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Industry-specific agglomeration advantages of the microelectronics industry in Eindhoven, the Netherlands.

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Abstract

This article verifies the presence of localization economies and R&D-related clustering in the microelectronics industry in Eindhoven, the Netherlands. Identifying these agglomeration advantages is relevant in view of the adopted Chips Act 2022, which seeks to build Europe's semiconductor sovereignty. Using microdata such as geographic coordinates, a type of economic activity, and the distances of firms to other economic entities, I study whether the location choices of electronics and microelectronics firms systematically favor the proximity to other similar companies, to R&D institutions, and to the overall centers of economic activity such as cities. First, a significant geographic concentration of electronics and microelectronics companies was revealed for 2018 by comparing firms' average distances to other similar companies with their average distances to all other firms. This comparison was conducted using sign tests. Next, particular reasons for such concentration were explored using the multiple linear regression modelling. The presence of an R&D institution within 1 km and 2.5 km from a given location significantly and positively correlated with the number of electronics and microelectronics companies within the same area. On the other hand, locations occupied by microelectronics companies did not have significantly more microelectronics neighbors after controlling for other factors. This result brings evidence of the presence of clustering around R&D facilities in Eindhoven but not of localization economies. Overall, this result aligns with the high status of the Dutch knowledge economy and may be used to attract resources to further exploit this regional competitive advantage.

Introduction

Whereas earlier the issue of economic development was largely left to market forces and international capital flows as exemplified by the neoliberal economic school and the Washington Consensus, policy-makers more and more tend to involve directly into regional economies and particular economic sectors (Alami & Dixon, 2020). In this environment, the domain of economic geography comes to the fore, containing theoretical underpinnings of a competitive advantage that can be created and exploited with custom-fitted regional policies. Up to now, such regional policies are studied as tools to develop particular regions (e. g. inner cities) with the aim of wealth creation or poverty and inequality alleviation (Delgado & Zeuli, 2016; Porter, 2015). This article, however, will explore the relevance of spatial factors in a strategic development, particularly in achieving the semiconductor sovereignty in Europe.

Researching the influence of the spatial/geographic factors such as location choices of firms on the regional performance is what highlights the domain of economic geography. In this article, spatial factors will be explored as the potential advantages for strategic regional development. Among such potential advantages are the so-called agglomeration advantages, which stem from the geographic proximity of competing and cooperating companies (Krugman, 1991). For example, geographic proximity is long revealed to enable firms in one industry to have a common labor pool, ensure knowledge spillovers between companies, and grant access to some non-traded local inputs (Marshall, 1920). Regions where such advantages exist are labeled as business clusters, with the well-known example being the Silicon Valley. The concept of agglomeration economies lies at the heart of regional development policies that establish industrial districts or innovation centers – highly concentrated centers of a specific economic productive activity (Belussi & Caldari, 2009; Marshall, 1910).

In Europe, these trends realize into the EU strategies to boost economic security and development by exploiting regional competitive advantages (European Commission, 2021). Concepts such as smart specialization, open strategic autonomy, and strategic industries emerge in the EU documentation and declarations, followed by the initiatives such as the Battery Alliance or the Alliance for Industrial Data, Edge and Cloud. By directing significant finances to regional economic development programs, the EU aims to “build industrial ecosystems and European value chains for emerging sectors supported by research and innovation funding” (European Commission, 2021, p. 40).

One of such most recent initiatives is the 2022 EU Chips Act that marks the foundation of the semiconductor industry in Europe (Peckham, 2022). Before, the EU was only accountable for 10% of the global semiconductor production (Johnston & Huggins, 2022), despite the presence of the high-tech R&D-intensive companies such as NXP, Infineon, and STMicroelectronics. With the Chips Act that claims to direct more than €15 billion to the microelectronics champions, SMEs, and start-ups, the semiconductor industry in Europe may be revitalized, doubling microchip production by 2030 (Cota, 2022). Thus, a further formation of business clusters stimulated and supported by these funds can be expected in Europe.

Particularly, the Netherlands and its Eindhoven region possess a regional competitive advantage in the form of an industry-oriented knowledge economy that can boost such a cluster formation (Raspe & Van Oort, 2006). In a stark contrast to the struggling European semiconductor manufacturing, the industry that supplies chip-making equipment is blooming in Europe with ASML located in Eindhoven, the Netherlands. This company is a monopolist in lithography systems required for chip production (The Economist, 2020). Proving its outstanding strategic importance for the semiconductor manufacturing, ASML has recently appeared at the center of geopolitical tensions, with China attempting to reveal ASML's technology by importing its most advanced machines and the US blocking the export (Sterling, 2022).

Eindhoven may be fit to receive some funding because the EU Chips Act recognizes the existing basis for such development and aims to support and build upon it. Having such a basis, Eindhoven does not only host ASML but many start-ups and SMEs focused on manufacturing and R&D in the microelectronics industry. This region, frequently labelled as the leading Dutch tech-hub or Brainport, does not consist of a few independent champions but is a dynamic ecosystem with many competing and cooperating companies clustering around each other (Van Winden et al., 2010).

Despite the accomplishments of the Brainport developers, such a success may quickly turn into decline unless some transformation occurs, which would require more support from policy-makers (Van Klink & De Langen, 2001). For example, a cluster of companies that all work within one industry may experience a threat of overspecialization and path dependence, unless it is timely reformed and diversified (Chapman, 2005). This is why the EU Chips Act may eventually be received in part by this region, developing the European microchips production on the basis of the already existing facilities of the Brainport (Monterie, 2011). This is especially plausible because the EU has already allocated funds to this region in multiple instances. Specifically, the EU cofounded interregional projects in which Brainport took part, such as ERMIS, Inno Infra Share, and Horizon2020 projects (de Vijver, 2017). Funding under the EU Chips Act may be expected to proceed through a similar cross-border project aimed at boosting the European innovation system.

Taking into account the described situation on the market for semiconductors, the EU Chips Act, and the fact that companies within the Eindhoven tech hub may become recipients of this financial stimulus, it is timely to assess the stance of the region's industrial development. As shown, agglomeration economies lie at the heart of the competitive advantage of business clusters. If no agglomeration advantages are present in the Eindhoven cluster any longer, then it may be not reasonable to direct the EU funds for its development. Moreover, whether the microelectronics industry in Eindhoven is in the growth or decline stage is important for this decision and may be revealed through such an analysis. Therefore, the research question is formulated as follows:

Are industry-specific agglomeration economies present in the microelectronics industry of the Eindhoven region?

On the one hand, this analysis is practically relevant in the present political environment with policy-makers gaining interest in the strategically-oriented regional development. Geo-economic affairs, lying at the intersection of geopolitics and economics, have recently gained attention of policy-makers worldwide (Wigell et al., 2018). As shown before, the EU politicians are pledging to reveal and terminate Europe's strategic economic dependencies, which makes them willing to establish a strong local semiconductors production. Geopolitical concerns interfere with national and regional economies, and some elements of state capitalism unprecedently emerge in democratic countries (Alami & Dixon, 2020). Creating special economic zones or industrial districts may be one of such elements.

Agglomeration advantages, which are the economic implications of location choices of companies, may be a factor influencing the creation of special economic zones, urban zoning policies, and industrial districts. Revealing spatial patterns within the Eindhoven manufacturing industry, such as the tendency of firms to cluster together, would allow us to test the presence of agglomeration advantages in this region and industry, thus indicating whether funds from the EU Chips Act and other regional policies should seek to build upon this competitive advantage.

On the other hand, applying cluster theory and agglomeration theory to a particular region is also academically relevant. Economic geography is still under development as an academic discipline and exhibits a fierce debate between competing concepts (Lagendijk, 2006). Yet, despite the richness of theories and concepts, quantitative methods to apply and test them are scarce and complicated. This article will outline recent theoretical advances in the regional economic geography and employ them in the quantitative analysis of the Eindhoven tech-hub. In addition, this article tries to connect the study of agglomeration advantages to the industry-cycle theory with the supporting literature that demonstrates the link between the industry lifecycles and the location choices of firms.

There are two aspects in the widely assumed academic approach to explore agglomeration economies that make this article substantially contribute to the existing literature. First, most of the empirical studies are bound to a certain time-period, a specific industry, and a region or a country. For example, Malmberg et al. (2000) evaluate the agglomeration economies for the export firms in Sweden in 1994. O'Connor et al. (2017) study clustering patterns in widely-aggregated economic sectors of Ireland in 2008 – 2012. Therefore, varying each of these aspects results in the plenty of opportunities for empirical research. Regarding the Netherlands and the latest period, Huisman and Van Wissen (2004) made it their focus of study, yet they have found the presence of agglomeration economies for the whole Dutch manufacturing industry and not specifically for the Brainport's microelectronics.

