Spatial Fragmentation of Industries by Functions

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Abstract

We show that key functions are spatially clustered with, or dispersed from, each other even within manufacturing industries in West Germany, and that these clustering or dispersion patterns have changed significantly during recent decades. Estimating levels and changes (1992–2007) of localizations and colocalizations of selected functions (production, headquarter services, R&D) within 27 West German industries by means of K densities, we identify two broad groups of industries. In "fragmenting" industries, which account for half of manufacturing employment, functions were more clustered with each other than the industry as a whole after the fall of the Iron Curtain but have, in accordance with regional theories of spatial fragmentation, been unbundled spatially from each other subsequently. In "integrating" industries, by contrast, which account for one third of manufacturing employment, functions were initially dispersed from each other but have subsequently been rebundled spatially with each other. This spatial rebundling may be a consequence of offshoring, i.e., international fragmentation.

Keywords: Localization, colocalization, fragmentation, offshoring, functions, K density, manufacturing, Germany

JEL classification: C19, L60, F23, R12

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1. Introduction

The global fragmentation of value chains is currently on top of the agenda in international economics. Globalization has arguably offered firms new opportunities for unbundling their activities during the last decades. Advances in information and communication technologies (ICT), organizational innovations, decreasing transport costs and trade liberalizations have allowed firms to break up their formerly integrated value chains into separate activities (production stages, functions or tasks) and outsource some of these activities to foreign suppliers or offshore them to foreign subsidiaries (Baldwin 2006, Helpman 2006, Antras and Yeaple 2014). This global fragmentation has affected the division of labor between countries significantly and in a variety of ways (e.g., Hummels et al. 1998, 2001, Schott 2004, Daudin et al. 2011). But to what extent has globalization also affected the spatial division of labor within countries? How extensively has, for example, production been outsourced or offshored from high-cost urban areas to lower-cost rural areas? Systematic empirical evidence on these questions is surprisingly scant.

In this paper, we contribute to answering these questions by systematically exploring the extent and the changes of the spatial division of labor along functional lines within manufacturing industries in Germany since the fall of the Iron Curtain (1992 – 2007). The spatial division of labor along functional lines has arguably become more relevant in recent decades than that along sectoral lines (Duranton and Puga 2005). We focus on three large functions, production, headquarter services (HQ) and research and development (R&D). We nonetheless account for the specificities of the various industries by exploring the spatial division of labor separately for 27 manufacturing industries. We measure the extent of the spatial division of labor by means of (employment-weighted) K densities of localization or colocalization of functions within industries, and the changes of this division of labor over time by differences between the corresponding K densities of localization or colocalization for 2007 and 1992. We show that, first, the location patterns of functions deviated significantly from those of their industries as a whole in both 1992 and 2007. HQ and R&D are more clustered in most industries while production is more clustered in some but more dispersed in other industries. This suggests that locational advantages in general, and agglomeration economies more specifically, do not work only at the level of industries, as studies like Ellison et al. (2010) suggest, or only at the level of functions, as Gabe and Abel (2013) suggest. Their relevance appears to vary across both functions and industries. Second, we show that the spatial division of labor among functions has changed significantly over time in most industries. We identify two major groups of industries. One group has, broadly in line with predictions by models of regional fragmentation such as Duranton and Puga (2005), become spatially more fragmented. Loosely speaking, production has, on aggregate, been moved away from locations where HQ and R&D have been clustering towards more remote locations. We call these industries domestically “fragmenting” industries. The second group of industries has, apparently against predictions by theory, evolved in the opposite direction. In these industries, which we call domestically "integrating"[1] industries, production has become more colocalized with HQ and R&D. It looks as if these industries, whose production plants were already located away from HQ and R&D in the early 1990s, have called their production plants back home to the HQ locations. We argue, however, and provide some supportive though indirect evidence, that these industries rather may also have become more fragmented, though at the global scale. They may have outsourced or offshored production from remote domestic plants to foreign countries, which looks like decreasing fragmentation from a national perspective. We show that they have disproportionately expanded outward foreign direct investments (FDI) or imports of intermediate goods, and have disproportionately reduced their domestic employment, especially in production. They may actually be just in a later stage of globalization than the domestically fragmenting industries.

While this paper is descriptive, economic theory may help interpret its findings and may guide subsequent research on the factors that drive the spatial fragmentation of industries. Theoretical models from the regional economics domain explain increasing spatial fragmentation of economic activity along functional lines by decreasing costs of managing remote production plants (see Ota and Fujita 1993, Duranton and Puga 2005 and Rossi-Hansberg et al. 2009). On the one hand, efficient management of a firm requires extensive communication, coordination and monitoring between production and headquarter, which is more costly across larger distances. On the other hand, urban areas offer headquarters particularly strong locational advantages in terms of richer supply of skilled labor, specialized business services or knowledge spillovers while rural areas offer production plants locational advantages in terms of lower labor costs. If the costs of managing remote plants are high, profit-maximizing firms will prefer concentrating headquarter and production at a single location in the urban area. It is more profitable to pay production workers the higher urban wage than incurring the additional costs of managing remote production plants across a distance. If these costs decrease, e.g., due to advances in ICT or organizational innovations, the firms will eventually offshore production to a rural area while retaining their headquarters in the urban area. Managing production across a distance will become more profitable than paying production workers the higher urban wage.[2] On aggregate, the location patterns of production and headquarters will consequently become more dissimilar over time.

This theory of spatial fragmentation of firms by functions has, to our knowledge, not yet been tested empirically in the regional economics domain.[3] We are not aware of a single paper that tries to assess the effects of decreasing costs of managing domestic multiplant firms on location decisions for functions in the presence of function-specific locational advantages. Even descrip-

[1] The term "integrating" is actually meant to be the antonym to "fragmenting".

[2] While these models focus on offshoring of production, similar arguments could be made for the outsourcing of production or other activities. Bargaining over the legal details of a contract, fixing and adjusting the technical details of a product, and coordinating production plans will be more costly across larger distances as well.

[3] We will discuss the related literature in the international economics domain below.

tive evidence on the aggregate extent of this spatial fragmentation is rare (see also Desmet and Henderson 2015, Section 4.1.1). Duranton and Puga (2005) show that urban areas in the U.S. have, on aggregate, been increasingly specializing in white-collar jobs during recent decades while rural areas have been increasingly specializing in blue-collar jobs. Bade et al. (2004) find a similar result for Germany. The present paper substantiates this descriptive evidence by showing that this aggregate picture of increasing spatial division of labor among functions masks considerable heterogeneity across industries.

In addition to this descriptive evidence, a growing body of empirical research suggests that regional differences in locational advantages do in fact shape the spatial concentrations of industries, occupations or functions at a given point in time. Marshallian localization economies— input-output linkages, labor pooling and knowledge spillovers— and factor costs rank high among these locational advantages. For industries, Ellison et al. (2010) find that all three Marshallian localization economies cause the localization of manufacturing industries in the U.S., with input-output linkages being somewhat more relevant than the other two externalities. Kolko (2010) finds that input-output linkages are even more relevant for the localization of services than for that of manufacturing industries. And Jofre-Monseny et al. (2011) find for Spain that Marshallian localization economies also shape the spatial concentration of newly established firms.[4] None of these studies disaggregates industries by functions, though, to check if, say, factor costs or labor pooling shape the spatial concentration of production to the same extent as that of headquarters. For occupations, Gabe and Abel (2013) find that their localization is shaped significantly by labor pooling and knowledge spillovers. They do not check, however, if these Marshallian localization economies differ across industries. And several studies investigate the causes of the spatial concentration of functions from firm-level data. Most of these studies focus on headquarters in the first place, though. Aarland et al. (2007) observe that the headquarters of multiplant firms are disproportionately located in urban areas while manufacturing as a whole is overrepresented in rural areas. They also find that the probability of having a stand-alone headquarter differs between industries and increases with firm size. Davis and Henderson (2008), Henderson and Ono (2008) and Strauss-Khan and Vives (2009) find that manufacturing firms prefer locating their stand-alone headquarters in larger metropolitan centers to benefit from thick markets for producer services and knowledge spillovers. Lovely et al. (2005) find that headquarters of exporters are more agglomerated than those of non-exporters in order to benefit from knowledge spillovers.[5] Fort (2013) complements this evidence by showing that labor costs are an

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[4] See Combes and Gobillon (2015) for a recent critical review of this strand of the literature.

[5] Somewhat complementary to the evidence on headquarter locations, Atalay et al. (2014) find that the main ownership advantage of multiplant firms in the U.S. results from intra-firm transfers of intangible inputs such as managerial oversight while there is very little intra-firm shipment of goods between vertically related plants. This does not imply that firms do not outsource domestically, of course. On the contrary, several studies, including Fally (2012), Fort (2013) and Schwörer (2013), show that domestic sourcing of intermediate inputs is still quantitatively much more important than foreign sourcing even though foreign sourcing has expanded disproportionately during recent decades. Mayer et al. (2010) find a similar "home bias" for the location choices

important motive not only for international but also for domestic outsourcing of production activities.

