Smart Manufacturing Technologies and International Production Structure: a Patent Analysis Approach

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Abstract

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ABSTRACT

The fourth industrial revolution (popularly labelled Industry 4.0) is driven by smart technologies such as the Internet of Things, Artificial Intelligence, Cloud Computing, Big Data Analytics and Additive Manufacturing. Implementation of said technologies for production activities is able to disrupt Global Value Chains and affect the structure of international production significantly. Industry 4.0 and its effect on production, employment or developing countries has recently received attention among international organizations and business scholars, as it is of great interest to both policy makers and business executives. However, little attention has been given to the impact of smart manufacturing technologies (SMT) on the structure of MNEs' international production activities.

This research aims at filling aforementioned research gap by building hypotheses based on the Industry 4.0 literature, but focusing on the use of smart technologies for production activities and the consequent effect on international production diversity and co-location of production and sales. The central research questions come down to: Are companies that make more use of smart manufacturing technologies more likely (1) to diversify production activities internationally and (2) to co-locate production and sales activities? The expectation is that, driven by smart manufacturing technologies' ability to reduce the importance of economies of scale (R??mann, et al., 2015) and labor costs (Strange & Zucchella, 2017), together with its facilitation of international coordination and monitoring (Buckley
Strange, 2015), multinational enterprises making more use of SMTs would have more internationally diversified production subsidiaries. Moreover, it can be expected that the implementation of SMTs encourages production in closer proximity to end-consumers as a result of both an enlarged freedom in production location choice offered by SMTs and an increasing importance of close relationships with customers due to SMT-induced forward integration tendencies (Porter & Heppelmann, 2014).

To empirically investigate the impact of SMT-use on the international production structure, this paper puts forward a previously untouched measure for SMT-implementation: the number of patents a company owns in smart technologies with a focus on production, obtained through text mining techniques in relevant CPC-fields in the European Patent Office’s PATSTAT database. Thereupon the patent data is matched with firm-level data obtained from Bureau Van Dijk’s ORBIS database through a record-linkage approach. ORBIS’ ownership data allows to relate company SMT-implementation to the international diversity of their production activities and the co-location of MNEs’ production and sales subsidiaries.

KEYWORDS

REFERENCES
Smart Manufacturing Technologies and International Production Structure: a Patent Analysis Approach

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ABSTRACT – This paper aims to empirically investigate the effect of smart manufacturing technology (SMT) use on the international diversity of production activities and the co-location of production and sales activities in the manufacturing sector, a research gap present in the literature on Industry 4.0 and Global Value Chain disruption. Existing literature is generally restricted to theoretical frameworks, country-level analyses or national case studies, strongly focusing on SMTs’ effect on reshoring tendencies, employment or developing countries, neglecting the possible disruptive effect of SMTs on MNEs’ international production structure. Firstly, this paper puts forward a previously unused measure for company SMT-implementation: the amount of patents they own in smart technologies with a focus on production, obtained through text mining techniques in relevant CPC-fields. The provision of one coherent measure for patents in SMTs is a contribution to the Industry 4.0 research field in itself. Secondly, econometric models are used to relate SMT-use to (1) the (international) diversity of production activities and (2) the co-location of production and sales activities.

KEYWORDS – Smart Manufacturing, Industry 4.0, Advanced Robotics, Artificial Intelligence, Internet of Things, Cloud Computing, Additive Manufacturing, internationalization, co-location, patents, Big Data Analytics

1. INTRODUCTION

The fourth industrial revolution (popularly labelled Industry 4.0) is driven by smart technologies such as Artificial Intelligence, the Internet of Things, Cloud Computing and Additive Manufacturing. Implementation of said technologies, in this research relabeled as ‘Smart Manufacturing Technologies (SMTs)’ if used for production activities, is able to disrupt Global Value Chains and affect the structure of (international) production significantly. Industry 4.0 and its effect on production, employment or developing countries has recently received attention among international organizations and business scholars, as it is of great interest to both policy makers and business executives. However, little attention has been given to the impact of SMTs on the structure of MNEs’ international production activities.