The second aspect which grants novelty to this research is the updated methodology. There is no single standard way of evaluating agglomeration economies as this academic field is yet in its development process. While many articles, such as Malmberg et al. (2000) or Eriksson et al. (2008), try to estimate agglomeration advantages by separating internal economies of scale, localization economies, and urbanization economies as the three determinants of the firm's performance (usually proxied through export volume), the present article will model the location choices of firms against different spatial factors such as the proximity to other similar firms or to R&D institutions. This method can be more appealing because location choices are less volatile than performance indicators such as export volume or profits. To control for that volatility, other methods require more extensive intertemporal data, which can be difficult to obtain or analyze. Assuming the ability of the decision makers to account for agglomeration economies when making a location choice, such an alternate can be a solid way to estimate the proximity benefits and avoid our variable of interest being affected by other irrelevant factors.

In the next section, theoretical foundations of this research will be established, touching upon the agglomeration theory, industry lifecycle, and economic characteristics of the Eindhoven tech hub. This will enable the formulation of specific hypotheses embedded into theory, testing which is necessary to answer the research question. After that, a reliable data source with an extensive dataset containing all the relevant variables will be introduced and described. Section 4 will explain the methods used to test the stated hypotheses. Section 5 will present the results of this analysis and an assessment of the hypotheses. Finally, section 6 will put the research into a broader context by discussing the results, hinting at the further possible analysis, and drawing a conclusion.

Theoretical framework

1. Economic overview of the Dutch microelectronics industry.

First, it is handy to have a general overview of the microelectronics industry in the Netherlands, including but not limited to Eindhoven. The Netherlands consists of 12 provinces, but for the statistical purposes it is frequently divided into 40 COROPs which will also be the main unit of our analysis. Figure 1 shows the map of the Netherlands divided into 40 COROPs and the locations of all Dutch microelectronics companies in 2015. For this study, the Zuidoost Noord Brabant COROP will represent the Eindhoven region, which is the main focus of our study. As can be seen, Zuidoost Noord Brabant is not an exclusive host of microelectronics firms. Some concentration may be observed, but other COROPs such as Arnhem/Nijmegen may seem to have a comparable number of microelectronics firms.

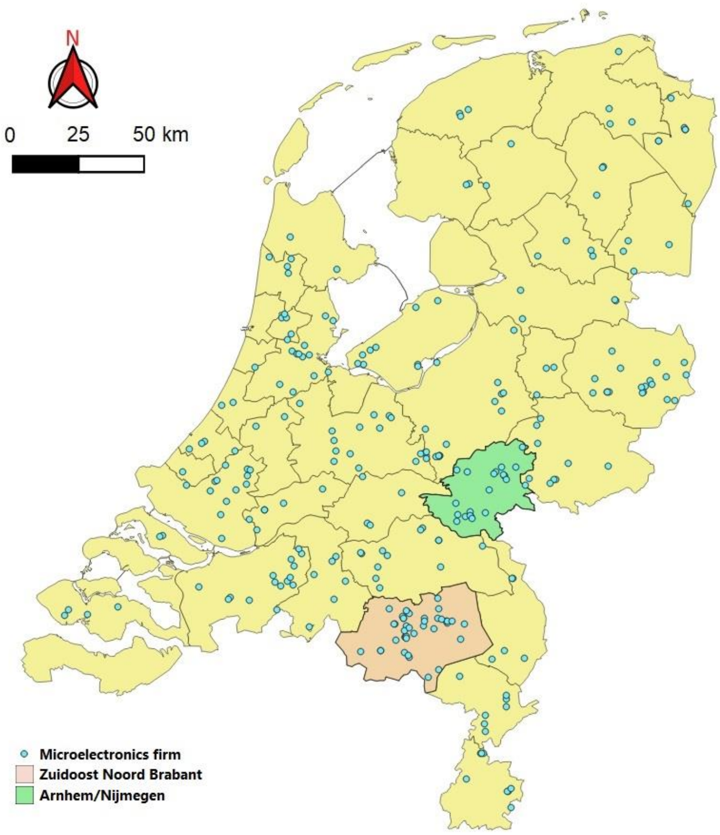


Figure 1. The locations of microelectronics firms in all COROP regions, 2015

To see whether the Eindhoven region is special in terms of its microelectronics industry, we outline the percentage of microelectronics workers within the total employed population in the Netherlands and its 6 COROPs that are leading in this indicator (Figure 2). As Figure 2 demonstrates, Zuidoost Noord Brabant (darkest line) is among these 6 leading COROPs. However, only Arnnhem/Nijmegen (lightest line) stands somewhat alone in having more microelectronic workers. The other 5 COROPs all have less microelectronics employees with their lines merging with each other. Therefore, Zuidoost Noord Brabant cannot yet be observed to have an exceptional microelectronics industry.

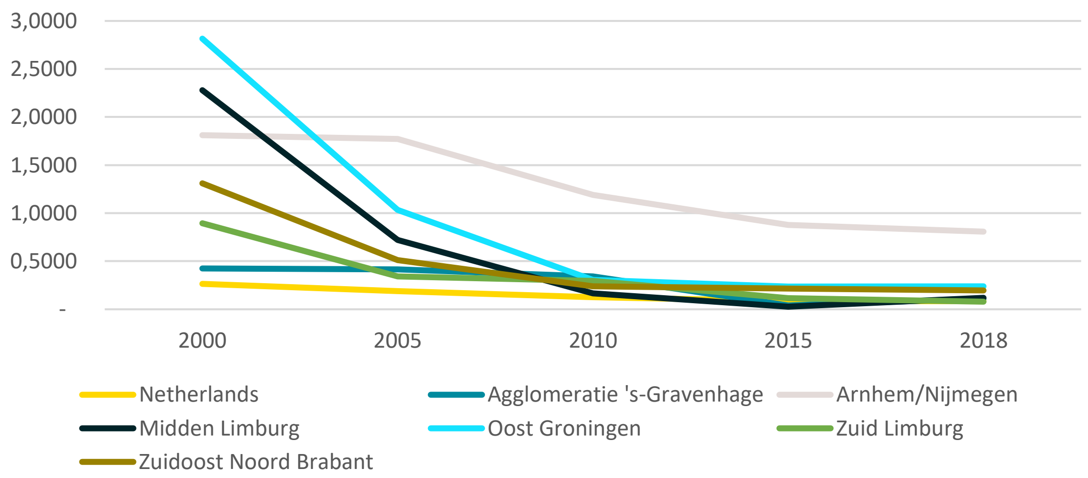


Figure 2. Percentage of employees in microelectronics within total employment per region, 2000-2018

Another important observation is that microelectronics employment as a proportion of total employment in the Netherlands is consistently falling already for two decades. Some general economic indicators shown in Table 1 are all steadily growing, indicating that this trend is industry-specific as there is no corresponding general economic downturn neither in the Netherlands nor in the Eindhoven region.

Table 1. A selection of the national and regional economic indicators

Netherlands	2000	2005	2010	2015	2020
GDP (market prices) (mil euros)	452007	550883	639187	690008	800095
GDP per capita (euros)	28383	33755	38470	40733	45874
working population (x1000)	8202	8340	8777	8807.6	9544.1
Zuidoost Noord Brabant	2000	2005	2010	2015	2020
GDP (market prices) (mil euros)	21212	24434	29936	34772	41876
GDP per capita (euros)	29801	33605	40618	46082	53516
working population (x1000)	378.9	384.1	419	435.7	470.8

Despite the decline in the microelectronics employment, Table 2 shows that the number of microelectronics companies in the 6 selected COROPs is not falling but is even seen to increase in Zuidoost Noord Brabant from 36 companies in 2000 to 41 company in 2018. Therefore, in terms of the number of microelectronic companies hosted, the Eindhoven region is leading clearly in all years, with twice as many companies as in the second-leading Aarnhem/Nijmegen. Later in the chapter we will explain why Aarnhem/Nijmegen leads in the microelectronics employment while Zuidoost Noord Brabant has more microelectronics companies.

Table 2. Number of microelectronics firms for the selected Dutch COROPs

	2000	2005	2010	2015	2018
Zuidoost Noord Brabant	36	37	42	40	41
Arnhem/Nijmegen	18	17	21	25	21
Midden Limburg	6	6	7	5	4
Oost Groningen	6	9	8	3	2
Zuid Limburg	11	11	8	7	4
Agglomeratie ‘s-Gravenhage	2	5	4	6	7

As Figure 1 has already shown, these two regions are not essentially different in area. Yet, Zuidoost Noord Brabant has twice as many microelectronics firms. Therefore, the initial hesitation about the specialty of the Eindhoven microelectronic industry may be dismissed. Thus, the Zuidoost Noord Brabant microelectronics industry is not selected for this study arbitrarily but is an interesting case to explore the role of the agglomeration economies in its development. It is especially so because this region, unlike other COROPs, is officially recognized as the leading regional high-tech hub, as discussed further.

2. Brainport Eindhoven

Innovative business activity in Zuidoost Noord Brabant is primarily represented by the Brainport Eindhoven – a cluster of high-tech companies developing along the 'Brainport' initiative launched by the Dutch authorities (Horlings, 2014). As Horlings (2014) characterizes it, Brainport Eindhoven is a "triple-helix co-operation between businesses, governments, and knowledge institutes" that focuses on technology innovation and commercialization, particularly in nanotechnology and microelectronics.