The theories of spatial fragmentation and the microeconometric studies just reviewed suggest that fragmentation takes place at the firm level, driven by explicit decisions to unbundle production processes along functional lines. In the present paper, we also use firm-level data but adopt a broader notion of fragmentation that focuses on geography rather than firms. This notion is more informative about the aggregate spatial consequences of changes in the functional division of labor. We use the firm-level data only to evaluate, by means of K densities, to what extent an industry as a whole is spatially clustering different functions with each other at a given point in time, and if the extent of this spatial clustering has increased or decreased over time.[6] The fragmentation we focus on is thus driven not only by firms' decisions to offshore activities to subsidiaries in other regions. It is also driven by decisions outsource activities to firms from the same industry in other regions. And it is even driven by competition on sales markets. Integrated firms may just lose market shares and downsize their production capacities while their competitors in other regions gain market shares and expand their capacities. Since ownership of establishments is not an issue in our study, we will simply use the term 'offshoring' to characterize all these kinds of changes in the spatial distribution of functions within industries.

We study spatial fragmentation separately for 27 manufacturing industries. This focus on industries allows us accounting for differences between industries in the technical and organizational constraints to spatial fragmentation of functions. In addition to this, the spatial distribution of an industry as a whole constitutes a particularly useful benchmark for the spatial distribution of the functions. A downside of the focus on industries is, however, that we cannot identify outsourcing across industries.

The theoretical models of regional fragmentation may actually be suited fairly well for explaining what we observe for the domestically fragmenting industries. The location patterns of production have become more dissimilar from those of HQ and R&D over time in these industries. The models are, however, apparently at odds with what we observe for the domestically integrating industries where the location patterns of functions have become more similar to each other. They would suggest that the domestic offshoring costs have increased over time, which is arguably rather implausible in the light of the recent advances in ICT.[7]

We rather suggest that the observed decreasing domestic fragmentation of the integrating indus-

for investments in production affiliates by French manufacturing firms. None of these studies addresses the spatial dimension of domestic sourcing or investments, though.

6 Since the establishments do not have a unique identifier in our dataset, we actually cannot trace the individual establishments over time. We can neither identify ownership relationships between the establishments from the data.

7 An alternative, similarly implausible explanation would be that these industries have switched to new products or processes that are associated with substantially higher costs of managing remote production plants, in spite of advances in ICT.

tries may be the consequence of their increasing international fragmentation. Quite interestingly, theoretical models from the international economics domain use a very similar trade-off as the regional models just sketched to explain international offshoring of production. Helpman (2006) and Antras and Yeaple (2014) survey these models. While most of these models focus on firm heterogeneity to explain why different modes of production—in-house production, outsourcing and offshoring—exist simultaneous in an industry at a given point in time, they are also informative about the effects of decreasing fragmentation costs over time. A model by Fort (2013) may be particularly relevant for understanding our results for both the fragmenting and the integrating industries. In this model, heterogeneous firms face three alternatives for locating tasks: in-house production (highest wage), domestic offshoring (lower wage) and foreign offshoring (lowest wage). There is a continuum of tasks, which differ from each other in the levels of their fragmentation costs. For a given task, these costs are generally higher for foreign than for domestic offshoring, though. The combination of firm heterogeneity, task heterogeneity and multiple locations generates a wealth of possible outcomes of Fort's model. Reduced to the essentials relevant for the present study, it suggests, however, that, as offshoring costs decrease over time due to advances in ICT, tasks for which foreign offshoring is significantly more expensive than domestic offshoring will be offshored first domestically and only later internationally. In addition to this, industries with lower levels of (domestic and international) offshoring costs will offshore earlier. For the empirical findings of the present paper, this would imply that for domestically integrating industries, which were already domestically fragmented in the early 1990s, larger-scale domestic offshoring may have become feasible already before the 1990s while larger-scale international offshoring may have become feasible only afterwards. For the domestically fragmenting industries, by contrast, which were still domestically integrated in the early 1990s, larger-scale domestic offshoring may have become feasible only since the early 1990s. While rigorous tests of these hypotheses are beyond the scope of the present paper, we provide some supportive evidence by showing that domestically integrating have disproportionately expanded their outward FDI or imports of intermediates while disproportionately reducing their domestic employment.

West Germany offers a particularly interesting case for studying spatial fragmentation of industries. It is still highly industrialized. Manufacturing industries still account for about 20% total GDP and employment, compared to barely more than 10% in France, the United Kingdom or the U.S. Moreover, Germany has been at the forefront of globalization after the fall of the Iron Curtain in 1989. The fall of the Iron Curtain exposed West German firms suddenly and unexpectedly to fierce competition from large low-cost countries with a fairly well-educated workforce next door to the east. This competition put West German firms under particularly high pressure to reduce costs and enhance efficiency but also offered them particularly rich opportunities for offshoring activities (Marin 2010, Görlich et al. 2014). We investigate fragmentation across a fairly long period of time, 1992 – 2007. This period covers most of the globalization era and virtually the whole time span since the fall of the Iron Curtain. This requires excluding East Germany from the analysis, however, which was deep in disequilibrium during the 1990s (Bickenbach and Bode 2013). After the reunification shock in 1990, which turned half to two-thirds of the East German capital stock obsolete and reduced output by half within a single year, East Germany went through a deep structural transformation during the 1990s that was fuelled by extensive public interventions, including heavy public subsidies of up to 50% for capital investments. We show in Section 6 that the exclusion of East Germany does not affect our results notably.

The paper is organized as follows. Section 2 describes the data. Section 3 introduces the empirical methodology and the terminology used in this paper. Section 4 presents and discusses the empirical results on the spatial fragmentation of West German industries and identifies the domestically fragmenting and integrating industries. Section 5 provides some additional facts on the evolution of outward FDI and imported intermediates as well as on employment growth by industries to support our hypothesis that the domestically integrating industries are actually globally fragmenting industries. Finally, Section 6 concludes.

2. Data

We use establishment-level data from the German employment statistic. This statistic covers all persons gainfully employed and subject to the public Social Security System in Germany, which is between 65 and 95% of total employment, depending on the industry. Self-employed, civil servants (*Beamte*), and workers with very low income are not subject to the public Social Security System. Establishment-level data is usually available from this data source for only a few recent years. We succeeded, however, in constructing an establishment-level data set for the year 1992 that is comparable to that in recent years. We thus choose the observation period to be 1992–2007. Unfortunately, we do not have unique establishment IDs for both years that would allow us to trace individual establishments over time.

Being used for calculating individual pension claims, the Social Security System employment database is very accurate. It is compiled from reports by all employers with at least one employee subject to the public Social Security System. These reports include personal characteristics of the employees, including occupation and qualification. The database moreover reports characteristics of the reporting establishments, most notably industry and location (municipality).

This paper focuses on manufacturing industries. For 1992 (2007), the dataset comprises 218,281 (169,387) establishments of manufacturing firms in 7,633 (7,092) West German municipalities[8] with a total employment of 7,266,280 (5,683,289). These aggregate figures indicate that the decrease of employment in the manufacturing sector in West Germany during the 15 years under study was accompanied by a decrease of the number of establishments of similar magnitude. The

[8] There have been a few changes in the administrative structure of West-German municipalities during the period under study. Most of these changes involve mergers of small municipalities with larger cities. We have not eliminated these changes over time from our data because we do not expect them to affect our results.

average establishment size stayed roughly constant (1992: 33.3 employees, 2007: 33.6 employees), and the number of municipalities with manufacturing establishments decreased only slightly. We disaggregate the manufacturing sector into 27 industries (see Table A1 in Appendix 3). Being based on the European NACE Rev. 2 industry classification, the classification we use takes into account the specific specialization patterns of the manufacturing sector in Germany by, for example, subdividing "Machinery" (NACE 28) into "Metal Forming Machinery and Machine Tools" (NACE 28.4), which is strongly represented in Germany, and "Other Machinery". The "Computer, Electronic and Optical Products" (NACE 26) and "Chemicals and Chemical Products" industries (NACE 20) are subdivided for similar reasons.

As to the functions, we focus on a subset of all functions performed in establishments, which we label production, HQ, and R&D. We define a function as the aggregate of occupations that typically perform this function, and measure a firm's workforce in each function as the sum of employment in all these occupations. Table A2 in Appendix 3 reports our assignment of occupations to functions. For example, we measure an establishment's R&D employment as the sum of all engineers, chemists and other natural scientists employed by this establishment. Table A3 in Appendix 3 reports summary statistics for West Germany as a whole. It shows that more than 80% of all establishments and about half of all employees in our dataset perform production, while about one fourth of all establishments (4% of all employees) perform HQ, and slightly more than 10% (4-6%), R&D. The functions not included in our analysis, among which are logistics and sales, account for about one third of all workers.

All establishments are georeferenced by the municipality where they are located. Unfortunately, postal codes are not available for finer georeferencing. We therefore approximate the distance between any two establishments by the Euclidean distance between the centroids of their municipalities, if the two establishments are located in different municipalities, or by two thirds of the municipality's hypothetical radius, if the two establishments are located in the same municipality. A municipality's hypothetical radius of is calculated from its area, assuming that it is circular. Two thirds of the radius is approximately the average distance between all points on a disk. These approximations of the distances between establishments introduce several measurement errors into our estimated K densities. We discuss the characteristics and possible sizes of these measurement errors in Appendix 1. Following Duranton and Overman (2005), we account for all measurement errors by kernel-smoothing across distances.

