 1.433 |
| $SUPPLIER_{comp}$ | 0.001 | 0.334 | 4.132 | 0.001 | 0.419 | 4.141 | 0.001 | 0.373 | 4.134 | 0.001 | 0.320 | 4.135 | 0.001 | 0.427 | 5.209 |
| $SUPPLIER_{comp.smart}$ | 0.001 | 0.847 | 5.004 | 0.001 | 0.768 | 5.008 | 0.001 | 0.815 | 5.004 | 0.000 | 0.915 | 5.031 | 0.001 | 0.730 | 6.141 |
| $SUPPLIER_{focal}$ | 0.012 | 0.029 | 1.803 | 0.012 | 0.026 | 1.803 | 0.013 | 0.022 | 1.804 | 0.012 | 0.026 | 1.805 | 0.011 | 0.056 | 1.805 |
| $SUPPLIER_{spec}$ | 0.007 | 0.350 | 1.698 | 0.005 | 0.543 | 1.712 | 0.005 | 0.468 | 1.703 | 0.008 | 0.311 | 1.706 | 0.006 | 0.480 | 1.791 |
| Accelerometer | 1.725 | 0.000 | 2.751 | 1.286 | 0.006 | 2.953 | 1.138 | 0.016 | 3.045 | 1.709 | 0.000 | 2.754 | 1.902 | 0.000 | 2.809 |
| Application processor | 0.972 | 0.033 | 3.119 | 0.811 | 0.075 | 3.149 | 0.584 | 0.206 | 3.264 | 0.889 | 0.054 | 3.195 | 1.107 | 0.021 | 3.071 |
| Camera | 1.062 | 0.037 | 1.910 | 0.892 | 0.079 | 1.926 | 0.676 | 0.188 | 1.980 | 0.924 | 0.077 | 2.014 | 0.955 | 0.091 | 1.894 |
| DRAM | 0.891 | 0.050 | 2.844 | 0.603 | 0.189 | 2.934 | 0.330 | 0.485 | 3.122 | 0.771 | 0.098 | 2.992 | 1.128 | 0.020 | 3.001 |
| GPS CHIP | 0.324 | 0.382 | 2.122 | 0.256 | 0.487 | 2.127 | 0.222 | 0.547 | 2.132 | 0.286 | 0.442 | 2.138 | 0.317 | 0.411 | 2.082 |
| HDI PCB | 1.040 | 0.031 | 2.315 | 0.550 | 0.269 | 2.503 | 0.369 | 0.467 | 2.604 | 1.007 | 0.037 | 2.324 | 1.137 | 0.025 | 2.440 |
| Image sensor | 0.874 | 0.146 | 1.538 | 0.789 | 0.188 | 1.541 | 0.593 | 0.324 | 1.560 | 0.758 | 0.214 | 1.580 | 1.023 | 0.099 | 1.610 |
| Power amplifier | 0.611 | 0.163 | 2.481 | 0.549 | 0.208 | 2.485 | 0.491 | 0.260 | 2.493 | 0.555 | 0.208 | 2.511 | 0.818 | 0.074 | 2.602 |
| Proximity sensor | 1.797 | 0.000 | 2.275 | 1.411 | 0.003 | 2.398 | 1.224 | 0.011 | 2.497 | 1.752 | 0.000 | 2.290 | 2.051 | 0.000 | 2.389 |
| Touchscreen controller | 0.647 | 0.156 | 2.596 | 0.346 | 0.453 | 2.684 | 0.286 | 0.536 | 2.700 | 0.603 | 0.187 | 2.614 | 0.798 | 0.094 | 2.715 |
| STOCK | | | | 0.000 | 0.000 | 2.242 | | | | | | | | | |
| $OEM_{smart}$ | | | | | | | 0.002 | 0.000 | 2.617 | | | | | | |
| $OEM_{\%smart}$ | | | | | | | | | | 0.010 | 0.245 | 2.496 | | | |
| %Market_share | | | | | | | | | | | | | 0.012 | 0.218 | 1.123 |
| (Constant) | 85.693 | 0.000 | | 85.751 | 0.000 | | 85.915 | 0.000 | | 85.617 | 0.000 | | 85.459 | 0.000 | |

On the MS side, the knowledge focalization on general purpose components ($SUPPLIER_{focal}$) has a positive relationship on all models but not the fifth, where the market share is added as a control variable. This result highlights the value of knowledge that the supplier has regarding the components in general. Therefore, even if the concentration of MS's component knowledge is general, it contributes to a better performance on the market satisfaction of the specific end product.