This cluster receives its name as a reference to the Port of Rotterdam and Schiphol airport in Amsterdam, thus hinting at their commensurable strategic importance for the Dutch economy. Indeed, integrating manufacturing and research, this geographically small region contributes a significant portion of the Dutch GDP and employment (Lagendijk & Boekema, 2008). In 2017, Eindhoven Brainport experienced the fastest economic growth among all regions of the Netherlands, with its industry growing seven times faster than the national average between 2005 and 2015 (Brainport Monitor, 2018). Already in 2008, this region was labeled as the 'economic heart' of the southeast Netherlands by Lagendijk and Boekema (2008).

Brainport Eindhoven historically stems from Philips, which was founded in Eindhoven in 1891 (Brainport Eindhoven, N/A). In 1984, ASML was established here by Philips and a chip producer ASMI located near Amsterdam (ASML, N/A). In 1995, ASML became an independent public company as Philips was largely exiting Eindhoven, and many smaller enterprises started appearing in the area. Along with the private initiative, this region since its foundation is financially and administratively supported by the public policies for regional development, such as the Horizon programme, Peaks in the Delta, Peaks in South-east Netherlands, and Brainport 2020 (Horlings, 2014). This effort paid out, and in 2016 Brainport Eindhoven accounted for 23.1% of the Dutch private R&D expenditures (Brainport Monitor, 2018).

However, Eindhoven Brainport is officially a cooperation of municipalities, and not a certain smaller area within the Zuidoost Noord Brabant (Ruis, N/A). In Brainport, there is a higher concentration of high-tech companies in this region when compared to other Dutch regions. This corresponds to and repeats the conclusions of our geographical observations outlined above. However, the fact that Brainport hosts more microelectronic companies than other regions may only indirectly hint at the presence of agglomeration advantages or can even be caused by unrelated reasons. For example, more companies might have started to locate there after Brainport was formally established and promoted as a tech hub. What is not clear and what this article will study is whether there are concentration trends *within* the Zuidoost Noord Brabant and specifically in its microelectronics industry against other manufacturing industries. Hence, the first hypothesis is formulated as follows.

H1: Electronics and microelectronics companies in Zuidoost Noord Brabant are geographically concentrated relative to other industries.

As will be seen, this hypothesis will essentially test if the Zuidoost Noord Brabant microelectronics industry enjoys higher agglomeration advantages than other manufacturing industries. Later in this chapter I will introduce the two main components of such advantages, urbanization and localization economies. While urbanization economies apply to multiple industries in one geographical area, localization economies are industry-specific. Therefore, the first hypothesis will test the presence of some agglomeration advantages in microelectronics revealed by the geographic concentration of firms, separating them from those urbanization economies that are equally applicable to other industries in the region.

Additionally, I will also limit the scope of the analysis to the Eindhoven municipality and test whether the microelectronic companies located there are exposed to higher agglomeration advantages than other manufacturing industries. It may well be that microelectronics firms locate in the Eindhoven municipality more frequently relatively to other industries, but are not concentrated *within* this municipality. In this case, we would be unable to conclude the presence of localization economies in the *Eindhoven's* microelectronic industry even though the first hypothesis could not be rejected. The same method must be thus applied for the two different scopes: across Zuidoost Noord Brabant and specifically within the Eindhoven municipality.

H2: Electronic and microelectronic companies in the Eindhoven municipality are geographically concentrated relative to other industries.

3. Classifying agglomeration economies

So far, we have discussed Brainport Eindhoven as single whole and not as a system of many interconnected actors. It is now important to explain what a business cluster is, why it emerges, and which of its different types may apply to the Brainport's case. In analyzing economically relevant spatial or geographic factors, agglomeration theory is a fruitful domain of economic expertise for the empirical analysis of the Brainport as a cluster of companies.

Multiple classifications of economic agglomerations are possible, such as industrial districts, Porter's clusters, growth poles, social networks, etc. (Granovetter, 1973; Marshall, 1920; Perroux, 1955; Porter, 1998). Each of them stresses different sources of advantages that companies receive from co-locating in a close proximity. Different analytical tools are used to evaluate the presence of these different agglomeration advantages. Thus, to analyze the Brainport as a cluster of companies it is important to select a suiting method by assuming a certain agglomeration effect underlying the existence of this cluster.

The first important categorization of agglomeration advantages is that of localization and urbanization economies (Karlsson, 2010). They concern the benefits that firms get when they locate next to, respectively, firms in the same industry and firms in other industries. Similar firms that cluster together gain access to a shared labor pool, knowledge spillovers, and common industry-specific facilities, e. g. a pipe network in the industrial ecosystem (Frosch & Gallopoulos, 1989). These are called localization advantages, or Marshallian externalities. Importantly, such a cluster differs from a mere concentration of similar firms which can occur because a certain location allows firms to cover a broader market area (Hotelling, 1929). As Brainport has one specific unifying theme – high-tech development – localization economies may play an important role in its existence. Meanwhile, we do not expect the location choices of the microelectronics companies to be affected by the Hotelling's law as their market is broad and often international.

Additionally, it must be carefully distinguished from the case where companies cluster next to each other as a side-effect of them locating next to the centers of innovation such as research institutes and universities, as studied by Zucker et al. (1998). Clustering around innovation centers is the case of urbanization economies – the benefits from the proximity of different cooperating, not competing, economic entities. Therefore, while it is clear that research institutes can cause microelectronic companies to cluster near each other, it would not necessarily mean that these companies *benefit from each other*. To test for localization economies, we therefore have to control for the presence of the research facilities in the proximity, such as the Eindhoven University of Technology and the High Tech Campus. At the same time, finding a strong association between the co-locating microelectronics firms and R&D institutions would in itself be a relevant result. Thus, the third hypothesis is:

H3: Clustering of the microelectronics firms in the Eindhoven region is associated with the presence of the R&D institutions in the vicinity.

The presence of localization effects may be further discerned into two scenarios. First, a cluster of firms within one industry may form around a main propulsive firm, a successful pioneer which then becomes a so-called 'growth pole' for the following newcomers (Perroux, 1955). In case of the Brainport, Philips is frequently mentioned as a firm that has put a cornerstone of the tech-hub (Horlings, 2014). However, Philips is no longer a leading Eindhoven company after it moved its headquarters to Amsterdam in 1997. This had caused a severely negative impact to the region, to mitigate which Philips directed significant funds to boost the development of Eindhoven as the regional innovation system (Horlings, 2014).

We have already observed a non-evident peculiarity while comparing the number of firms and the number of workers in the microelectronics industries of Arnhem/Nijmegen and Zuidoost Noord Brabant. According to the growth pole clustering, this divergence may suggest that Arnhem/Nijmegen has such a propulsive firm with a large number of employees, which would explain its higher microelectronics employment along with less microelectronics firms present. Indeed, Table 3 demonstrates the number of workers in the biggest microelectronics firm for the 6 COROPs selected before.

Table 3. A number of employees in the biggest microelectronics firm for the 6 Dutch COROPs

	2000	2005	2010	2015	2018
Zuidoost Noord Brabant	1953	538	122	224	191
Arnhem/Nijmegen	4950	4800	3331	2310	1828
Midden Limburg	930	383	116	18	95
Oost Groningen	833	250	107	99	97
Zuid Limburg	670	208	360	81	85
Agglomeratie ‘s-Gravenhage	1542	1539	1272	102	387

As shown, the biggest microelectronics firm in Arnhem/Nijmegen has almost ten times higher employment than the biggest Zuidoost Noord Brabant microelectronics firm. In line with the described transformations within Brainport, initially there was a propulsive firm in the year 2000 but it is no longer present in the later period. Despite these falling employment numbers, however, Table 2 has demonstrated that the number of microelectronics firms did not decrease accordingly for most of these COROPs, in fact increasing from 36 firms in 2000 to 41 firm in 2018 for Zuidoost Noord Brabant.

That is why another scenario in which localization effects emerge is more compatible with Brainport’s development. Namely, Porter’s cluster theory may have more explanatory power. As Porter (1998) claims, small and innovative firms in an emerging industry tend to cluster together to benefit from knowledge spillovers and information flows. These firms are competing with each other and are comparable in scale, contrary to the growth pole scenario.

Such is the situation in the High Tech Campus in Eindhoven, a home to around 200 SMEs. Such a dense concentration of ambitious, research-intensive, and innovative start-ups and enterprises won this region the title of “the smartest square kilometer in Europe” (Philips, 2019). High Tech Campus posits itself as a platform for innovation and cooperation which is crucial in the first stages of a business launch in a high-tech industry and which overshadows the possible disadvantages of working next to one’s competitors. Thus, Brainport fits more into Porter’s theory of clusters as a single propulsive champion cannot be identified. The presence of the Porter’s localization economies is tested with the following hypothesis.

H4: Location choices of Brainport's microelectronics firm correlate with the presence of other microelectronics firms in the vicinity after controlling for the presence of R&D institutions in the vicinity.