3. Methodology

We evaluate the change over time of the spatial fragmentation of an industry by means of three complementary indicators, namely the differences between 2007 and 1992 of the three pairwise colocalizations of its functions under study (production↔HQ, production↔R&D, HQ↔R&D). We measure each of these pairwise colocalizations of two functions in 1992 and in 2007 by the (employment-weighted) K density of colocalization proposed by Duranton and Overman

(2005).[9] The changes of these densities over time indicate to what extent each function has moved away from (or toward) those locations where the respective other functions have been situated, while the levels of colocalization in 1992 additionally indicate how strongly the functions were initially clustered with (or separated from) each other. In addition to these K densities of colocalization, we also estimate (employment-weighted) K densities of localization of each function in 1992 and their changes over time. These localization measures help in assessing the contributions of the individual functions to the pairwise colocalizations or their changes over time. Using Monte Carlo methods, we construct confidence intervals for all these measures to assess if the localizations and colocalizations as well as their changes over time deviate systematically from the corresponding levels and changes in the industry on aggregate.[10]

The weighted K density of localization of a function *j* within industry *i* at time *t* is defined as (Duranton and Overman 2005: 1095)

$$\hat{K}_{ijt}(d) = \frac{1}{h\sum_{r=1}^{N_{it}-1}\sum_{s=r+1}^{N_{it}} L_{ijrt}L_{ijst}} \sum_{r=1}^{N_{it}-1}\sum_{s=r+1}^{N_{it}} L_{ijrt}L_{ijst}\, f\left(\frac{d-d_{rs}}{h}\right). \quad (1)$$

Correspondingly, the weighted K density of colocalization of two functions *j* and *k* is defined as (Duranton and Overman 2008: 220)

$$\hat{K}_{ijkt}(d) = \frac{1}{h\sum_{r=1}^{N_{it}}\sum_{s=1}^{N_{it}} L_{ijrt}L_{ikst}} \sum_{r=1}^{N_{it}}\sum_{s=1}^{N_{it}} L_{ijrt}L_{ikst}\, f\left(\frac{d-d_{rs}}{h}\right). \quad (2)$$

$\hat{K}_{ijt}(d)$ and $\hat{K}_{ijkt}(d)$ denote the estimated kernel densities of establishments located at distance *d* from each other, N_{it} is the total number of establishments in industry *i*,[11] d_{rs} the geographical distance between establishments *r* and *s*, approximated by the Euclidean distance between their municipalities' centroids, L_{ijrt} and L_{ikst} the number of function *j*-workers in establishment *r* and function *k*-workers in establishment *s*, respectively, $f(\cdot)$ the kernel function, which we take to be Gaussian, and *h* the bandwidth.[12] By weighting all establishments by the sizes of their workforces in the respective functions (*j* or *k*), we use individual workers rather than whole estab-

[9] Distance-based measures like the K density have been used frequently for assessing the localization or colocalization of industries. See, among others, Duranton and Overman (2005, 2008), Klier and McMillen (2008), Arbia et al. 2010, Ellison et al. (2010), Marcon and Puech (2010), and Thomas-Agnan and Bonneu (2014).

[10] To characterize this reference for our measures, we additionally estimate (employment-weighted) K densities of localization for each industry to assess if the industry as a whole is more or less localized than the manufacturing sector on aggregate.

[11] For the analysis of the localization of a single function (equation 1), it is sufficient to limit the set of observations to the $N_{it}(N_{it}-1)/2$ unique establishment pairs (see Duranton and Overman 2005) while the analysis of the colocalization of two functions (equation 2) requires evaluating all N_{it}^2 establishment pairs.

[12] Following Duranton and Overman (2005), we use kernel smoothing to account for measurement errors as far as possible. We use a fixed bandwidth of 20km for all K densities. Columns (3) – (6) of Table A5 indicate that the classification of industries into fragmenting, localizing and other industries is fairly robust to variations of the bandwidth.

lishments as the basic units of our analysis. (1) thus evaluates the distances of each function-*j* worker to all other function-*j* workers in the same industry, excluding those in the same establishment, and measures the relative frequency (density) of worker pairs at each distance. The value of the K density in (1) at a given distance *d* will, ceteris paribus, be the higher, (i) the more establishments that employ function *j*-workers are located at approximately this distance from each other, and (ii) the larger these establishments are in terms of the number of their function *j*-workers. (2) evaluates the distances of each function *j*-worker to all function *k*-workers in the same industry, including those in the same establishment. The value of the K density in (2) at a given distance *d* will, ceteris paribus, be the higher, (i) the more establishments that employ function *j*-workers are located at approximately this distance from establishments that employ function *k*-workers (and vice versa), and (ii) the larger these establishments are in terms of their function *j*- or *k*-workers, respectively. The changes over time of the localization of an individual function or the colocalization of two functions within an industry are calculated by the differences between the corresponding K densities for 2007 and 1992 at all distances.[13] Positive differences over time indicate increasing, negative decreasing localization or colocalization.

Our choice of weighting establishments by the sizes of their workforces in the respective functions rather than by uniform weights reflects our specific notion of fragmentation, i.e., our focus on geography rather than firms. It implies that the K densities for a single point in time are sensitive to the distribution of the function-specific workforces across municipalities but invariant to the distribution of workers across establishments within the municipalities. The K densities will not be higher at short distances just because the function-specific workforce in a municipality is scattered across many small establishments rather than a few large establishments. Unweighted (i.e., uniformly weighted) K densities, by contrast, assign higher weights to municipalities with more establishments, ceteris paribus. Our choice also implies that the changes of the K densities are sensitive to any kind of offshoring across municipalities but invariant to offshoring within municipalities. They will register the relocation of, say, a production plant, including all its production workers, from a cluster of the industry to a remote municipality. This relocation will shift mass of the density from lower to higher distances by reducing the relative weight of the cluster and increasing that of the remote municipality. They will actually register any shifts in the function-specific employment weights across municipalities, irrespective of their causes. But they will not register offshoring of functions across establishments within the same municipality, unless this offshoring affects the total number of workers in this function and municipality. Changes of unweighted K densities, by contrast, would not register offshoring across municipalities, if it takes place among existing establishments, while it would register offshoring within municipalities, if it affects the number of establishments (e.g., mergers or spin-offs).

[13] We prefer this method over the dynamic bivariate (space-time) K functions discussed in Arbia et al. (2010) mainly because we have only two observations in time. Dynamic K functions require observations in continuous time or at least longer time series in order to mitigate edge effects.

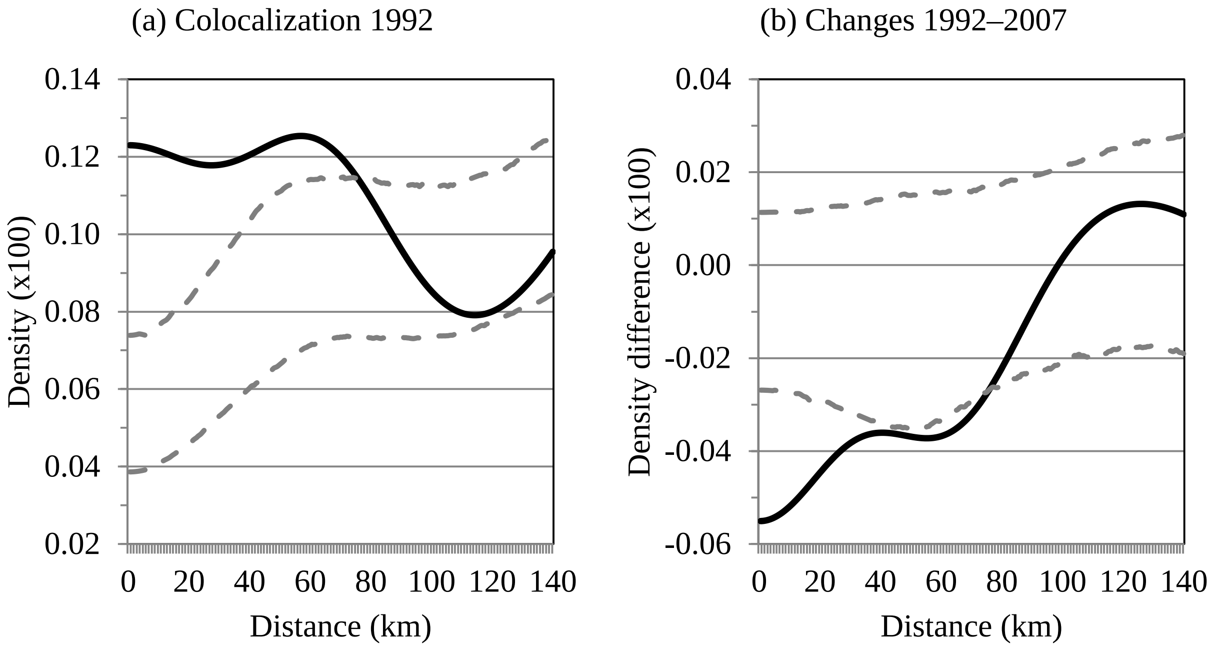
Employment-weighted K densities are more sensitive to economies of scale at the establishment or function level than unweighted K densities, though. Due to lumpiness, even unweighted K densities will, ceteris paribus, report higher localization (or colocalization) of functions with stronger economies of scale and, thus, fewer establishments (Duranton and Overman 2005). Employment weights tend to aggravate this overstatement. The changes of our estimated K densities over time may consequently be affected by changes in the extent of function-specific scale economies. For example, even if firms have never had any incentives to cluster production plants with each other, the K densities may suggest an increase of the localization of production over time just because the production capacities have been concentrated in fewer plants (and locations) to exploit increasing scale economies. We control for both the lumpiness and the function-specific size distribution of establishments by proper design of the counterfactual references.