Although the general rule indicates that concentrating on component knowledge in general and for the smartphone components is crucial for the OEM and the MS, the dummy variables of some components have a positive relationship with market satisfaction. Therefore, the general knowledge of MSs and the general and specific knowledge of OEMs is particularly significant for the achievement of market satisfaction for accelerometer and proximity sensors and, to a lower extent, for application processor, camera module, DRAM and HDI PCB.

Regarding firm-level control variables, only STOCK and $OEM_{smart}$ have a positive impact on market satisfaction. Therefore, the success of the smartphone depends on the overall size of the stock of knowledge, which is also a proxy of the company size, and on how much the OEM decides to invest for the smartphone rather than for other end products.

## 5. Discussions

From a theoretical point of view, the insights confirm the role of knowledge of both the OEM and the MS in increasing market satisfaction. However, this is done by investigating different degrees of technological knowledge of both actors in the smartphone industry. By analysing the end product knowledge and the component knowledge of both actors, the work demonstrates that the concentration of component knowledge for both the actors is associated with greater market satisfaction. In literature, no quantitative studies have been found that reveal a direct relationship between the component knowledge and the market satisfaction. Scholars who study knowledge management on modular products mainly focus on the effect of knowledge on the product innovation (Chen *et al.*, 2020; Park, 2018; Yoon *et al.*, 2017; Zhou *et al.*, 2019), while this work focuses on measuring the relationship between end product and component knowledge and the market satisfaction. Therefore, the relationship between knowledge and market satisfaction is relevant for complex and dynamic markets such as the smartphone, where knowledge is a key driver. Specifically, the article contributes to understand the importance of knowledge management in presence of modular products investigating the role of OEMs and MSs in the smartphone industry. Indeed, while the importance of knowledge on complex high-tech products in terms of their end product is widely addressed in literature (Linden *et al.*, 2009; Sanchez and Mahoney, 1996), the role of knowledge of the single players on the single modules deserves an in-depth study. Although several researchers emphasized the general importance of OEMs' and MS's knowledge on single components through surveys or qualitative data (Brusoni, 2001; Zirpoli and Becker, 2011), the issue of modularity in high-tech modular products is increasingly important because of their increasing complexity and higher rate of development. Literature recognizes the importance for the OEM to preserve knowledge (Hsiao *et al.*, 2020; J. Lee and Veloso, 2008); however, at the same time, it also recognizes the MS as a source of knowledge and innovation (Bozdogan *et al.*, 1998; Solesvik and Westhead, 2010). In particular, few studies have suggested the importance in high-tech sectors of preserving knowledge on single modules in general way (Takeishi, 2002). Scholars affirm that by acquiring components, the OEM also incorporates the technological knowledge embedded in such components (Howard and Squire, 2007; Koufteros *et al.*, 2007). However, it is acknowledged that by relying on external partners firms lose knowledge and control about the development of the focal component (Chen *et al.*, 2020). This is particularly critical in black-box approaches, where interfaces allow the OEM to assemble the component and exploit its technological value and innovativeness regardless of its specific technical knowledge on the module (Patrucco *et al.*, 2017). In literature, with reference to other R&D intense industries, few studies suggested that it is necessary to preserve knowledge on supplied components and that the higher level of knowledge facilitates both suppliers selection and purchasing decisions (Burton and Galvin, 2018; Lee *et al.*, 2020). However, this work demonstrates that OEM's knowledge on high-value supplied components makes the difference and is positively associated with market satisfaction. In particular, a general accumulated knowledge about the focal component contributes to the enhancement of market satisfaction, but it is also important the technological knowledge about specific applications of the focal component on the end product. Therefore, this work highlights how the OEM should have both a general and specific knowledge on the modules even if purchased from external suppliers.

However, this article shows that also MS component knowledge is positively associated with market satisfaction, and hence, the MSs plays an important role for the market satisfaction. Although the components analysed are different from a technological point of view, it is theoretically relevant that this result is achieved for each of them by demonstrating a general rule. This general rule is particularly emphasized for some components: accelerometer, application processor, camera module, DRAM, HDI PCB and proximity sensor. Indeed, these components are typical of a smartphone and characterize its overall performance.