4. Industry cycles in Brainport

The last essential element without which this study would be incomplete is the intertemporal dynamics of geographical concentration in Brainport. As noted by Polenske (2007), geographic concentration of firms may be a temporal leftover from the period in which agglomeration advantages were present even if they no longer exist. Most recently, a common pattern of a life cycle in clusters were identified by Fornahl and Hassink (2017), with the stages of emergence, growth, decline, and potential renewal. Therefore, it is necessary to see if the geographic concentration is consistent so the agglomeration advantages are still in effect. The industry cycle theory may serve a strong theoretical foundation for this final part of the analysis (Bergman, 2007).

Vernon (1966) describes how the industry cycles influence the agglomeration advantages for different regions and industries. Clustering is important in the early development of a particular product because effective communication, information flows, and knowledge spillovers are crucial in the process of innovation and product development. These processes dominate on the early stages of the industry lifecycle, while losing in importance in maturing industries. Still further, Audretsch and Feldman (1996, p. 271) conclude that "what may serve as an agglomerating influence in triggering innovative activity to spatially cluster during the introduction and growth stages of the industry life cycle, may later result in a congestion effect, leading to greater dispersion in innovative activity."

As shown before, Brainport is an already established concept in Eindhoven. Figure 2 and Table 2 demonstrated that there are twice as more microelectronics companies than in other regions, and the microelectronics employment in the Netherlands is consistently falling for decades. It hints at the maturity or even a decline stage within Eindhoven's microelectronics. Therefore, the clustering phenomenon in Brainport may simply be a residual of the agglomeration economies present in the previous periods. However, a significant positive relation between the industry maturing and the de-concentration trends is not strictly necessary. Industries often undergo transformations, preserving the concentration trends of the companies within these industries. Because of this uncertainty, the last hypothesis must seek to test whether the firms within such a maturing cluster gradually disperse across Zuidoost Noord Brabant. Revealed de-concentration trends in Brainport would allow us to conclude the absence of agglomeration economies in Brainport's microelectronics.

H5: Localization and R&D-related economies of the Brainport's microelectronics companies diminish over time.

All the hypotheses in this analysis are interconnected. Proceeding from one to another, they gradually isolate and estimate different spatial factors that altogether determine the locations of the microelectronics companies in Brainport. In total, I will test the significance of the geographic concentration of the Brainport's microelectronics firms, its connection to some spatial factors such as the neighboring R&D institutions, and check dynamically if this concentration is persistent.

Data

The data for this analysis come from the LISA database. LISA contains the micro-level information on all paid work activity in the Netherlands. The most essential and unique feature about this dataset is that it contains the geographic locations of companies, which is key to this research. Available spatial data consist of the x- and y-coordinates for each company, a COROP name and a municipality in which it is located.

Companies in the dataset are classified according to the SBI classification of economic activity, and the 4-digit SBI codes are assigned to each company. This is a sufficiently high level of disaggregation for the industry classification as we are able to identify the companies working in the manufacture of electronic components (SBI code 2611), which include transistors, semiconductors, and some other microelectronic elements.

For the purpose of our research, we have extracted the data on all Zuidoost Noord Brabant companies and selected those that work in sectors C: Industry and 72: Research and Development. In total, there are 3813 selected companies in 2015 and 4082 companies in 2018. As Table 2 has already presented, among these are 40 microelectronics companies in 2015 and 41 company in 2018. For each firm, the extracted variables included its SBI activity code, its number of employees, the x- and y-coordinates (in a coordinate system Amersfoord/RD-new, or EPSG:28992) , its COROP name and number, its municipality name and number, and its 6-digit postcode.

The most recent year for which the data was available is 2018. The data for 4 years were extracted, from 2015 to 2018. As will be discussed in the methodology section, extracting data across multiple consequential years was not a viable decision. However, the utilized method will still use the 4-year period to include a possible intertemporal variation into account.

For the sake of the descriptive statistics and visual observations added in the theoretical framework I have extracted the same data for the firms within the manufacture of microelectronic equipment (SBI codes 2611 and 2612) for the period of 2000 – 2018 across all COROPs. However, the main aim of this research is to test the current presence and significance of the agglomeration economies within Brainport, and not to track the history of their variation. Therefore, the most recent available years will provide the valid overview of the present situation in Brainport.

It is necessary to note that to obtain the results, only the data for years 2015 and 2018 were used, omitting two years in between. Moreover, I focused on the aforementioned industries and not on all Eindhoven firms to preliminarily account for some general agglomeration economies. For example, general urbanization economies such as the proximity to urban amenities may be more relevant for service industry rather than manufacturing. Therefore, we must compare the microelectronics companies (manufacturing) only with other manufacturing industries to not let these urbanization effects influence our results.

For the methods described in the next section, it was necessary to obtain the distances between each pair of firms. This was done with the use of the coordinates of companies and the Pythagoras theorem:

$$\text{Distance}_{i,j} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$$

Where i and j are two selected firms and X and Y are their coordinates. Thus, we obtained a matrix showing, for each company, its distance to all the other firms. The calculated distances were proved with Google maps to accurately represent the distance in meters between any two firms. For each firm the number of neighboring firms with the distances smaller than 1000 meters and 2500 meters were calculated. Additionally, for each firm its distance to all other firms was summed up and divided by the number of all other firms to obtain the average distance value. The following table presents the descriptive statistics of the data that were thuswise created.

Table 4. Descriptive statistics for the obtained variables in 2018.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Average distance to all other firms (in meters)	4082	16594.43	3933.48	11795.68	29835.91
Number of firms within 1 km	4082	36.04	22.10	0	106
Number of firms within 2.5 km	4082	172.85	102.52	0	474
Firm located in Eindhoven	4082	0.21	0.45	0	1
Firm has at least one R&D institution within 1 km	4082	0.25	0.86	0	1
Firm has at least one R&D institution within 2.5 km	4082	0.35	0.48	0	1

These statistics provide us with some preliminary insights. For a total of the 4082 selected companies, we see that firms have on average around 36 neighboring firms within 1 km radius and 173 neighboring firms within 2.5 km radius. Around 21% of all Zuidoost Noord Brabant firms are located in Eindhoven. Around 25% of the firms have an R&D institution within 1 kilometer and 35% – within 2.5 kilometers. Lastly, we can see an approximation of the average distances between the firms. As shown, a firm with the minimal average distance to all other firms is located on average 11796 meters away from other firms. The biggest average distance is 29836 meters, and the mean of this variable is 16594.43 meters. At first, it may be doubtful whether any meaning can be attached to this indicator. However, this variable will be used to study centralization and clustering of firms with the method described in the next section.

The main limitation of these data is the absence of firm performance variables. In other articles on agglomeration advantages, performance indicators of companies such as their export shares or profits are often used (Stavropoulos & Skuras, 2016). LISA database does not contain these data for the listed companies. Only firm's employment can be considered such an indicator available. Nonetheless, the methodology section will show how this limitation may be overcome and why omitting the considerations of firm-level performance may actually be no less relevant or even advantageous in the study of the regional agglomeration economies. In general, this research studies and attempts to explain the location choices of firms using other spatial factors. Location choices are therefore credibly taken as an explanandum, as the outcome to be analyzed, and not as the explanans of some performance variable.

Methodology

This article is primarily concerned with the geographical concentration of firms. It seeks to uncover significant and not incidental spatial clustering of microelectronics companies and its potential reasons, such as the proximity of R&D institutions or other similar firms nearby. In this section, I will outline the general approach selected for this study and explain specifically the methodology to test each of the stated hypotheses. Relevant advantages and limitations of these methods will also be discussed.

Firms concentrate on a geographical plane for many reasons. Figure 3 depicts locations of all microelectronics firms and firms in other selected industries across Zuidoost Noord Brabant in 2018. By taking all firms across all industries we may already observe a trend for concentration, as firms are not monotonously distributed across the geographical plane. Thus, there are some general reasons for firms to cluster irrespectively of the industry they work in. As mentioned in the theoretical framework, these reasons together are called urbanization economies. Indeed, the observed patterns of concentration visibly correspond to the geographical locations of cities. In the center of this map where firms many cluster, the Eindhoven municipality is located.