Estimation of the localization of a single function by equation (1) or the colocalization of two functions by equation (2) in an industry yields a density distribution for (employment-weighted) establishment pairs across all distances between 0 and 891.5km. 891.5km is the highest distance between two municipalities in West Germany. Since the area below each density distribution is standardized to one, comparatively high densities at short distances are necessarily mirrored by comparatively low densities at longer distances. We therefore focus on distances up to 140km. 140km is lower than the distance between many larger West German cities[14] but high enough to encompass the distances across which establishments can share agglomeration economies through frequent face-to-face contacts or similar local inputs. It is also high enough to encompass the distances across which firms' departments (or contractors) can closely interact with, and monitor each other through frequent meetings. For illustration, the solid lines in Figure 1 show the estimated bivariate K density of colocalization of production and HQ in the Chemical Products industry in 1992 (panel a) and the estimated changes of this colocalization between 1992 and 2007 (panel b). The Chemical Products industry is one of the industries we classify as fragmenting industries. The comparatively high densities at lower distances of up to about 60km in panel (a) indicate that comparatively high fractions of the production and HQ workers in this industry were located at close distance from each other in 1992. This colocalization has decreased subsequently, as panel (b) indicates. The changes of the density are negative up to a distance of about 100km between 1992 and 2007.

To distinguish systematic from random localizations or colocalizations, we follow Duranton and Overman (2005) in using Monte Carlo methods to construct a counterfactual reference for each K density under the null hypothesis that the location patterns of the functions under study are the

[14] Estimated K densities for population or aggregate employment typically show a local peak at around 150km. Examples of city pairs at a distance of roughly 150km from each other are Munich-Nuremberg, Frankfurt-Stuttgart, Frankfurt-Cologne, Frankfurt-Kassel or Hamburg-Hannover.

Figure 1. Colocalization of production and headquarter services in Chemical Products industry



results of random location decisions. A detailed description of these methods is given in Appendix 2. In a nutshell, for the K density of localization of a single function in (1), this counterfactual reference represents random location choice for this function, i.e., the null hypothesis that there are no incentives or disincentives for collocating establishments active in this function. By repeatedly resampling the actual establishments active in this function with their actual function-specific employment sizes among the actual locations of all establishments of the industry, we construct a confidence interval consistent with this null hypothesis of no localization. For the measure of colocalization of two functions in (2), we construct a similar confidence interval consistent with the null hypothesis of no colocalization. This hypothesis holds that firms have no incentives or disincentives for colocating the two functions with each other, or, more precisely, that both functions are distributed randomly and independent of each other across the actual locations of all establishments of the industry, given the actual numbers and function-specific employment sizes of the establishments active in the respective functions.

For illustration, the dashed lines in Figure 1 above represent the upper and lower bounds of the counterfactual 90% confidence intervals for the colocalization of production and HQ in the Chemical Products industry in 1992 and its changes 1992–2007, respectively. The densities between these bounds should be considered as resulting from random location choices for the functions. The actual K density for 1992 in panel (a) is above the upper bound of its confidence interval at short distances. We conclude that production and HQ were significantly colocalized in 1992. This colocalization is estimated to be statistically significant up to the distance of about d_{jk}^{*} = 75.5km. The negative change of the K density between 1992 and 2007 is below its confidence interval at short distances (panel b), which indicates that the colocalization of the two functions has decreased significantly. The minimum threshold distance where the K density hits the confidence interval happens to be 75.5km as well.[15]

Even though the point estimates of the minimum threshold distances may be informative about the spatial reach of the forces driving the systematic location patterns, we will focus on their signs only in the results section. For the initial-year measures, "+" will indicate statistically significant (co-)localization, "–", significant (co-)dispersion.[16] For the measures of the changes over time, "+" will indicate significantly increasing (co-)localization or significantly decreasing (co-)dispersion, "–", significantly decreasing (co-)localization or significantly increasing (co-)dispersion.

To classify domestically fragmenting or integrating industries, we use a simple majority rule applied to the significant changes of the colocalizations of all three pairs of functions, or, equivalently, to the signs of these changes. We call an industry domestically "fragmenting", if more function pairs have become significantly less colocalized (or more codispersed; "–" sign) than more colocalized (or less codispersed; "+" sign) at short distances during the period 1992–2007. And we call an industry domestically "integrating", if more function pairs have become significantly more colocalized (less codispersed; "+") than less colocalized (more codispersed; "–").[17] In addition to this, we say that an industry was fragmented in 1992, if more function pairs were significantly codispersed than significantly colocalized, and say that it was integrated, if more function pairs were significantly colocalized than significantly codispersed.[18]

4. Results

This section reports and discusses the results on the fragmentation of West German industries by functions in the initial year, 1992, and the evolution of this fragmentation over time between 1992 and 2007. Table 1 summarizes these results. Each cell of Table 1 reports the result of one K

15 The estimated K density for 2007, which is not reported here, shows that the two functions were still significantly colocalized up to a distance of 47.5km at the end of our study period, though.

16 We use "codispersion" as the antonym to "colocalization". We will say that two functions are codispersed if the actual K density is below the lower bound of its confidence interval at short distances. Notice that codispersion does not necessarily mean that both functions are individually dispersed. Both may be individually clustered, though at distinctly different places.

17 The industries that exhibit no significant changes in the colocalizations of function pairs at all are grouped into a third category, called "other" industries.

18 Some additional, practical aspects are worth being noted. First, following Duranton and Overman (2005), we use the reflection method (Silverman 1986) to prevent the K density estimates at distances close to zero from being biased downward. Second, we aggregate the observed distances between establishments to intervals of 500 meters to speed up the K density estimations. Each distance interval is represented by its upper bound (i.e., 500m, 1km, 1.5km, …, 891.5km). This implies that all K densities reported in this paper are estimated from 1,783 unique distance points, respectively 3,566 points after applying the reflection method. Column (1) of Table A5 (Appendix 3), which reports the results for distance intervals of 100 meters, indicates that this aggregation of distances does not affect the classification of industries significantly.

Table 1. Localization and colocalization of functions by industries in West Germany 1992–2007

	Localization							Colocalization					
	All	Production		HQ		R&D		Prod.–HQ		Prod.–R&D		HQ–R&D	
	92	92	Δ	92	Δ	92	Δ	92	Δ	92	Δ	92	Δ
	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Fragmenting industries													
Structural Metal Products	+	+	–	+	–	+	–	+	–	+	–	+	–
Basic Metals	+	+	–	+	–	+	–	+	–	+	–	+	–
Fabricated Metal Products	+		–						–		–		
Machinery and Equipm. nec		+	–	+	–	+		+	–	+		+	–
Chemical Products	+	+	–	+	–	+	–	+	–	+	–	+	–
Plastic Products	–	–	–	+					–			+	
Magnetics, Optics	+			+		+		+	–	+	–	+	–
Other Nonmetallic Minerals	–			+		+	–	+		+	–	+	–
Food, Beverages, Tobacco	–			+	–	+	–	+	–	+		+	–
Rubber Products	+	+		+		+		+		+		+	–
Wood	–			+	–	+		+		+		+	–
Measuring, Testing, etc.	+	–		+	–	+	–					+	–
Other Manufacturing	+	–	+	+	–	+	–	+		+		+	–
Integrating industries													
Metal Form. Machinery, Mach. Tools	+	–	+					–	+	–	+		+
Consumer Electronics	+	–	+		+		+	–	+	–	+		+
Leather, Apparel	+	–	+		+	+		–			+		+
Printing	+	–					+						+
Furniture	+	+	+	+		+	–	+	+				
Electrical Equipment				+		+			+			+	+
Basic Chemicals, Petroleum	+	+			+			+		+			+
Motor vehicles	+			+		+		+		+		+	+
Other industries													
Textiles	+					+				+		+	
Paper, Paper Products						+				+		+	
Glass, Ceramics	+	+	–	+		+		+		+		+	
Computers				+		+		+		+		+	
Air- and Spacecraft	+			+		+		+		+		+	
Other Transport Equipment	+	–											

Notes: Results of weighted uni- or bivariate K density estimations. See Section 3 for a detailed description of the methodology. All: Industry as a whole (relative to total manufacturing), Prod: production, HQ: headquarter services, R&D: research and development. "+" indicates statistically significant localization or colocalization (columns "92"), or statistically significant change towards higher localization or colocalization 1992–2007 (columns "Δ"). "–" indicates statistically significant dispersion or codispersion (columns "92"), or statistically significant change towards higher dispersion or codispersion 1992–2007 (columns "Δ"). No entry indicates that there was no significant (co-) localization or (co-) dispersion, or no significant change over time. See Table A4 (Appendix 3) for the corresponding point estimates of the threshold distances.