This research aims at filling aforementioned research gap by building hypotheses based on the Industry 4.0 literature, but focusing on the use of smart technologies for production activities and the consequent effect on (international) production fragmentation and co-location of production and sales. The central research questions come down to: Are companies after implementing SMTs (1) more likely to (internationally) diversify production activities and (2) more likely to co-locate production and sales activities? Furthermore, this paper puts forward a previously untouched measure for company SMT-implementation: the number of patents they own in smart technologies with a focus on production, obtained through text mining techniques in relevant CPC-fields. The provision of one coherent measure for SMT-patents is a contribution to the Industry 4.0 research field in itself.
2. DEMARCATION OF SMTs

Since the concept of smart manufacturing can seem somewhat ambiguous, it is useful to provide some clear-cut definitions clarifying what the idea exactly comprises. The National Institute of Standards and Technology (NIST) (2017) defines a smart factory as “fully-integrated, collaborative manufacturing systems responding in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs”, whereas Kusiak (2018) describes smart manufacturing as “an emerging form of production integrating manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, control, simulation, data intensive modelling and predictive engineering”.

In this research the focus is on companies making use of smart technologies for production activities, or related to the production process. Four distinct (yet related) smart technologies are considered in this paper, all contributing to a smart production system in a different manner. The first three smart technologies (of which more thorough definitions are provided in Table 1) are the necessary building blocks of smart, integrated production robotics: Artificial Intelligence, the (Industrial) Internet of Things and Cloud Computing. It is important to note that these technologies are complementary and are oftentimes uses simultaneously, however using one of these technologies in manufacturing is sufficient to be defined as smart production. The fourth smart technology of interest to this research is Additive Manufacturing (definition in Table 1), a distinct smart production process in itself.

Table 1 - Smart technologies and definitions in production context

<table>
<thead>
<tr>
<th>Technology</th>
<th>Definition in production context</th>
<th>Sources</th>
</tr>
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<tbody>
<tr>
<td>Artificial Intelligence (AI)</td>
<td>Supporting technology enabling production with autonomous, flexible, and cooperative robots, which have greater capabilities (e.g. recognizing complex patterns, processing information, drawing conclusions and making decisions) and are able to work safely side by side with humans.</td>
<td>Chiarvesio &amp; Romanello (2018)</td>
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<tr>
<td>(Industrial) Internet of Things (IoT)</td>
<td>Technology involved in the embedding of products with sensors, resulting in a connection to standard technologies, enabling these smart products to process data, communicate and even interact with other firm products and processes.</td>
<td>Strange &amp; Zucchella (2017)</td>
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<tr>
<td>Additive Manufacturing (AM)</td>
<td>Collective term for the manufacturing procedure enabling “3D printing” of physical objects (building up successive layers of materials), instead of subtracting materials from the original resource or intermediate product, consequently circumventing the assembly of components.</td>
<td>Hannibal &amp; Knight (2018)</td>
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Smart manufacturing is often referred to as a whole system (e.g. a smart factory), however each smart technology can be implemented in different value chain activities, with different possibilities (Chiarvesio & Romanello, 2018). Since the focus of this research is on the use of
aforementioned smart technologies for production activities and not on their general use, from this point on they will be referred to as Smart Manufacturing Technologies (SMTs).

3. LITERATURE & HYPOTHESES

The following chapter provides an overview of foregoing research upon which hypotheses on the effect of SMT-implementation on the (international) structure of MNEs production subsidiaries are built. Section 3.1 concerns the potential effect of SMT-use on the (international) diversity of production subsidiaries and section 3.2 shifts the focus towards the potential effect of SMT-use on co-location of production and sales subsidiaries tendencies. It is important to consider that certain arguments serve as an explanatory factor for both the (international) diversity of production and the co-location of sales and production activities.

3.1. SMTs & THE (INTERNATIONAL) DIVERSITY OF PRODUCTION

First off all, one of the most disruptive attributes of SMTs is their ability to reduce the importance of economies of scale, consequently facilitating fragmented, decentralized production structures. The explanation for this can be found in the fact that smart robots are more flexible, agile and adaptable (Roland Berger, 2014; Rüßmann, et al., 2015; Sirkin, Zinser & Rose, 2015; Scalabre, 2016; Chiarvesio & Romanello, 2018; Bolwijn, Casella, & Zhan, 2018). For example, it is easier to relocate smart robots within production facilities as they can be reconfigured to perform new jobs or tasks quickly (Sirkin et al., 2015; De Backer et al., 2018). Consequently, SMTs accommodate the production of smaller, more diversified batches (more product variants) at lower marginal costs (Roland Berger, 2014; Rüßmann, et al., 2015; Sirkin et al., 2015; Scalabre, 2016; De Backer, DeStefano, Menon, & Suh, 2018; Chiarvesio & Romanello, 2018, Bolwijn et al., 2018). Additive Manufacturing is undoubtedly the most radical technology when it comes to flexibility and diminishing the importance of economies of scale as it allows every product to be manufactured for roughly the same marginal cost. Consequently, the minimum efficient scale for SMTs, and especially for AM is low, in comparison to traditional manufacturing technologies (Laplume, Petersen, & Pearce, 2016).