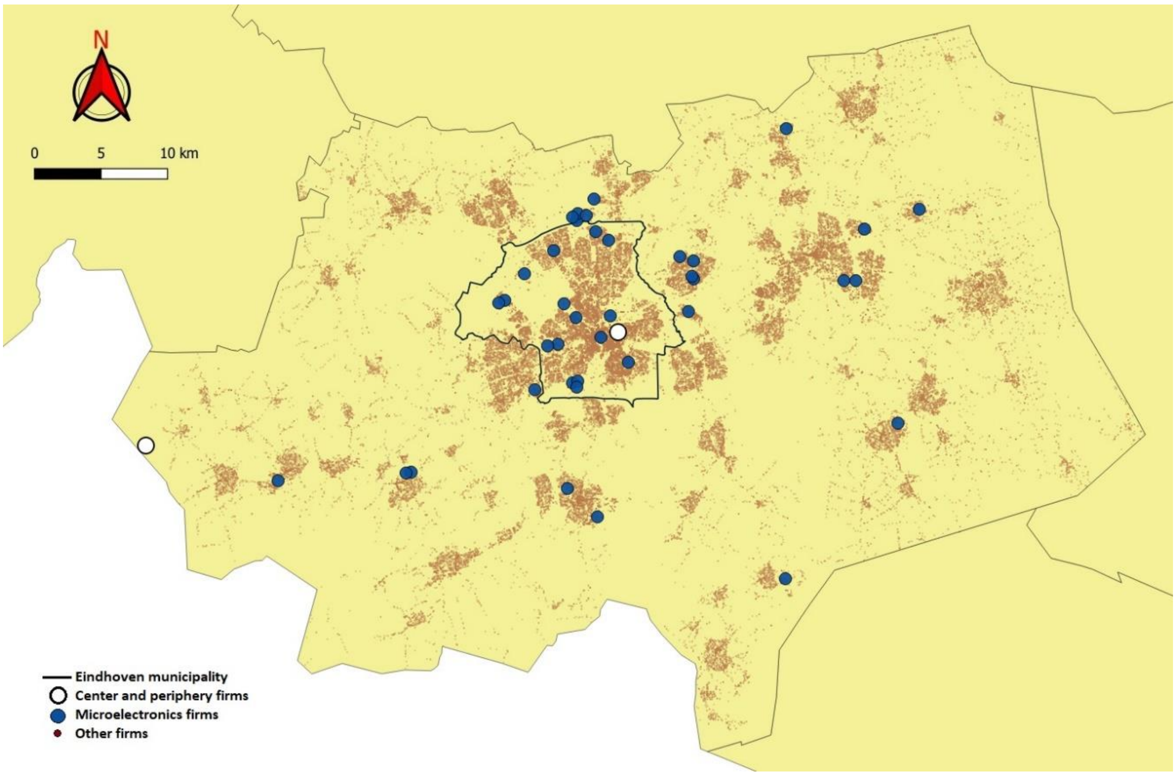


Figure 3. Locations of all microelectronics and other firms in Zuidoost Noord Brabant, 2018

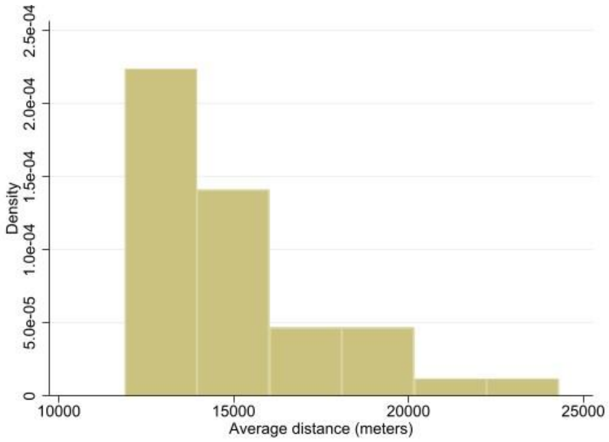
Figure 3 shows the firm located in the Eindhoven municipality marked with a white circle. This firm has the lowest average distance to all other firms seen in Table 4 – 11796 meters. For any firm, the higher its average distance to all other firms, the further away from the center this firm is located. The same white circle also marks the firm with the largest average distance – 29836 meters (the left side of the map). This implies that the general concentration of companies is associated with the geographical center of the region.

The reasons for this non-industry-specific concentration may vary from an access to amenities, public facilities, and infrastructure, to lower rents, better market access, or complementary business activities. Therefore, we must first isolate the relevant agglomeration economies from these general causes to test if microelectronics companies are concentrated in Eindhoven. The question is not whether they are concentrated per se – they surely are, as all other firms due to the general urbanization economies – but whether they are concentrated *relative to* all other firms and thus experience some *industry-specific* clustering effects.

To estimate localization or urbanization economies of the region empirically, literature on agglomeration often uses the indices of regional employment specialization or diversification (Dewhurst & McCann, 1998). However, I consider this method not suitable because it juxtaposes these two effects and does not consider cases where both types of advantages may be present. Regional employment may either be found specialized in one industry or not specialized (hence diversified). Moreover, by using employment figures this approach neglects potential technological productivity differences between industries and allows the firms with big employment numbers to skew the results significantly. Meanwhile, in the theoretical framework I adopted the Porter's cluster theory for this analysis which pays due attention to small highly innovative firms, deeming them no less relevant than large industry champions.

Based on this reasoning, the new method is needed, working with firms and their locations as its main units of analysis. To see if the location choices of microelectronics companies are special compared to the location choices of all other companies, I use the following method. For each microelectronics firm, its average distance to all other microelectronics firms is compared to its average distance to all other firms. The logic of this comparison is as follows. If the set of all microelectronics firm locations is not different from a random sample of firms from Zuidoost Noord Brabant, then for each microelectronics firm its average distance to other microelectronics firms would be similar to its average distance to all other firms. In this case, there are no specific clustering effects in microelectronics. However, if the majority of microelectronics firms have a significantly smaller average distance to other microelectronics firms than to firms in other industries, then there are some industry-specific agglomeration economies or at least urbanization economies matter for this industry significantly more than for others. To further separate these two possibilities and test for localization economies only, I conduct the same study on a narrower scale, within the Eindhoven municipality, where urbanization economies are assumed to be ubiquitously present.

The comparison itself will proceed through a sign test. Roughly half of the microelectronics firms are expected to have a smaller average distance to other microelectronics firms than to a random set of firms if there is no industry-specific concentration. I use this nonparametric method because the average distances of firms are not normally distributed, nor any other statistical distribution can be assumed for the population. Already from the map in Figure 3 it is seen that the distribution of the distances will be skewed to the right, as many firms cluster next to the central firm (marked in white) thus having a smaller average distance value. Indeed, a visual observation of Figure 4 and Figure 5 confirm that the distances are skewed to the right, so the distributions of average distances for microelectronics firms and for other firms are not normal. Commonly applied methods to make the data resemble the normal distribution, such as a logarithmic transformation, were not successful.



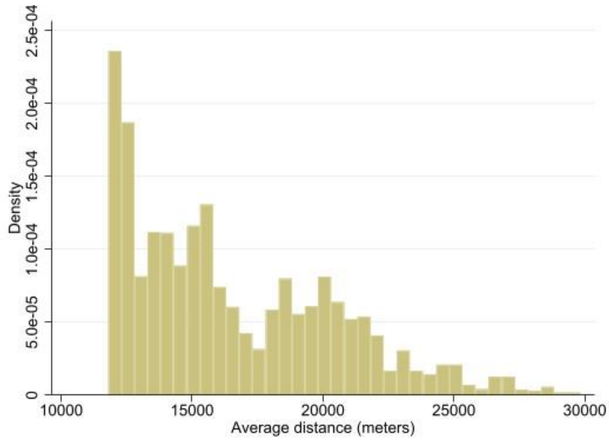


Figure 4. Average distances for microelectronics

Figure 5. Average distances for all selected firms

To test the second hypothesis, the same sign test will be repeated only for the Eindhoven municipality area. Additionally, for the highest practical insight, the same two tests will be performed for the list of all *electronics* companies, which may be regarded as a wider industry of our interest. Studying electronics may relevantly complement the study of microelectronics because “the results of these models appear to be sensitive to the level of sectoral aggregation used” (McCann, 2007, p 34), and the most accurate level of sectoral aggregation is not proclaimed elsewhere in the academic literature.

The advantage of this method is the reasonable amount of data required to run this analysis. Compared to the input-output model used by, for example, Sonis et al. (2007), which requires extremely extensive data on interfirm linkages and their output flows, the outlined method is applicable in cases where such data are not available. Moreover, it focuses on the geographic proximity rather than industrial interdependencies. Yet, being more simple, it also involves the limitation of a less eloquent and meaningful result, which then has to be supported with a deeper inquiry.

For this reason, hypotheses 3 and 4 in their turn are concerned with specific possible reasons for such concentration. As was discussed in the theoretical framework, many potential reasons may be influencing the location choices of firms, from urbanization economies that affect all industries to some industry-specific agglomeration economies. To simultaneously control for and estimate the impact of several possible factors I will run a multiple linear regression. A dependent variable must represent a location choice of each firm while independent variables must seek to explain and predict it. Hypothesis 3 focuses on the presence of R&D institutions nearby, hence this factor must be among the independent variables in the regression. Moreover, general urbanization economies have to be controlled for. Additionally, in line with hypothesis 4 we can expect some Porter’s localization economies, implying that the location choices of microelectronics firms in Zuidoost Noord Brabant were influenced by the locations of other microelectronics firms more than the location choices of other firms. Again, the same regression must be then performed for the wider electronics cluster.