density estimation for the localization of a function (see equation 1) or the colocalization of a pair of functions (equation 2) in each of the 27 industries. The left panel (columns 1 – 6) reports the results for the localizations of the individual functions (production, HQ, and R&D) while the right panel (columns 7 – 12) reports those for the colocalizations of the three pairs of functions (production – HQ, production – R&D, HQ – R&D). There are two columns for each function or pair of functions. The respective first of these two columns, labeled "92" (columns 1, 3, 5, …), report if the function (pair of functions) in question was significantly more localized (colocalized) ("+") or more dispersed (codispersed) ("–") than the industry as a whole in 1992. And the second columns, labeled "Δ" (columns 2, 4, 6, …), report the directions of the changes of these localizations or colocalizations between 1992 and 2007. "+" indicates that the function (pair of functions) has become either significantly more (co-) localized or significantly less (co-) dispersed, depending on its initial state. "–" indicates that it has become significantly less (co-) localized or significantly more (co-) dispersed.[19] For comparison, column (0) of Table 1 reports the K density of localization of each industry as whole relative to aggregate manufacturing. These localization measures characterize the references for all the function-specific localization measures. "+" ("–") indicates that employment in all functions of the industry taken together was significantly more localized (more dispersed) than employment in manufacturing on aggregate.

4.1. Localization and colocalization of functions within industries

Table 1 shows that the spatial distributions of functions deviate frequently from those of the industries as a whole. Remarkably, there is only a single among the 27 industries, "Fabricated Metal Products", where actually none of the three functions deviated significantly from the location patterns of their industries as a whole in 1992. Especially the smaller, knowledge-intensive functions, HQ and R&D, each of which accounted for only about 4% of total manufacturing employment in 1992 (see Table A3), were significantly more clustered than their industries as a whole ("+") in most industries (columns 3 and 5). HQ and R&D were also purposefully (significantly) clustered with each other in most industries in 1992 (column 11). Such strong localizations and colocalizations of knowledge-intensive functions are well-documented in the literature (e.g., Davis and Henderson 2008, Henderson and Ono 2008, Jaffe et al. 1993, Bode 2004). They typically take place in urban areas and are attributed to agglomeration economies arising from thick local markets for skilled labor and for specialized services as well as from knowledge spillovers (Carlino and Kerr 2015).

Even production, which accounts for more than 50% of total employment, deviates frequently from the location patterns of the industries as a whole (column 1). It was significantly more clustered in 8 and significantly more dispersed ("–") in another 8 industries. Production was also significantly colocalized with knowledge-intensive functions in many industries (columns 7 and

[19] No entry indicates that there was no significant (co-) localization or (co-) dispersion, or no significant change over time. Table A4 in Appendix 3 reports the corresponding point estimates for the threshold distances where the estimated K densities dip into their confidence intervals. Table A5 reports the results for 2007.

9). The colocalization of production with HQ is statistically significant in 16 industries, that with R&D even in 19 industries. By contrast, there are only 3 (2) industries where production was purposefully dispersed from HQ (R&D). The large frequency of colocalizations between production and knowledge-intensive functions are partly due to the high localization of the knowledge-intensive functions. Recall from the previous section that we derive the confidence interval for a K density of colocalization under the hypothesis that both functions in question are, independent of each other, distributed randomly across the establishments of the industry. Strong clustering of a single function may be sufficient to reject this hypothesis, if the other function is not distinctively located far away from these clusters. In one industry, "Other Manufacturing", production is estimated to be significantly colocalized with HQ and R&D in 1992 even though production itself is significantly dispersed. Both the dispersion of production and its colocalizations with HQ and R&D are rather weak in this industry, though. The minimum threshold distances are fairly low (17–27km; see Table A4 in the Appendix), and the corresponding density plots, which are not depicted here, show that the densities are just outside their confidence intervals at distances below these thresholds.

The results for 2007 (see Table A5 in Appendix 3) corroborate these findings. They also show distinct localization patterns of functions within industries. Production was localized or dispersed in fewer industries, though, while HQ and R&D were localized in more industries. Quite interestingly, while the scope of industries where HQ and R&D are localized (extensive margin) has increased, the extent of localization of these functions (intensive margins) has decreased in many of those industries where they were already localized in 1992.

The distinct localization patterns of functions within industries suggest that Marshallian localization economies do not only work at the industry level, as studies like Rosenthal and Strange (2001), Alecke et al. (2006) or Ellison et al. (2010) find. They may also work at the functional level within industries, as the theoretical models of functional fragmentation reviewed in Section 1 suggest. Studies like Davis and Henderson (2008) or Strauss-Khan and Vives (2009) support this view for selected functions. There should still be ample scope for broader evaluations of the determinants of localization across all industries and functions, though.

In most industries, the localization and colocalization patterns of the individual functions tend to deviate in similar directions from their references. In the "Structural Metal Products" industry, for example, all three functions were more localized than the industry in 1992 (see Table 1). The similarities between the functions in the directions of their localization patterns may indicate that the industries do not provide a useful reference. If, for example, functions are distributed spatially like manufacturing on aggregate while industries are more dispersed, the significance of our localization measures will be dominated by the industries rather than the functions. The localization of functions from dispersed industries will disappear, if manufacturing rather than industry employment is chosen as the reference. To check this, we report the localizations of the industries as a whole in column (0) of Table 1. The column shows that the majority of industries

(18 of the 27) were more rather than less localized than manufacturing on aggregate in 1992.[20] And among those 18 industries that were more localized, production was significantly localized in 7 and significantly dispersed in another 6 industries. These deviations in opposite directions suggest that the localization patterns of functions within industries do not just offset the localization patterns of the industries on aggregate. There is obviously no systematic relation between the localization of functions and that of overall manufacturing.

Turing to the changes of the localizations or pairwise colocalizations of the three functions between 1992 and 2007 (see Table 1, columns 2, 4 and 6, and 8, 10 and 12, respectively), we observe, first, that there has been a considerable mobility within the manufacturing industries since the early 1990s. More than 40% (71) of all 162 estimated K densities changed significantly during the 15 years under study. Interestingly, the directions of these changes vary markedly across the industries but only little across the functions within the industries. In most industries, functions have become either less clustered (respectively more dispersed) or more clustered (respectively less dispersed). But there are only two industries, "Other Manufacturing" and "Furniture", where the localization of production have increased significantly while that of knowledge-intensive functions have decreased significantly. This uniformity of the changes within the industries indicates that the changes of localization and colocalization have been driven by industry-specific factors in the first place rather than by function-specific factors. This is one of the reasons why we believe that our classification of domestically fragmenting and integrating industries in the next subsection is informative.

Second, we observe that the initial states and the changes over time of the localizations and colocalizations appear to be related to each other. Functions have tended to become less clustered, individually and with each other, in those industries where they were significantly clustered in 1992 while they have tended to become less dispersed or codispersed in industries where they were significantly dispersed in 1992. There are actually only two industries, "Furniture" and "Plastic Products", where significant initial localization or dispersion of production in 1992 was amplified subsequently. This reverse relationship between the initial state and the subsequent dynamics is another reason why we believe that our classification of domestically fragmenting and integrating industries is informative.

4.2. Domestically fragmenting and integrating industries

Since our sample of 27 industries and 3 functions is too small for reliable econometric analyses of the forces that drive the evolutions of the spatial fragmentation of industries over time, we identify instead the general tendencies of these evolutions and discuss plausible explanations on the backdrop of the theoretical models of fragmentation outlined in Section 1. This will hopefully help future empirical research in assessing the actual drivers of the observed changes in

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[20] This share of localized industries is somewhat higher than that of 50% reported for the UK by Duranton and Overman (2005).

spatial fragmentation more accurately.

Two main groups of industries may be identified by means of the changes of the pairwise colocalizations of functions over time (columns 8, 10 and 12 in Table 1). The first group comprises the 13 industries where at least one function pair has become significantly less colocalized after 1992. We call these industries, which are depicted in the upper part of Table 1, domestically “fragmenting” industries. They account for slightly more than half of total West German manufacturing employment. Almost all of these industries were highly integrated in the early 1990s with respect to the three functions under study. The two knowledge-intensive functions, HQ and R&D, were colocalized not only with each other (column 11) but also with production (columns 7 and 9) in most of these industries.