In order to handle the flexibility SMTs propose and the possibility of production individualization on demand, faster decision making procedures by virtue of a reduction in organizational hierarchies is necessary (Lasi, Kemper, Fettke, Feld, & Hoffmann, 2014). On top of this, due to the need for reconfigurability of physical assets in the smart factory, vertical separability of the physical assets (e.g. production subsidiaries) and cyberspace (e.g. overarching systems handling the production and collecting data) becomes more attractive (Kusiak, 2018). In general SMTs are expected to favor a larger amount of smaller, geographically fragmented, decentralized manufacturing subsidiaries where value is added locally, but coordination occurs at a centralized instance (Roland Berger, 2014; Weinman, 2016; Bolwijn et al., 2018).
Secondly, SMT-implementation decreases the coordination and transaction costs associated with (internationally) fragmented production by coordinating and synchronizing product and information flows, facilitating the international division of labor in the global factory and allowing firms to locate activities in their optimal place, even when not owning the whole value chain (Buckley & Strange, 2015). SMTs and their ability to coordinate communication more easily is associated with a higher probability of foreign fragmentation (Fort, 2013) and gives firms more options to move towards a dispersed, modular, decoupled production activity network regardless of the location (Rezk, Srai & Williamson, 2016; Götz & Jankowska, 2017). In the past few decades we have seen the emergence of information and communication technologies (ICT) leading to a reduction in transportation, communication and coordination costs, fostering an extension of the geographical boundaries of companies (Chen & Kamal, 2016) and the expectation is that SMTs further facilitate this trend by making it easier and cheaper to transfer a wide array of data and codified knowledge between local production subsidiaries (Roland Berger, 2014; Rezk et al., 2016). For example, the use of Computer Aided Manufacturing (CAD) or Engineering (CAE) makes it possible to share manufacturing designs and specifications in an electronic format between R&D or design labs and production facilities no matter the geographical location (Chen & Kamal, 2016; Rezk et al., 2016) and cloud computing facilitates real-time learning between robots in different locations (De Backer et al., 2018). Moreover, digitalization contributes to an easier transferability of technological firm-specific advantages (Banalieva & Dhanaraj, 2019), making international diversification of production more feasible without losing technological knowledge. Digitalization also makes technological firm-specific advantages more easily copied (Banalieva & Dhanaraj, 2019), however as this study focused on SMTs which are patent-protected, this is expected to be less of a restriction on internationalization. In general, SMTs are believed to facilitate the (international) fragmentation of production subsidiaries.

Thirdly, on top of making it more manageable to coordinate geographically dispersed production activities, SMTs also enable MNEs to make use of Big Data Analytics – the collection, analysis and real-time evaluation of data collected through SMTs (Chiarvesio & Romanello, 2018) – more easily by providing a wide array of computerized data (ranging from product- to consumer-data). Big Data Analytics facilitates the uncovering and monitoring of market trends abroad, stimulating the identification of possible international opportunities (Strange & Zucchella, 2017). This way a lack of foreign market knowledge, often mentioned as a cost related to international diversification (Zaheer, 1995), is significantly reduced, positively affecting the diversity of international production.