These arguments lead to the following regression model estimated with ordinary least squares:

$$Y = a + b_1*X_1 + b_2*D_1 + b_3*D_2 + b_4*D_3 + u$$

Where Y is the number of (micro)electronics firms within 1km (2.5 km) radius from a given location, X_1 is the number of all firms within 1km (2.5km) radius from a given location, D_1 is a dummy variable which is equal to 1 when the given location is occupied by a (micro)electronics firm, D_2 is a dummy variable indicating that the given location is within the Eindhoven municipality, D_3 is a dummy variable for locations that have an R&D institutions with at least 10 employees within 1km (2.5km). Finally, u is the error term, which is assumed to be normally distributed. This regression will run two times to test separately for the agglomeration advantages within 1-kilometer and 2.5-kilometer radius.

This regression will run through all the selected firms' locations, not only the locations of the microelectronics firms. The underlying reason is that it tests different possible locations in terms of their potential for the agglomeration economies in microelectronics. If microelectronics companies and other companies locate with the same frequency near other microelectronics firms, the coefficient b_2 will be insignificant, which would doubt the presence of Porter's localization economies. At the same time, I do not check *all possible geographical points* but only those in which some firm is already located to control for some general spatial factors that have determined these location choices (such as the availability of infrastructure in each geographical point). Additionally, non-industry specific factors such as rents are controlled for by the variable X_1, which anticipates that more microelectronics neighbors are expected in locations with more any-industry neighbors.

For the R&D dummy, only R&D institutions with 10 and more employees will be considered. Agglomeration economies are evaluated for 1-km and 2.5-km radius. Taking bigger radiuses is not reasonable, as such an area would be comparable to the size of the whole Eindhoven municipality. Moreover, Rosenthal and Strange (2003) show that agglomeration advantages are mostly present within very narrow areas, extending hardly further than 5 miles from the center of the cluster. Finally, the regression will also be performed for the electronics companies and not only the microelectronics for a more extensive overview.

The major limitation of this regression is some potentially missing variables controlling for other relevant industry-specific spatial factors (e.g. zoning policies or access to industry-specific infrastructure). However, with the relatively small number of microelectronics companies, adding more control variables would bring more statistical noise into the model. For this reason, a small number of microelectronics firms is the limitation of this whole research which cannot be avoided if we explore specifically Brainport microelectronics and not Dutch or European microelectronics. Nonetheless, it was explained that most of the spatial factors affecting firm locations irrespectively of their industries are accounted for, so as some urbanization economies that vary in importance for different industries.

Additionally, it may be tempting to question this method with the following logic. The analyzed location choices may represent the *perceptions* of the decision-makers regarding the potential advantages of each possible location. Therefore, microelectronics companies may cluster because they *perceive* clustering to be advantageous, while in fact it has no influence on their performance. We therefore have to assume that the location choices represent and reveal actual agglomeration advantages and not the mere unfounded perceptions of companies regarding such advantages.

However, there is a strong reason to believe that. The microelectronics industry of Eindhoven has been present for a considerable period of time, as the descriptive statistics in the theoretical framework has shown. The patterns of entry and exit, provided a sufficient period of time, would make more competitive firms survive. Therefore, even if each location choice was made without due regard to the spatial factors or was influenced by the unfounded perceptions, we would expect the actual spatial factors, including agglomeration *disadvantages* such as higher rents and congestion, to steadily influence the landscape of Zuidoost Noord Brabant. The result that the industry is still geographically concentrated and firms do not dissipate across the region would imply some real underlying 'gravitation' force that pulls them together. The impact of spatial factors on performance would therefore be reflected in the perseverance of this cluster and the fact that despite the maturity of the cluster, these firms did not de-concentrate geographically.

Mentioning that, it would be more conclusive to actually study the entries and exits of firms which might reveal intertemporal trends for concentration or de-concentration. The analytical tools for that are available, one example being a Diggle's K-statistic in the study of the Dutch industries by Huisman and Van Wissen (2004). However, for the present scope of the study there would simply be an insufficient number of entries and exits to make meaningful conclusions. Between 2017 and 2018, for example, there were only one entry and two exits of the microelectronics firms. Therefore, while being informative for the country-wide analysis of more generalized industries (e. g. manufacturing as a whole), entries and exits could not be investigated in this research.

Still, to bring at least a rough approximation of the intertemporal dynamics of spatial concentration or de-concentration in Brainport, I will perform the same regression analysis for two years, 2015 and 2018, and compare the results. It will show whether the degree of the geographical clustering and the reasons underlying it are changing throughout time. Due to the practical limitations, this comparison will be just an approximation and not a strict test. Specifically, I will check whether the value in the year 2018 for each variable lies within two or more standard errors from the value of the 2015 value for this variable. This would allow us to test hypothesis 5.

Results

This section presents the results of applying the described methodology on our data. First, the results of the sign tests will reveal the significance of a geographic concentration of the microelectronics companies relative to other Brainport companies. As discussed before, there are four sign tests in total – focused on the microelectronics and on a wider electronics cluster both studied in Zuidooost Noord Brabant and in a narrower region, the Eindhoven municipality. Second, the results of the multiple regression that aims to explain the concentrating behavior of the microelectronics companies will be reported. Lastly, the results of the regression analysis of the earlier data will evaluate hypothesis 5.

The results of the sign tests are presented in the following tables.

Table 5. Sign test for the microelectronics firms in Zuidoost Noord Brabant in 2018

		N
Average distance to other microelectronics firms – Average distance to all other firms	Negative Differences[a]	39
	Positive Differences[b]	2
	Ties[c]	0
	Total	41

a. *Average distance to other microelectronics firms < Average distance to all other firms*
b. *Average distance to other microelectronics firms > Average distance to all other firms*
c. *Average distance to other microelectronics firms = Average distance to all other firms*

Table 6. Sign test statistics for the first sign test

	Average distance to other microelectronics firms – Average distance to all other firms
Exact Sig. (2-tailed)	.000[a]

a. *Binomial distribution used*

Table 6 and table 8 show that while a significant result is obtained for the first sign test, the second sign test is inconclusive. Hence, microelectronics companies are geographically concentrated relatively to other companies in Zuidoost Noord Brabant, but not in the Eindhoven municipality. That is because 39 of 41 microelectronics companies in the region have a smaller average distance to other microelectronics companies than their average distance to all other companies. In Eindhoven, while 10 out of 16 microelectronics companies we closer on average to other microelectronics companies than to all other companies, the number of observations required to conclude the significance of their concentration is insufficient.

Table 7. Sign test for the microelectronics firms in the Eindhoven municipality in 2018

		N
Average distance to other microelectronics firms – Average distance to all other firms	Negative Differences[a]	10
	Positive Differences[b]	6
	Ties[c]	0
	Total	16

d. *Average distance to other microelectronics firms < Average distance to all other firms*

e. Average distance to other microelectronics firms > Average distance to all other firms
f. Average distance to other microelectronics firms = Average distance to all other firms

Table 8. Sign test statistics for the second sign test

	Average distance to other microelectronics firms – Average distance to all other firms
Exact Sig. (2-tailed)	.455[a]

a. Binomial distribution used

For the wider electronics cluster, similar results are observed as shown in Table 9 and Table 11.

Table 9. Sign test for the electronics firms in Zuidoost Noord Brabant in 2018

		N
Average distance to other electronics firms – Average distance to all other firms	Negative Differences[a]	218
	Positive Differences[b]	17
	Ties[c]	0
	Total	235

g. Average distance to other electronics firms < Average distance to all other firms
h. Average distance to other electronics firms > Average distance to all other firms
i. Average distance to other electronics firms = Average distance to all other firms

Table 10. Sign test statistics for the third sign test

	Average distance to other electronics firms – Average distance to all other firms
Exact Sig. (2-tailed)	.000[a]

b. Binomial distribution used

Again the concentration of these companies in the whole Brainport region is significant, but not significant in the Eindhoven municipality. 218 out of 235 microelectronics companies in Zuidoost Noord Brabant were on average closer to other electronics companies than to all other companies. As discussed earlier, it implies that the set of all electronics companies is significantly different in terms of their location choices from the whole population of companies in this COROP and does not resemble a set of randomly selected Brainport's firms. Therefore, Table 6 and Table 10 presented solid evidence in favor of hypothesis 1 as the geographical concentration of the electronics and microelectronics companies in Zuidoost Noord Brabant is statistically significant.

For the Eindhoven municipality, the result is now reversed as significantly more electronics companies (49 out of 76) are closer on average to all other firms than to other electronics firms. This implies a de-concentration effect – electronics companies might prefer the locations on the Eindhoven's periphery *and* far from other electronics companies to more central locations within the municipality, which would explain the result. This result does not align with hypothesis 2. Thus, it was not possible to reveal the statistically significant geographic concentration of the microelectronics and electronics companies within the Eindhoven municipality.