The second group comprises the 8 industries where at least one function pair has become significantly more colocalized or less codispersed after 1992. We call these industries, which are depicted in the middle part of Table 1, domestically “integrating” industries. In five of these eight industries, production has become more colocalized with HQ or R&D while in the remaining three industries, only the two knowledge-intensive functions have become more colocalized with each other. These industries account for about one third of total West German manufacturing employment. As to their initial localization patterns, four of the domestically integrating industries were significantly fragmented in 1992 (“Metal Forming Machinery and Machine Tools”, “Consumer Electronics”, “Leather and Apparel”, ”Printing“). Production was significantly codispersed from the knowledge-intensive functions (columns 7 and 9), or was at least significantly dispersed individually (“Printing”). The remaining four industries were already significantly integrated in 1992 (“Furniture“, ”Electrical Equipment“, ”Basic Chemicals and Petroleum“, ”Motor vehicles“).[21]

The domestically fragmenting industries have behaved pretty much—though not perfectly—in accordance with what regional models of firm fragmentation such as Duranton and Puga (2005) suggest when distance-related costs of monitoring and coordinating functions across larger distances decrease over time. In accordance with these suggestions, formerly colocalized functions have been spatially separated from each other. Production, HQ and R&D were significantly colocalized with each other in almost all these industries in 1992, and the colocalization of production with HQ has decreased significantly in eight of the 13 industries, that of production with R&D in six industries, and that of R&D with HQ even in 11 industries. This may indeed indicate that, broadly speaking, the spatial costs of interactions not only between production and HQ but also between production and R&D and between R&D and HQ have decreased since the early 1990s. Also in accordance with these suggestions, production has become more dispersed in at

[21] A third group, “other” industries (lower part of Table 1), comprises those six industries that exhibit no significant changes in the colocalizations of functions at all. Like the fragmenting industries, these industries are characterized by significant colocalizations of the three functions with each other in the early 1990s. We will not discuss the results for these industries in more detail below.

least about half of these industries. This may indicate that production has indeed been relocated to remote areas with lower labor costs in these industries. However, in apparent contradiction with these suggestions, HQ has not become more localized. It has rather become significantly more dispersed in eight of the 13 industries. The theory suggests that HQ should have been increasingly clustered in urban areas with abundant supply of labor and specialized services as well as extensive knowledge spillovers. There are at least two reasons why the observed increase in the dispersion of HQ is not necessarily inconsistent with the suggestions by the theories. The first reason is that HQ may have been clustered more with HQ from other manufacturing industries because *inter*-industry knowledge spillovers gained in importance relative to intra-industry knowledge spillovers. And the second reason is that the scope of urban areas where the HQ cluster may have increased. The K density of localization may have decreased in spite of an increasing concentration of HQ in urban areas, if the number of urban areas where HQ clusters had increased. In fact, Bade et al. (2004) show that the specialization on white-collar workers has increased faster in smaller than in the largest metropolitan areas in West Germany. Similarly, Holloway and Wheeler (1991) find that the concentration of Fortune-500 HQs in the largest metropolitan centers of the U.S. has decreased while that in smaller metropolitan centers has increased.

In contrast to the domestically fragmenting industries, the domestically integrating industries seem not to fit the regional models of firm fragmentation well. Decreasing costs of monitoring and coordinating different functions across a distance may explain why the knowledge-intensive functions have become more localized in several of these industries (Table 1, columns 4 and 6). Firms from these industries may have clustered them more to exploit localization economies specific to these functions to a greater extent. But they do not explain well why production has become more colocalized with knowledge-intensive functions in several of these industries (columns 8 and 10).

The increasing colocalization of functions in the integrating industries may rather be the consequence of international offshoring. The industries may have offshored specifically those production activities that were already located remotely within Germany in 1992. We will present evidence on the industries' offshoring intensities in the next section. In our localization and colocalization indicators, this offshoring of production from remote locations in Germany should show up in two ways. The production left in West Germany should, first, have become more localized individually, and should, second, also have become more colocalized with knowledge-intensive functions.[22] We observe this for four of the eight integrating industries: "Metal Form-

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[22] If, for example, Siemens, a German consumer electronics company headquartered in the southern Germany city of Munich, offshores a production line from one of its northern German plants to China, the aggregate distance between Siemens' remaining production plants in Germany will decrease, and more mass will move to shorter distances in our estimated univariate K density for the localization of production in the consumer electronics industry. In addition to this, the aggregate distances between Siemens' remaining production plants and its HQ and R&D centers will decrease, and more mass will move to shorter distances in our estimated bivariate K

ing Machinery and Machine Tools", "Consumer Electronics", "Leather and Apparel" and "Furniture".

For another three integrating industries, "Printing", "Basic Chemicals and Petroleum" and "Motor Vehicles", we observe increasing colocalization of the knowledge-intensive functions with each other but neither increasing localization of production nor increasing colocalization of production with HQ or R&D. The German "Motor Vehicles" industry, for example, has arguably extensively offshored production towards Eastern Europe during the past two decades. Instead of closing down plants and "exporting German jobs abroad" through offshoring, this industry has apparently merely reorganized its production in the first place, i.e., reassigned activities across the existing and the new locations throughout Europe.

5. Industry growth and offshoring

5.1. Industry growth

Table 2 reports the growth rates between 1992 and 2007 of the industries' shares in manufacturing establishments and employment. It reports these growth rates for the industry as a whole as well as for the largest function, production. All growth rates are standardized by the corresponding growth rates of manufacturing on aggregate. Notice that the total number of manufacturing establishments decreased by 22.4% in West Germany between 1992 and 2007. Employment decreased by 21.8%.

We observe from Table 2 that most of the fragmenting industries expanded, relative to manufacturing as a whole, in terms of both the number of establishments and employment between 1992 and 2007. This is true for all functions taken together (columns "Total" in Table 2) and for production activities. Employment in production expanded even faster than total employment in most of these industries. Likewise, the number of establishments where production took place expanded faster than the total number of establishments.[23]

By contrast, most of the integrating industries contracted in terms of the number of establishments and employment, and production contracted somewhat faster than the industries on aggregate. There is considerable heterogeneity among the integrating industries, though. Nonetheless, among the industries that contracted particularly fast are the four industries where production was already dispersed within West Germany in 1992, and had also been codispersed from

densities for the colocalization of production with HQ or R&D in the consumer electronics industry.

23 Important exceptions from these general patterns are "Measuring, Testing etc." and "Other Manufacturing", whose shares in manufacturing employment decreased considerably. As we will argue in the next subsection, these two industries may actually match the characteristics of domestically localizing industries better than those of fragmenting industries.

Table 2. Growth rates of shares of industries in total manufacturing establishments and employment 1992 – 2007 – all functions and production activities

Industry / Industry group	Total		Production	
	# Establ.	Empl.	# Establ.	Empl.
Total manufacturing	0.00	0.00	0.00	0.00
Fragmenting industries	0.09	0.09	0.11	0.15
Structural Metal Products	0.70	0.63	0.68	0.72
Basic Metals	0.81	0.25	0.84	0.41
Fabricated Metal Products	0.20	0.09	0.16	0.11
Machinery and Equipment nec	0.46	0.79	0.47	0.70
Chemical Products	0.22	–0.19	0.23	–0.23
Plastic Products	0.47	0.53	0.47	0.60
Magnetics, Optics	0.01	0.17	0.10	–0.09
Other Nonmetallic Minerals	0.03	–0.15	0.02	–0.15
Food, Beverages, Tobacco	–0.20	0.07	–0.22	0.16
Rubber Products	0.17	0.00	0.22	0.09
Wood	0.25	0.14	0.21	0.19
Measuring, Testing etc.	0.08	–0.27	0.12	–0.26
Other Manufacturing	–0.51	–0.62	–0.50	–0.66
Integrating industries	–0.20	–0.09	–0.23	–0.15
Metal Forming Machinery, Machine Tools	–0.19	–0.30	–0.19	–0.29
Consumer Electronics	0.03	0.29	0.04	0.03
Leather, Apparel	–0.56	–0.63	–0.60	–0.75
Printing	0.08	–0.07	0.02	–0.07
Furniture	–0.38	–0.43	–0.39	–0.42
Electrical Equipment	0.05	0.24	0.01	0.04
Basic Chemicals, Petroleum	0.75	0.67	0.86	0.50
Motor Vehicles	–0.11	0.08	–0.10	0.04
Other industries	0.05	–0.18	–0.01	–0.18
Textiles	0.05	–0.47	–0.02	–0.48
Paper, Paper Products	0.30	0.04	0.26	0.11
Glass, Ceramics	0.00	–0.16	–0.06	–0.15
Computers	0.18	0.01	0.11	–0.21
Air and Spacecraft	0.45	0.51	0.52	0.89
Other Transport Equipment	–0.40	–0.53	–0.39	–0.49

knowledge-intensive industries.[24] These industries may already have exploited their domestic opportunities for cost reductions by the early 1990s, and may have "offshored jobs abroad" to cut their costs further.

[24] These industries are "Metal Forming Machinery and Machine Tools", "Consumer Electronics", "Leather and Apparel" and "Printing". In "Consumer Electronics", non-production employment expanded considerably, though.

5.2. Offshoring

We use three standard indicators of offshoring by industry. The first indicator is the growth rate of an industry's intensity of outward FDI between 1992 and 2007. We measure the FDI intensity by the value of FDI stocks held by German firms abroad per domestic worker.[25] To eliminate scale effects, we standardize the industry-specific growth rates of the FDI intensities by the corresponding growth rate of manufacturing on aggregate. The FDI intensity is meant to capture the relocation of production capacities abroad. Some caution is warranted when interpreting this indicator in the context of our hypothesis about the relationship between domestic integration and offshoring, though. It reflects not only vertical FDI, which is at the core of our hypothesis, but also horizontal and more complex forms of FDI.