Finally, implementation of SMTs is associated with greater system integration both within the company (from production to corporate) and between different companies (from suppliers to distributors) through real-time data sharing (Roland Berger, 2014; Rüßmann et al., 2015; Chiarvesio & Romanello, 2018; Kusiak, 2018). The rationale for this SMT-driven tendency for system integration can be found in the fact that in order to empower truly automated value chains with synergies taking place between companies in the same supply chain (Rüßmann, et al., 2015), other parties such as suppliers, distributors and intermediaries should be capable to handle the complex data generated by SMTs. Only if standardization among different
companies in the supply chain is in place, external connectivity can be realized and data-flows can be accommodated (Kusiak, 2018). In order for multiple firms to work together in the field of SMTs, both firms need to do matching investments as their systems need to be compatible and specialized digital knowledge should be available in both companies. Because the more complex the introduced technologies are (which is certainly the case for SMTs), the more specialized and expensive the complementary investments would need to be, the expectation is that companies in the same value chain as the SMT-implementing firms would be less inclined to devote resources to these systems. The expectation is that this would result in more engagement in both forward and backward integration from the SMT-implementing firm’s part, in order to circumvent suppliers, distributors and intermediaries who are not up to the improved standards of SMTs and consequently not able to provide synergies. The SMT-driven tendency of system integration with different parties in the value chain can be broken down into forward and backward integration, with different expected consequences for companies’ production structure. The forward integration aspect is more relevant for Hypothesis 2 and is therefore discussed in section 3.2, while the backward integration aspect is of interest for Hypothesis 1, as explained in the following paragraph.

The enlargement in the propensity to engage in backward integration driven by the implementation of advanced production technologies can be related to previous literature on similar topics. For example, Chen and Kamal (2016) observed ICT-adoption to be positively correlated with the probability of in-house production and this probability increased the more complex the nature of the technologies. After all, complex scientific knowledge requires greater synchronization and coordination between firm units to maximize profits (Chen & Kamal, 2016). Moreover, Bolwijn et al. (2018) state that in non-commodity supply chains digitalization encourages higher levels of supplier integration for inventory control and product development. De Backer et al. (2018), however observe no significant relation between robotics use and backward participation in developed or emerging countries (although this was measured at the country level). Moreover, backward integration could be preferred in order to avoid leaking valuable technological product or process knowledge to other companies, which would be more easily copied due to digitalization (Banalieva & Dhanaraj, 2019). In general, SMT-implementation is expected to be positively related to backward participation in the value chain, resulting in one integrated production process. Naturally, for MNEs this would result in a larger amount of production subsidiaries (and the international diversity thereof).

Simultaneously an important comment should be made: as manufacturing systems become increasingly complex, the importance of intermediate components in the production process tends to decrease. SMTs are more and more capable of producing final products from raw materials or a smaller number of intermediate components at once. As in smart factories the number of physical component varieties decreases, the importance of traditional suppliers is likely to decline as well (Porter & Heppelmann, 2014). Additive Manufacturing is the most extreme example of this trend as it enables to manufacture whole physical objects directly from raw materials, leapfrogging intermediate products completely (Laplume et al., 2016). Buonafede, Felice, Lamperti and Piscitello (2018), in their country- and sector-level research on AM, claim that this SMT might decrease firms’ reliance on intermediates processed abroad.
and find evidence for this statement in the fabricated metal products, machineries and equipment industries. For multinational enterprises in charge with producing their own intermediate components internally in the first place, implementation of SMTs could lead to a decrease in the amount of production subsidiaries occupied with the manufacturing of intermediate goods. However, as the expectation is that instead of these intermediate good production facilities a more integral production structure with fewer production stages would emerge (Rezk et al., 2016) and given the fact that a lot of companies outsource intermediate component production, the net effect on the (international) diversity of MNEs portfolio of production subsidiaries should still be positive.

In general scholars and experts hypothesize smart manufacturing technologies to favor the decentralization and fragmentation of production, which for multinational enterprises would be reflected in a more (internationally) diversified portfolio of production subsidiaries, resulting in Hypothesis 1.

**Hypothesis 1:** Multinational enterprises have a more (internationally) diversified portfolio of production subsidiaries after implementing SMTs.

3.2. SMTs & THE CO-LOCATION OF PRODUCTION AND SALES

Whereas sections 3.1 deals with the potential consequences of SMT-implementation on the (international) diversity of production subsidiaries of MNEs, this section covers the possible effects in terms of production in closer proximity to end-consumers (measured as the co-location of production and sales subsidiaries).