Table 11. Sign test for the electronics firms in the Eindhoven municipality in 2018

		N
Average distance to other electronics firms – Average distance to all other firms	Negative Differences[a]	27
	Positive Differences[b]	49
	Ties[c]	0
	Total	76

j. Average distance to other electronics firms < Average distance to all other firms
k. Average distance to other electronics firms > Average distance to all other firms
l. Average distance to other electronics firms = Average distance to all other firms

Table 12. Sign test statistics for the fourth sign test

	Average distance to other electronics firms – Average distance to all other firms
Exact Sig. (2-tailed)	.015[a]

c. Binomial distribution used

Despite the statistically significant result for microelectronics and electronics within the region as a whole, we cannot yet conclude the presence of some industry-specific agglomeration economies. Geographic concentration was revealed, but its reasons may vary, as discussed in the theoretical framework. What is not yet accounted for is the case when (micro)electronics companies are indeed geographically clustered but they do so because of some general and not industry-specific advantages (e. g. urbanization economies of the Eindhoven municipality, or proximity to the market). This suspicion is enforced with our inability to see the concentration effect *within* the Eindhoven municipality (Tables 8 and 12). Therefore, the geographical concentration observed in Table 6 and Table 10 must be explained by the regression analysis.

The results of the regression analysis are presented in Table 13. The first model evaluates the relation between the number of the microelectronics firms within 1 km from any given firm location, the number of all firms within 1 km, an Eindhoven dummy, and a microelectronics dummy. The result indicates that keeping other factors constant, in 2018, microelectronics firms were expected to have on average 0.236 microelectronics companies more within 1 km radius than companies in other industries. This coefficient is significant at 5% significance level. This hints at the presence of localization economies, whereby microelectronics firms tend to systematically locate in places with more microelectronics neighbors than other firms.

Table 13. Regression analysis results for Brainport's microelectronics in 2018 and 2015

Dependent variable	(1) Number of the microelectronics firms within 1 km radius		(2) Number of the microelectronics firms within 1 km radius		(3) Number of the microelectronics firms within 2.5 km radius		(4) Number of the microelectronics firms within 2.5 km radius	
	2015	2018	2015	2018	2015	2018	2015	2018
Belongs to the microelectronics industry	0.219** (.105)	0.236** (.107)	0.162 (.103)	0.083 (.099)	0.655*** (.216)	0.449*** (.231)	0.654*** (.216)	0.445** (.201)
Number of firms within 1 km radius	0.016*** (.000)	0.013*** (.000)	0.016*** (.000)	0.012*** (.000)				
Number of firms within 2.5 km radius					0.013*** (.000)	0.007*** (.000)	0.013*** (.000)	0.006*** (.000)
Located in Eindhoven	0.398*** (.027)	0.379*** (.027)	0.307*** (.028)	0.129*** (.028)	1.765*** (.066)	2.043*** (.062)	1.684*** (.074)	1.547*** (.070)
Has at least one R&D institution within 1 km			0.206*** (.018)	0.300*** (.013)				
Has at least one R&D institution within 2.5 km							0.054** (.023)	0.200*** (.014)
Constant	-0.181*** (.020)	-0.107*** (.020)	-0.188*** (.019)	-0.093*** (.019)	-0.325*** (.043)	-0.149*** (.042)	-0.317*** (.043)	-0.016 (.042)
Observations	3813	4082	3813	4082	3813	4082	3813	4082
Adjusted R^2	0.30	0.23	0.33	0.32	0.55	0.54	0.55	0.56

Note. Standard errors are in parentheses; *** $p < 0.01$, ** $p < 0.05$

The two control variables, both statistically significant, account for the non-industry-specific urbanization effects. All else equal, the first control variable indicates that having one more any-industry neighbor in 2018 is associated with having 0.013 more microelectronics neighbors within 1 km. This can be a sign that the general urbanization economies are influential in the location decisions of the microelectronics firms, although this is not the focus of the present article and cannot be concluded certainly. Another control variable shows that being located in Eindhoven is associated with having 0.379 microelectronics firms more within 1 km than being located outside of this municipality, keeping other factors fixed.

A constant coefficient of -0.181, which is negative in all models, has only a provisional interpretation as our dependent variables are bound to 0. Equating all dummy variables to 0, a company with the average number of any-industry neighbors (which is equal to 36.04) has on average 36.04*0.016 – 0.181 = 0.3956 microelectronics firms within 1 km, all else equal.

Next, we introduced into this model a dummy variable indicating whether any given firm location has at least one R&D institution with 10 or more employees within 1 km radius. As seen, this coefficient is statistically significant at 99% confidence level, and implies that having an R&D organization in the vicinity is associated with having 0.300 more microelectronics companies within 1 km radius in 2018, all else equal. This is an important result showing that the location choices for the microelectronics companies are better associated with R&D neighbors than for the firms in other industries.

When this dummy was added, the adjusted R^2 increased from 0.23 to 0.32. Therefore, while the first model was able to explain 23% of the variation in our data, adding the R&D dummy allowed us to explain 32% of the variation. Additional important change is that another variable of our interest, the microelectronics dummy, ceased to have a statistically significant beta coefficient. This change might imply that the clustering of the microelectronics companies is present but is better explained by the vicinity to an R&D institution rather than by Porter's localization economies. Due to the increase in the explanatory power of the model when adding the R&D dummy, the second model has priority in influencing our verdict about hypotheses 3 and 4.

The third and the fourth models depicted in Table 13 repeat the analysis of the first two models for the 2.5-km radius. Controlling for the R&D-related clustering, belonging to the microelectronics industry is associated with having 0.445 more microelectronics companies within 2.5 km on average, all else equal. This coefficient is statistically significant at the 95% level of confidence and is enforced by two control variables. Importantly, introducing the R&D dummy this time does not affect the model as in models 1 and 2, as both the adjusted R^2 stays close to the previous 0.54 and the beta coefficient for the microelectronics dummy stays significant at 95% confidence level. The R&D dummy is statistically significant and shows that having an R&D institution within 2.5 km is associated with 0.200 more microelectronics companies on average, all else equal.

The differences between 1 km and 2.5 km scale should be interpreted carefully. For example, the Eindhoven dummy is 2.043 on the 2.5 km radius and 0.398 on the 1 km scale. Yet, 2.5-km radius covers the area of roughly 20 km^2, while 1-km radius covers only 3.14 km^2 area. Thus, a reasonable numeric difference for the same variable between the two scales cannot be interpreted meaningfully.

To check for any intertemporal dynamics, these models were run for the year 2015 as well. In terms of the adjusted R^2, the significance and signs of the coefficients for all four models for 2015 look similar to the respective models for 2018. Both models 2 and 4 exhibit a smaller microelectronics dummy for 2018 than for 2015; the 2018 value is however within one standard error of the 2015 coefficient, which does not allow us to conclude a statistically significant difference between the two years.

Yet, such a conclusion can be made with regard to the R&D dummy. In 2018, having an R&D institution within 2.5 km is associated with having 0.200 more microelectronics firms within 2.5 km, all else equal. The corresponding value for 2015 is only 0.054, which is within 11 standard errors from the 2018 value. Both coefficients are statistically significant, so this can indicate an increasing importance of the vicinity to R&D institutions for the clustering decisions. A similar result holds on the scale of 1 km radius, where the R&D dummy increases from 0.206 in 2015 to 0.300 in 2018.

The same modelling was also performed for the electronics firms. As can be seen in Table 14, the significance of different location factors follows a similar pattern as for the microelectronics industry. Focusing on a 1-km radius, we see that the electronics companies in 2018 have on average 0.408 more electronics neighbors that all other companies, all else equal. This coefficient is significant at the 95% confidence level. However, adding a dummy for having an R&D institution within 1 km makes this coefficient no longer statistically significant, while increasing the adjusted R^2 from 38% to 51%. Again, it implies that the proximity to R&D institutions can better explain the concentration of the electronics companies than Porter's localization economies. As such, having at least one R&D institution with 10 or more employees within 1 km and 2.5 km is associated with having 0.775 and 0.839 electronics neighbors more on average, other factors held constant.

As for the 2.5 km radius, the effect of introducing the R&D dummy also resembles the result for the microelectronics industry. The adjusted R^2 increases only from 0.74 to 0.78, meaning that these models explain 74% and 78% of the variation in our data. The beta coefficient of the electronics dummy implies that an electronics company has on average 0.449 more electronics companies within 2.5 km radius, all else equal. This coefficient is however significant only at the 90% confidence level.

Finally, an intertemporal change also resembles that of the microelectronics industry. Localization effect, as signified by the electronics dummy, is not higher than one standard error above the value for 2015 in all the models. Meanwhile, the R&D-related effect rises in scale, with the R&D dummy increasing by multiple standard errors from its 2015 value for both 1-km and 2.5-km radius.