The second and third indicators are the growth rates of the intensities of imported intermediate materials between 1995 and 2007, calculated as the standardized growth rates of imported intermediate materials per worker. We distinguish between imported intermediate materials in a wide and a narrow definition.[26] The wide definition comprises the value of imports of intermediate goods from all manufacturing industries, the narrow definition, the value of imports of intermediate goods from the own industry only. These two indicators are meant to capture the effects of offshoring of components production to the extent that this offshoring creates additional imports of intermediate goods. All three indicators should increase faster for those industries that engaged more extensively in offshoring.

Table 3 reports the values of all three indicators for each of the 27 industries in our sample as well as for the aggregates of the 13 fragmenting, eight integrating and six other industries.[27] The industry group aggregates indicate that the fragmenting industries expanded their international activities in terms of FDI and imported intermediates less extensively than the integrating industries.[28] We infer from this that integrating industries have also tended to become more fragmented, though at a larger, namely international, scale.

These general patterns are not mirrored by each and every industry to the same extent, of course. In "Basic Metals" and "Chemical Products", for example, the intensity of intermediates imports

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[25] The data on outward FDI stocks is available from the Deutsche Bundesbank (Bestandserhebung über Direktinvestitionen, Statistische Sonderveröffentlichung 10, Table I.3).

[26] These indicators are developed by Geishecker (2006), where they are labeled "material offshoring". See also Baumgarten et al. (2013) and Schwörer (2013). These indicators assign material imports to domestic industries by means of the industries' input coefficients for these goods. We thank Tillman Schwörer for sharing his most recent estimates with us.

[27] The last column of Table 3 additionally depicts location coefficients for East Germany, which will be discussed in the next subsection.

[28] The absolute amounts of FDI and imported intermediates show a similar picture. The FDI stocks (in Euro) increased by 129% (from 42 to 96 bill.€) for the domestically fragmenting industries and by 279% (from 27 to 101 bill.€) for the domestically integrating industries. And the shares of imported intermediates (wide) increased by 117% for the domestically fragmenting and by 145% for the domestically integrating industries.

Table 3. Indicators of international offshoring and "offshoring" to East Germany

Industry / industry group	FDI	Imported intermediate materials		Import / Export ratio	Location coefficient East GER
		wide	narrow		
	1992–2007	1995–2007	1995–2007	1992–2007	2007
Total manufacturing	0.00	0.00	0.00	0.00	1.00
Fragmenting industries	**–0.25**	**–0.09**	**–0.06**	**0.01**	**1.12**
Structural Metal Products	–0.67	–0.38	–0.45	–0.48	1.50
Basic Metals	–0.57	0.00	0.02	0.18	0.90
Fabricated Metal Products	0.14	–0.06	–0.04	0.11	0.87
Machinery and Equipm. nec	–0.47	–0.40	–0.37	0.24	0.76
Chemical Products	–0.18	0.30	0.42	0.09	0.89
Plastic Products	–0.36	–0.48	–0.47	–0.30	0.94
Magnetics, Optics	–0.28	–0.29	–0.32	0.10	1.41
Other Nonmetallic Minerals	1.40	–0.36	–0.46	–0.50	1.54
Food, Beverages, Tobacco	0.55	–0.30	–0.35	–0.15	1.41
Rubber Products	–0.01	–0.21	–0.24	–0.17	0.81
Wood	–0.25	–0.51	–0.60	–0.56	1.16
Measuring, Testing etc.	0.99	0.61	0.78	0.13	1.00
Other Manufacturing	3.59	1.38	1.16	0.08	1.66
Integrating industries	**0.47**	**0.23**	**0.23**	**0.00**	**0.75**
Metal Forming Machinery, Machine Tools	0.36	0.52	0.70	0.16	0.77
Consumer Electronics	–0.35	–0.42	–0.43	–0.37	1.02
Leather, Apparel	6.82	0.17	0.10	–0.14	0.77
Printing	5.56	–0.44	–0.46	0.01	0.94
Furniture	2.02	0.38	0.38	–0.12	0.99
Electrical Equipment	–0.32	–0.10	0.00	–0.03	0.71
Basic Chemicals, Petroleum	–0.96	–0.38	–0.34	0.24	0.75
Motor Vehicles	0.81	0.31	0.25	0.11	0.55
Other industries	–0.16	–0.14	–0.21	–0.01	1.17
Textiles	–0.46	0.01	–0.28	0.03	1.40
Paper, Paper Products	–0.78	–0.45	–0.47	–0.07	0.97
Glass, Ceramics	1.42	–0.33	–0.43	–0.01	1.49
Computers	–0.82	–0.22	–0.23	–0.07	0.74
Air and Spacecraft	–0.42	–0.36	–0.47	2.84	0.46
Other Transport Equipment	0.87	1.05	0.50	–0.08	2.17

Notes: FDI: Relative growth rate 1992–2007 of FDI stocks per worker, industry / total manufacturing. Imported intermediate materials: Relative growth rate 1995–2007 of imported materials per worker, industry / total manufacturing; wide definition: value of imported goods from all manufacturing industries abroad; narrow definition:: value of imported intermediate inputs from the same industry abroad (see Geishecker 2006). Location coefficient East GER 2007: Share of industry in total manufacturing employment, East Germany / Germany.

increased faster rather than slower than the manufacturing average. This might be due to significant price increases at international commodity markets since the mid-2000s rather than to offshoring, though. And in "Measuring, Testing etc." and "Other Manufacturing", even both FDI and intermediate imports feature above-average growth rates. Recall from the previous sections that production was, in contrast to that of most other fragmenting industries, already dispersed within West Germany in these two industries in 1992 (see Table 1, column 1). In addition to this, these two industries reduced their employment significantly faster than manufacturing on aggregate during the study period (see Table 2). In these respects, these two industries fit better into the group of localizing industries than into that of fragmenting industries.[29] In fact, we classified these two industries as fragmenting industries just because the colocalization of HQ and R&D decreased significantly while the colocalizations of knowledge intensive functions with production did not change significantly.

Likewise, some of the integrating industries, most notably "Consumer Electronics" and "Electrical Equipment", did not offshore particularly extensively. Their intensities of FDI and imports of intermediates grew slower rather than faster than the manufacturing average.

5.3. "Offshoring" to East Germany

Our analysis has ignored East Germany so far. East Germany is covered neither by our analysis of domestic fragmentation nor by the indicators of offshoring. We therefore check, for the sake of completeness, if our inferences are biased by relocations of activities from West to East Germany. We use the location coefficient by industry (sometimes labeled "Balassa index") for East Germany in 2007 as an indicator of the intensity of these relocations. This coefficient is defined as the ratio of an industry's share in manufacturing employment between East Germany and Germany as a whole. By using the level of the coefficient in 2007 rather than its growth rate as our indicator, we assume for simplicity that any manufacturing activity situated in East Germany in 2007 was "offshored" from West Germany after the fall of the Iron Curtain. The East German economy went through a fundamental reconstruction after the fall of the Iron Curtain, which was in fact shaped decisively by investments by West German firms (Bickenbach and Bode 2013). We take a location coefficient of greater than one, which means that the industry is overrepresented in East Germany, as an indication of disproportionately extensive offshoring to East Germany.

The location coefficients for the 27 industries in East Germany are depicted in the last column of Table 3. They indicate that almost all domestically integrating industries are underrepresented in East Germany while many of the domestically fragmenting industries are overrepresented. This suggests that East German locations play a similar role as remote West German locations in terms of our hypothesis. Fragmenting industries have expanded geographically into both West and East German locations while integrating industries have not just relocated activities from West to East Germany.

[29] Indeed, "Other Manufacturing" is one of the three industries Feenstra and Hanson (1996: 242) mention explicitly as being particularly prone to offshoring. As for the "Measuring, Testing and Electromedical equipment" industry, it is worth noting that production of traditional surgical instruments has been offshored to a considerable extent, mainly to Pakistan but also to Poland, Hungary and Malaysia (Nadvi and Halder 2005).

6. Conclusions

We explore the spatial fragmentation of manufacturing industries by functions in West Germany and the changes of this fragmentation since the fall of the Iron Curtain (1992 – 2007). We measure this fragmentation by means of K densities of the localization and colocalization of functions within the industries, i.e., by the extent to which functions are clustered with, or dispersed from each other. Using Monte Carlo methods, we also assess if the functions are purposefully clustered with, or dispersed from each other. We show that the spatial distributions of functions differ significantly from those of the respective industries as a whole in virtually all West German manufacturing industries. Knowledge-intensive functions like headquarter services (HQ) and research and development (R&D) are purposefully clustered, both individually and with each other, in most industries, and production is purposefully clustered, individually and with knowledge-intensive functions, in some industries but dispersed in others. This suggests that agglomeration economies do not work only at the industry level, as studies like Ellison et al. (2010) suggest, or only at the level of functions, as Gabe and Abel (2013) suggest. They appear to vary in relative importance across industries and functions. We also show that the localization and colocalization patterns of functions have changed considerably since the fall of the Iron Curtain in most industries. While the directions and intensities of these changes differ considerably across industries, they are fairly homogeneous within industries. This suggests that the forces behind these changes may be shaped by industry-specific characteristics in the first place and only to a lesser extent by function-specific characteristics.