An imperative element contributing to the expectation of production in closer proximity to customers is the larger freedom of production location choice offered by SMTs, arising from multiple reasons, some of them already touched upon in section 3.1. For starters, the opportunities offered by SMTs regarding decentralized production facilitate the relocation of production activities closer to customers (and thus sales subsidiaries) in order to regain flexibility which was lost through global production networks (De Backer et al., 2018; Dachs et al., 2019a). After all, the search for scale economies was one of the main reasons for the reduced attractiveness of producing in close proximity to end-consumers in the first place (Buonafede et al., 2018). Secondly, as SMT-implementation is expected to stimulate both leapfrogging intermediates and backward integration, establishing production subsidiaries in proximity to suppliers to diminish transporation costs becomes of minor importance, again providing MNEs with more freedom concerning their production location. A third factor contributing to an increased freedom of production location is related to SMTs ability to reduce the importance of labor costs in the production process. In general robotics can be seen as an alternative to low-skilled human labor and smart robotics, with their increasing range of technical capabilities and feasible operations, are becoming more and more intelligent, autonomous and capable of fulfilling complex tasks (Strange & Zucchella, 2017). Consequently, SMTs might eventually be able to displace higher-skilled workers as well. SMT-implementation causes labor to be replaced as a key driver for manufacturing competitiveness, making place for e.g. the presence of technological skills, programming or automation talent.
Given the fact that worldwide the capital-cost differentials are very small in comparison to the prevailing labor-cost differentials (Laplume et al., 2016), for MNEs operating more SMTs, factor costs (labor and capital) are of lower importance in their production subsidiary location choice, offering more freedom in this respect. In general, the expectation is that through the increased freedom in production location choice offered by SMT-implementation, production in closer proximity to customers is facilitated. Companies are expected to base their location decisions less on production costs and more on proximity to customers after implementing SMT technologies (Strange & Zucchella, 2017).

However it should also be mentioned that the location of raw material (suppliers) and providers of sensors, software and analytics might increase in importance in MNEs production location choice (Porter & Heppelmann, 2014), along with the presence of technological knowledge in the form of software specialists, mechanical engineers and data analysts (Sirkin et al., 2015; Strange & Zucchella, 2017) or digital infrastructure in the form of connectivity, operating systems and data storage possibilities (Porter & Heppelmann, 2014; Bolwijn et al., 2018; Buonafede et al., 2018), dwindling this freedom again. In general however, MNEs with SMTs are expected to base production location decisions more on customer proximity due to the increased freedom in location choice (Scalabre, 2016; Chiarese & Romanello, 2018).

Secondly, production in closer proximity to customers is also simplified by the unique flexibility that SMTs entail in terms of product variety and volume. Surely, smart manufacturing empowers higher levels of customization, simplifies the targeting of local niche customer populations (De Backer et al., 2018; Bolwijn et al., 2018) and enables production levels to meet seasonal or demand fluctuations (Bolwijn et al., 2018) by e.g. storing real-time data in the cloud (Rüßmann et al., 2015), which is even more important for local production facilities. Furthermore this manufacturing flexibility of SMTs allows the production of more diversified batches, enlarging transportation costs from offshore destinations (Zhou & Wan, 2017), again favoring customer proximity.

Besides smart manufacturing facilitating production in closer proximity to customers, they might also necessitate it for reasons mentioned in the subsequent paragraph. The expected positive relation between SMT-implementation and backward participation in the value chain has already been discussed in section 3.1, however SMT-use is also predicted to be positively associated with forward integration. Preliminary evidence exists on a positive relation between industrial robotics use and forward participation in the value chain, for developed countries (De Backer et al., 2018). Motives for this can be found in the fact that, just as was the case for backward integration, in order to enjoy all value chain-wide synergies SMTs have to offer, system integration with all chains in the chain should be carried out. Matching investments in complex and expensive systems would have to be made and distributors might be reluctant to engage in such processes, motivating firms which have effectuated SMT-investments to participate in forward integration, circumventing distributors who are not up to the new standard anymore. By virtue of rich customer data provided by SMTs, MNEs are able to estimate the demand specificities of their goods more precisely and effectively, again stimulating forward integration as MNEs no longer have to rely on
wholesalers and distribution channel partners to obtain customer information (Porter & Heppelmann, 2014; Bolwijn et al., 2018) and enabling MNEs to manage their clients directly (Chiarvesio & Romanello, 2018). Ownership of this complex customer data obtained through smart production also becomes increasingly valuable (Bolwijn et al., 2018), again supporting forward integration in favor of relying on retailers or wholesalers. As smart production connects the customer more to the manufacturer, the latter is pushed to get more in touch with the former’s habits, increasingly moving from a business-to-business logic towards a business-to-consumer perspective (Chiarvesio & Romanello, 2018). In general the expectation is that after SMT-implementation, forward integration and consequently closer contact with customers becomes ever more important (Brennan et al., 2015), favoring production in close proximity to customers. Faster changing customer preferences and increasing demand for quick responsiveness have already been shown to be main reasons for production reshoring in general (Zhai, Sun & Zhang, 2016; Johansson & Olhager, 2018; Dachs, Kinkel, Jäger & Palčič, 2019b) and the expectation is that this will only grow in importance in the future (Brennan et al., 2015), emphasizing the importance of customer proximity for contemporary companies in general.