When components are purchased from external MSs, it is not so obvious that an OEM should necessarily preserve knowledge on single modules to achieve greater market satisfaction. However, this work demonstrates that there is a positive relationship for both the general and specific concentration of component knowledge of the OEM on the market satisfaction ($OEM_{comp,smart}$, $OEM_{focal}$ and $OEM_{spec}$). In the same way, the association between the concentration of MS's component knowledge and the market satisfaction is not immediate and evident. Indeed, the novelty and the theoretical contribution of the work concern the direct positive relationship between the concertation of MS's general component knowledge and the market satisfaction of the end product ($SUPPLIER_{focal}$). The market satisfaction achieved by both the OEM's and MS's knowledge are independent of the general component knowledge ($OEM_{comp}$ and $SUPPLIER_{comp}$). On the contrary, the greater the concentration of knowledge on the components, the greater the market satisfaction achieved ($OEM_{focal}$, $OEM_{spec}$ and $SUPPLIER_{focal}$). While most of the knowledge management literature does not identify specific and quantified levels of knowledge, the degrees of knowledge suggested with this work have shown different behaviours in terms of linkage with market satisfaction, adding new information and details on the relationship among OEM's and MS's knowledge and market satisfaction. The analysis was performed on the smartphone market, which is only part of the broader high-tech sector. Similar contexts to the smartphone industry, based on innovative modular architectures, could exhibit similar behaviours. This study can be seen as an exploration to evaluate other knowledge dynamics in other high-tech sectors where technological knowledge is among the main drivers of competitive advantage. Products belonging to the macro-category of the high-tech industry and modular products could be featured by similar relationships.

As for the methodological implications, the research highlights the critical aspects of the knowledge management on the smartphone and its components through the analysis of patent data. The stock of knowledge of OEMs and MSs was segmented into different knowledge domains with different levels of detail. Through this study, it was possible to quantify the knowledge needed by the OEM and the MS on the components and indicate which is positively associated to satisfy the final market. Using a double filter on the patent data, it was possible to intercept the technological knowledge of a smartphone on multiple levels (end product/component) and perspectives (general/specific). The article aims to operationalize knowledge using patent data allowing replicability for other future studies. Indeed, the work demonstrates the value of content analysis and text mining techniques to find such an association, resulting in a significant traditional methodological gap that this work intends to overcome. The proposed two-step filtering allows for a solid identification of patents that are truly relevant and applicable to the final product and/or its components. This approach could be used for similar studies on other products and markets, as well as for other research purposes. This particular methodology allows to study innovation strategies on complex and modular products, as it is possible to identify knowledge that refers to specific components with a high level of precision.

As for the practical and managerial implications of the research, the paper proposes one of the first studies on the analysis of the content of patent data linked to the combination of modularization strategies and knowledge management of complex products. The methodology can be implemented in managerial tools to carry out internal knowledge management analyses on each single component and understand the knowledge strategies to be adopted. As the smartphone is a complex product with many technological components, the methodology could be also used to manage the complexity of other high-tech products or to analyse various high-tech sectors. The framework can be used by companies to verify the levels of knowledge possessed on single modules and test the effects of this knowledge on product performance. Additionally, it can be used by industry analysts to conduct studies in high-tech industries featuring modular products. In particular, the work suggests to managers of firms competing in rapidly evolving markets to implement specific knowledge management strategies on modular products that may have an association with market satisfaction. For example, in high-tech industries, specific end product and component knowledge for an OEM could be positively linked to market satisfaction; therefore, focusing knowledge on components of a specific market could be a good practice. Furthermore, the research suggests that a general component knowledge could not have an impact on market satisfaction of a specific end product. Therefore, it is more relevant to focus on the specific component knowledge on a specific end product. The $SUPPLIER_{focal}$ metric could be also used for direct supplier evaluation or be included in more complex supplier evaluation tools in combination with other selection criteria. OEMs managers and decision-makers should select MSs with adequate degrees of component knowledge.