Table 14. Regression analysis results for Brainport's electronics in 2018 and 2015

Dependent variable	Number of the electronics firms within 1 km radius		Number of the electronics firms within 1 km radius		Number of the electronics firms within 2.5 km radius		Number of the electronics firms within 2.5 km radius	
	2015	2018	2015	2018	2015	2018	2015	2018
Belongs to the electronics industry	0.313*** (.113)	0.408*** (.113)	0.267** (.112)	0.081 (.101)	0.621*** (.204)	0.616** (.258)	0.614*** (.204)	0.449* (.238)
Number of firms within 1 km radius	0.051*** (.000)	0.029*** (.001)	0.051*** (.000)	0.027*** (.000)				
Number of firms within 2.5 km radius					0.040*** (.000)	0.028*** (.000)	0.040*** (.000)	0.022*** (.000)
Located in Eindhoven	-0.528*** (.054)	1.522*** (.054)	-0.630*** (.056)	0.883*** (.051)	-1.310*** (.114)	6.911*** (.141)	-1.470*** (.129)	0.449*** (.151)
Has at least one R&D institution within 1 km			0.232*** (.035)	0.775*** (0.24)				
Has at least one R&D institution within 2.5 km							0.106*** (.040)	0.839*** (.031)
Constant	-0.301*** (.039)	-0.001 (.039)	-0.308*** (.039)	0.041 (.035)	-0.046 (.075)	-0.809*** (.096)	-0.030 (.076)	-0.248*** (.091)
Observations	3813	4082	3813	4082	3813	4082	3813	4082
Adjusted R^2	0.44	0.38	0.45	0.51	0.61	0.74	0.61	0.78

Note. Standard errors are in parentheses; *** *p < 0.01, ** p < 0.05*

Before having a final evaluation of our hypotheses, some comparison of the electronics and microelectronics industries must be made. Eindhoven dummy is negative and statistically significant for the electronics industry in 2015. It can imply that electronics companies avoided locations within Eindhoven relative to firms in all other manufacturing industries. In 2018 this effect cannot be observed, so as for the microelectronics industry. Secondly, the industry-dummy which accounts for localization is similar between the two tables, and the R&D dummy may hint at somewhat higher R&D-related clustering in electronics.

We must now interpret these results in relation to the stated hypotheses 3 and 4. Hypothesis 3 stated that clustering in microelectronics is positively associated with the presence of the R&D institutions nearby. On the scope of the 1-km radius, we have seen that the presence of the R&D institutions significantly adds to the explanatory power of the regression model, is itself statistically significant, and explains clustering better than the dummy for belonging to the microelectronics industry. The same situation is seen for the wider electronics cluster. The same results hold for the 2.5 km radius.

Proceeding from the structure of this paper, this result is viewed as a sufficient evidence in favor of hypothesis 3, deeming it highly likely that some agglomeration effect related to the vicinity to R&D institutions is present in the Brainport's microelectronics and electronics industries. A less clear result is obtained with regard to hypothesis 4. In 2018, for both electronics and microelectronics, on the scale of 1 km the localization economies were not visible, as the industry dummy was not statistically significant after controlling for the R&D institutions nearby. On the scale of 2.5 kilometers, some localization effect was revealed as highlighted by the statistically significant coefficients – 95% confidence level for microelectronics and 90% confidence level for electronics in 2018. Because of this inconsistency, it is not possible to conclude that sufficient evidence was presented to support hypothesis 4. Therefore, the present article was unable to reveal localization economies in Brainport's electronics and microelectronics after controlling for other factors.

Finally, hypothesis 5 should be evaluated which claimed that agglomeration economies in Brainport diminish over time. As we have seen, the R&D related dummy clearly exhibits an increase between 2015 and 2018, both for electronics and microelectronics and for 1 km and 2.5 scale. Although a formal significance test for this increase was outside of the article's scope, this is a solid indication of no diminishing R&D-related agglomeration effect. As for the localization economies, it was not possible to establish their presence so the intertemporal comparisons are also not possible. Therefore, hypothesis 5 is rejected in regard to the R&D related agglomeration, but not in regard to the localization economies. It is still possible that localization economies were present in some earlier period and diminished in significance. Thus, the R&D-related concentration effect has become bigger between 2015 and 2018, and localization economies were not identified in both years or ceased to be considerable.

Overall, despite the maturity of the microelectronics industry in the Eindhoven region, it remains geographically concentrated, as the sign tests have shown. Together with the revealed R&D-related agglomeration advantages which empirically validate the Dutch industry-oriented knowledge economy as conceptualized by Raspe and Van Oort (2006), this can be a sign of an ongoing growth and an argument in favor of directing some financing within the Chips Act 2022 to Brainport. This will be discussed in more detail in the next and final section.

Discussion and conclusion

The conducted evaluation of the hypotheses allows us to answer the research question. This article tried to see whether industry-specific agglomeration economies are present in the Brainport's microelectronics industry. Specifically, localization economies and R&D-related agglomeration were tested. Localization economies stem from the advantages of locating next to companies working in the same industry, while R&D-related economies stem from knowledge spillovers that benefits innovative high-tech industries as a result of locating next to R&D institutions. Evaluating these advantages is important in assessing the overall potential of Brainport's microelectronics, which in turn may guide the direction of the Chips Act 2022 financing aimed at revitalizing the semiconductor industry in Europe.

First, the geographical concentration of the microelectronics and electronics companies was revealed for the Brainport region as a whole but not for its central part, the Eindhoven municipality. Among the particular factors associated with such concentration, the regression analysis revealed the proximity to R&D institutions. Meanwhile, microelectronics firms were not revealed to have more microelectronics neighbors than firms in other industries. Therefore, localization economies could not be established. Lastly, between 2015 and 2018, the R&D-related clustering grew in scale as the main intertemporal difference that was observed. Other variables of our interest did not considerably differ for these two years.

Such a result is comparable to other studies of localization economies. Malmberg et al. (2000) similarly showed that localization economies are overemphasized in academic literature and can hardly be found for the Swedish manufacturing industry. Rather, innovative milieu is more important for agglomeration, which agrees with our result. Furthermore, Feldman (1993) established a positive relation between the industry agglomeration and the presence of large dominant firms. As discussed before, Brainport's microelectronics does not have such a dominant propulsive firm, so the absence of localization economies is in line with the relation synthesized by Feldman (1993).

Answering the research question, these findings indicate that the industry-specific agglomeration economies in Brainport's microelectronics are indeed present. We see that microelectronics companies especially cluster around R&D institutions and within the Eindhoven municipality. These inferences are even more credible as the proximity to R&D institutions dominates the proximity to the same-industry firms as an explanatory variable. Overall, this result confirms the description of the Dutch economy as a highly developed knowledge economy (Raspe & Van Oort, 2006), as the link between R&D and its commercialization in the form of high-tech microelectronics companies is hereby observed.

With regard to the Chips Act 2022, this result is the argument in favor of employing Brainport's potential in the quest for the European semiconductor sovereignty. The long established 'triple-helix' cooperation of businesses, government representatives and knowledge institutes has therefore received a partial empirical validation, which is an important practical implication of this article (Horlings, 2014). Such a cooperative symbiotic environment is a fertile ground for innovation and development as discussed in the theoretical framework, and it is a solid competitive advantage to be diligently mobilized for the EU strategic aims.

The method used to identify the agglomeration economies in this paper depends on the viability of a few critical assumptions. Crucially, our results are based on the observed location choices of companies thereby assuming that location choices actually reflect the relevant spatial factors. For our interpretation to hold, the location choices of microelectronics firms must have been made with due regard to the general and industry specific location factors among which are agglomeration economies. To overcome the fragility of this assumption, some performance indicators that are sensitive to spatial factors could be added in the future research.

Another major limitation is the insufficient number of the microelectronics firms under our investigation. As seen before, most research focuses on the country-scale and on the more aggregated industries, hence including more companies into the studied sample. For this research, however, it was unfeasible as Brainport is limited to the Eindhoven region and does not spread over the whole of the Netherlands. Lastly, this article does not sufficiently incorporate intertemporal changes. A rough evaluation is given, but a more detailed inquiry is clearly desired.

The soundness of the utilized methodology, particularly of using the geographic coordinates, is an important implication for economic theory. As discussed before, Huisman and Van Wissen (2004) mapped the entries and exits of firms to track localization economies, showing that insightful methods can be borrowed from other disciplines such as epidemiology and geostatistics. Yet, regional economic analysis and economic geography still mostly use tools and methods that study the regions of interest holistically and paradoxically miss the spatial dimension (Dinc, 2002). This partly stems from the scarcity of geodata necessary to map locations and distances between different economic entities. As the article has demonstrated, relevant insights can be drawn by using such data whenever available.

Overall, the most essential empirical discovery of this article is the spatial concentration of Brainport microelectronics around local R&D facilities. In a direct connection to that, the last suggestion for the future research is to inquire deeper into the specific reasons for this R&D-related agglomeration, to investigate the channels through which the general innovative milieu contributes to the specific industrial developments within the region. As such, this article could reveal the concentration of microelectronics firms around R&D institutions, which is only a sign of knowledge spillovers in Brainport. As Boschma and Ter Wal (2007) note rightly, spatial proximity is a hint but not a definitive cause of knowledge externalities. What matters ultimately is the local and non-local connectivity, a position of a firm within the regional social network, the productive relationality between heterogeneous regional actants. All these particular channels of regional industrial innovation must be tracked down in the future works on economic geography.

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