To summarize, the expectation of production in closer proximity to end-consumers after SMT-implementation is driven by (i) an enlarged freedom in production location choice (as a result of the smaller importance of centralization, supplier location and labor costs), (ii) an enlarged ease to serve heterogeneous local markets (by virtue of production flexibility) and (iii) an increasing importance of close relationships with customers due to forward integration tendencies. The prediction is that it is both easier and more important for companies with SMTs to produce in closer proximity to the customer, leading to Hypothesis 2.

**Hypothesis 2:** Multinational enterprises are more likely to co-locate production and sales subsidiaries after implementing SMTs.

4. METHODOLOGY

Whereas most of the literature on SMT-implementation and its possible effects on production location decisions mainly revolves around theory building and case studies, the few papers that make use of quantitative data suffer from substantial limitations. The most common difficulty is related to obtaining reliable data on company-level SMT-diffusion. This is why most of the research in this field is based on the one hand on company surveys (Dachs et al., 2019a; Müller, Dotzauer, & Voigt, 2017) or secondary data from newspaper articles or company websites (Ancarani, Di Mauro, & Mascali, 2019), resulting in fairly small sample sizes, or on the other hand works with country-level data (Buonafede et al., 2018; De Backer et al., 2018), neglecting firm heterogeneity. To solve aforementioned issues, this paper puts forward a previously unused measure for company SMT-implementation: the number of patents MNEs own in smart technologies with a focus on production, obtained through text mining techniques in relevant CPC-fields.

With the help of a search query, established by bundling information from relevant scientific papers and reports by international organizations, from both technical and economic literature, all patents related to smart technologies with a focus on production are retrieved through EPO’s
PATSTAT software. The backbone of the search query is based on CPC-fields relevant to smart technologies, in which patents linked to AI, IoT, CC and AM with a focus on production are identified with the help of text mining techniques. After a data cleaning and name harmonization procedure, it is possible to determine for each company (or subsidiary) the amount of patents of interest it owns.

The patent data is then linked to firm-level data obtained from Bureau Van Dijk’s ORBIS database through a record linkage approach (Peruzzi, Zachmann, & Veugelers, 2014). For patents not owned by a Global Ultimate Owner (GUO) but by a subsidiary, the GUO is identified through a consolidation procedure. Afterwards, GUOs not active in a manufacturing sector (NACE code C) are deleted from the data. Finally a dataset with all GUOs in the manufacturing sector and their smart manufacturing patents with a focus on production (SMT-patents, the main independent variable) is obtained. It is important to clarify that the focus of this research is on the implementation of SMTs for production activities in manufacturing companies and not on so-called ‘digital firms’. The latter type of firm is characterized by the central role of the internet in their operating and delivery model and are very different from traditional manufacturing players (the interest of this research) because they rely on the internet and other digital technologies for sales and commercialization activities, rather than for production and operations (although these dimensions obviously are not mutually exclusive) (Bolwijn et al. 2018). The distinction between both types of companies is important because purely digital companies are characterized by an asset-lightness, with limited physical commitments in foreign markets (often limited to corporate offices), as noted by Bolwijn et al. (2018). The possibility to operate globally with limited physical investments would limit the international diversity of production, at least in terms of tangible assets (e.g. subsidiaries) (Bolwijn et al. 2018). Hence the inclusion of fully digital firms in this research would at least partially oppose Hypothesis 1.

For Hypothesis 1 the dependent variable is the (international) diversity of MNEs’ portfolio of production subsidiaries, measured as the amount of (countries in which) production subsidiaries (NACE codes 10 – 32) are in place per GUO. For testing Hypothesis 2 the dependent variable is the co-location of production and sales activities, measured as the ratio between the amount of countries in which the GUO has both production and sales subsidiaries and the amount of countries in which the GUO only has sales subsidiaries (NACE codes 45 – 47).
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