## 6. Conclusions

The work suggests a methodology for investigating the knowledge preserved by OEMs and MSs in the smartphone industry to achieve high market satisfaction. Information on knowledge and technological capability is collected from patent data, suggesting a new approach for finding an association between patented technologies and commercialized products. Product and components knowledge is evaluated through the association of patent data with keywords. This allows to obtain a greater level of detail, if compared to the use of IPC codes, and to analyse how the component knowledge of single players can influence the market satisfaction. Finally, by defining the different levels of knowledge and experience of each actor, it is possible to analyse the influence of knowledge and competence that OEMs and MSs have within their own portfolio. The results confirm the relevance of the tool, with several theoretical, methodological and managerial implications, as shown in the discussion section.

The main limitation of the work concerns the use of patent data to delineate the stock of knowledge possessed by a company, as not all inventions are filed for patents. However, most of the knowledge possessed by companies operating in the high-tech sectors is likely to be covered by intellectual property tools, mainly patents.

Future research could expand the sample of smartphones, as well as the number of technological knowledge and market metrics to be analysed. A further step could be the analysis of other high-tech products based on modular product, to find industry-specific behaviours or similarities with the results found for the smartphone.

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## Appendix

**Table A1** List of 144 supplier analysed

| | | |
|---|---|---|
| AAC Technologies Holdings | Goertek | Qualcomm |
| Advanced Analogic | Goodix | Realtek Semiconductor |
| Aichi Steel | Guangzhou Vigoo Electronic Technology | Renesas |
| Alps Alpine | Heptagon Advanced Micro-Optics | RF Micro Devices |
| Amperex Technology | Honeywell International | Richtek Technology |
| Anadigics | Hosiden Corporation | Robert Bosch |
| Analog Devices | HTC | Rohm |
| Aptina Imaging | Huawei Technologies | Samsung |
| ARM | Huizhou Desay Battery | SanDisk |
| Asahi Kasei Microdevices | Hynix Semiconductor | Sanyo Electric |
| AT&S Austria Technologie | Ibiden | Scud Group Limited |
| Atheros Communications | Infineon Technologies | Seiko Epson |
| Atmel | Intel | Seiko Holdings |
| AU Optronics | Intersil | Sharp |
| Audience | Intrack Tecnologia | Shenzhen Aokal Technology |
| Austriamicrosystems | Invensense | Shenzhen Longrunfa Technology |
| Avago Technologies | J Touch Corporation | Silicon Motion |
| Balda | Japan Display | Simplo Technology |
| BMT Battery | Kionix | Sirf |
| BOE Technology | Knowles Electronics | Skyworks Solutions |
| Broadcom | Korea Circuit Co | Solomon Systech |
| BYD | Kunshan Zhongding Electronics | SONY |
| Capella Micorsystems | LG Chem | Star Micronics |
| Chimei | LG Display | ST-Ericsson |
| Cirrus Logic | LG Innotek | STMicroelectronics |
| Compeq Manufacturing | Lite On Semiconductor | Sunny Optical |
| Comtel | Lite-On Technology | Sunwoda Electronics |
| Coslight Group | Marvell Technology | Synaptics |
| CSR UK | Maxim Integrated Products | Taiwan Semiconductor |
| Cypress Semiconductor | MediaTek | Texas Instruments |
| Daeduck Electronics | Meiko Electronics | Tianjin Zhonghuan Semiconductor |
| DAP Corporation | Melfas | Tianma Microelectronics |
| Dialog Semiconductor | Memsic | Tocad Energy |
| Dolby laboratories | Micron Technology | Toshiba |
| Dongguan Hengkaida Energy Technology | Minebea Mitsumi | TPK |
| Dongguan Qitian electronic | Multek | TPO Displays |
| DSP | Murata Manufacturing | Triquint Semiconductor |
| Dynapack | Nan Ya Plastic Corporation | Truly opto-electronics |
| Elan | Nanya Technology | TWS |
| Elentec | National Semiconductor | TXC Corporation |
| Elpida Memory | Nokia | Unimicron |
| Em-Tech | Novatek Microelectronics | Unitech Industries |
| FDK Corporation | NXP Semiconductors | Universal Scientific Industrial |
| FocalTech Systems | Ofilm Group | Via Technologies |
| Founder Technology | OmniVision Technologies | Wintek |
| Foxconn | Osram Opto Semiconductors | Yamaha Corp |
| Freescale Semiconductor | Panasonic Corporation | Young Fast |
| Fujitsu Semiconductor | Phuong NAM Electric | Zhen Ding Technology |


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