We identify two main groups of industries by means of the changes of the colocalizations of their functions. One group, which we call domestically “fragmenting” industries and which accounts for about half of manufacturing employment in West Germany, was spatially highly integrated (= weakly fragmented) after the fall of the Iron Curtain but has become significantly more fragmented during the subsequent decades. This is broadly in line with what theories of spatial fragmentation of firms suggest to happen if firms face decreasing costs of coordinating and monitoring different activities across larger distances. They will unbundle functions from each other, locating each function at locations that offer them particularly favorable conditions, i.e., lower factor costs for production activities and higher Marshallian externalities for knowledge-intensive activities like HQ and R&D.

The second group, which we call domestically “integrating” industries and which accounts for about one third of manufacturing employment in West Germany, has behaved in the opposite way. This group was spatially fragmented after the fall of the Iron Curtain but has become significantly less fragmented (more integrated) during the subsequent decades. This increasing domestic integration does not sit well with what theories of spatial firm fragmentation suggest. It would require an increase rather than a decrease of the costs of coordinating and monitoring different activities across larger distances. It sits better with theories of international fragmentation, though. These theories suggest that decreasing costs of coordinating and monitoring across national borders will induce firms to offshore (or outsource) production activities abroad to benefit from even lower factor costs in low-wage countries. Domestically integrating industries may already have had exploited domestic opportunities for cost reductions by the early 1990s—which may be the reason why they were already fragmented within West Germany by that time—and may subsequently have offshored production from remote domestic regions to foreign countries. While such offshoring of domestically remote production is actually an increasing international fragmentation, it will show up in our measures as decreasing domestic fragmentation. Indicators of international fragmentation tend to support this possible explanation. Domestically integrating industries have offshored activities more extensively than the domestically fragmenting industries and shrank faster in terms of both employment and number of establishments within West Germany.

The results of this paper suggest future research in several directions. First, the analysis of colocalizations of different functions within industries in this paper may be complemented by an analysis of the colocalizations of similar functions across industries, possibly including producer service industries. This analysis will be informative as to the relevance of function-specific localization economies across industries. Second, empirical research on the determinants of the spatial distribution of economic activity in general, and on the relative importance of the three Marshallian externalities more specifically should investigate functions within and across industries. The large heterogeneity in the localization and colocalization patterns across functions *and* industries we document in this paper suggests that the results of industry-level studies such as Ellison et al. (2010) or occupation-level studies such as Gabe and Abel (2013) may be subject to aggregation biases. Disaggregation by both industries and functions may reduce these biases. Third, empirical research should investigate the factors driving the changes of the localizations and colocalizations of functions within industries. To what extent does globalization actually contribute to explaining these changes? And fourth, the linkages and interdependencies between domestic and foreign fragmentation should be investigated in more detail both theoretically and empirically.

Appendix 1: Bandwidth choice and measurement errors for distances

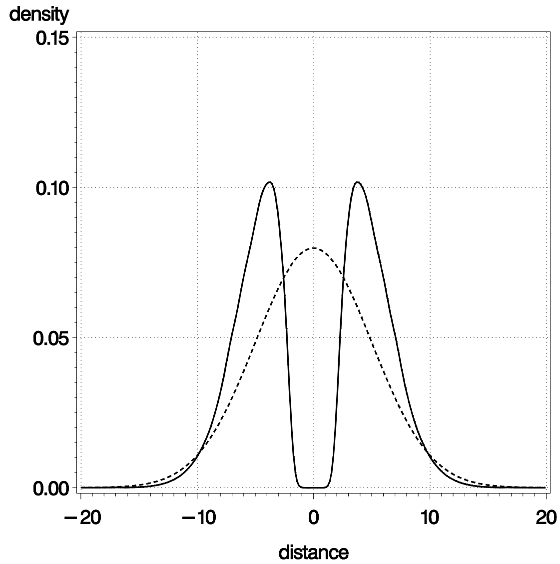
The choice of the bandwidth is important for several reasons. One reason is that it affects the bias of the kernel density estimator (Silverman 1986). Several methods for selecting an optimal bandwidth are discussed in the literature and are available in standard statistical software packages. These bandwidths usually take the statistical properties of the sample dataset into account. A frequently used selection method, Silverman's rule of thumb, suggests, for example, that the bandwidth should increase with the interquartile range and decrease with the size of the sample. Such a bandwidth, which would range between 50km and 90km in for our data, depending on the functions under study, would oversmooth our Kernel densities greatly because our aggregation of establishment pairs across distance intervals of 500m (see Section 3) reduces our sample size significantly.

Another reason is that the bandwidth should account for the measurement errors in our distance data. Our approximation of *inter*regional distances is subject to measurement errors from three sources. First, Euclidean distances do not take into account the curvature of the earth. This bias can be expected to be negligible for a small country like Germany where the maximum distance is below 1,000 km. Second, Euclidean distances do not take into account the density and quality of the available infrastructure. The actual travelling time per km may differ between high- and low density areas. On the one hand, the denser road networks in high-density areas will offer more direct connections. On the other hand, congestion may reduce the speed. While Combes and Lafourcade (2005) show that Euclidean distances and economic distances are correlated very highly with each other (0.97), we have no reliable information on the magnitudes of the errors that result from approximating economic by Euclidean distances.

And finally, not all establishments are located at their municipalities' centroids. The corresponding error may be positive or negative, depending on where exactly the establishments are actually situated relative to the centroids. If the municipalities' areas were perfectly circular, the magnitude of this error ranged from zero to the sum of the radii of the respective two municipalities. The variance of this error thus tends to be higher for larger municipalities, ceteris paribus. To give an idea of the possible magnitudes of the errors in interregional distances, Figure A1 depicts the distribution across municipalities of their lower and upper bounds, calculated under the assumption that all municipalities are circular. For any two municipalities *r* and *s* these errors are bounded between $-(\tau_r + \tau_s)$ and $(\tau_r + \tau_s)$ where τ denotes the radius of a municipality.[30] For comparison, Figure A1 also depicts a normal distribution whose tails roughly encompass the highest possible approximation errors. The standard deviation of this distribution is 5km. A bandwidth of 5km will thus be sufficient to account for the highest possible measurement errors

[30] This radius is calculated as $\tau_r = \sqrt{A_r / \pi}$, where A_r is the municipality *r*'s area (in sqkm). The radii range from 0.35km to 15.5km for West German municipalities, with a mean of 2.7km and a 90th percentile of 4.7km.

Figure A1. Distribution of approximate maximum approximation errors for distances between West German municipalities and normal distribution with standard deviation of 5km



Notes: Solid line: density of the maxima of the approximation errors for distances between establishments from different municipalities under the assumption that all municipalities' areas are circular. Dashed line: density of N(0, 25).

that result from approximating firms' locations within municipalities by the municipalities' centroids. Adding to these 5km another 15km to account for the mismatch between economic by Euclidean distances, we choose a bandwidth of 20km for all pairs of functions as a baseline. Columns (3) – (6) of Table A6 (Appendix 3) report the results of robustness checks for bandwidths of 10km, 15km, 25km and 30km. They indicate that the classification of industries is fairly robust to choice of the bandwidth.

Appendix 2: Counterfactual references

This appendix discusses the methods of constructing counterfactual references for the uni- and bivariate K densities as well as for their changes over time.

Significance of localization or colocalization

A question that arises naturally from inspecting the extent of localization or colocalization at a given point in time is whether this is the result of systematic, purposeful location decisions by firms, motivated by the wish to locate functions close to each other, or just the consequence of a series of independent location decisions that happened to generate some accidental spatial clustering of functions. We follow Duranton and Overman (2005) in using Monte Carlo methods to construct a counterfactual reference for each K density. We construct this reference under the null hypothesis that the location patterns of the functions under study are the results of random, industry-specific location decisions.

For the measure of localization of a single function in (1), this counterfactual reference indicates how the density distribution for the localization of this function may have looked like in 1992 (or 2007), if firms from the respective industry had had no incentives or disincentives for colocating establishments performing this function with each other. We construct this reference for function *j* in industry *i* by repeatedly resampling (without replacement) all establishments that perform function *j* (including their function-*j* workers) randomly among the population of all industrial sites occupied by establishments from industry *i* in West Germany in the same year, irrespective of whether or not function *j* was actually performed at this site. By resampling only among the sites occupied by the industry rather than among those occupied by any manufacturing industry, we focus on the motives for clustering establishments within this industry. We do not want to call a function localized just because its industry is more localized than manufacturing as a whole. By resampling *without* replacement, we make sure that each feasible industrial site is occupied by at most one establishment in the counterfactual distribution. And by resampling the existing establishments together with their actual number of function-*j* workers, we retain not only the number but also the size distribution of this function across establishments. We thereby exclude the effects of managerial decisions on optimal lot sizes from our analysis. We do not want to call a function localized just because its large minimal optimal lot size requires concentrating employment in only a few sites.

Repeating this random resampling 1,000 times, we obtain 1,000 counterfactual spatial distributions of the actual establishments for function *j* in industry *i*, from which we estimate 1,000 counterfactual weighted univariate K densities in the same way as we estimate the actual K density (see equation 1). We use these 1,000 counterfactual K densities, in turn, to construct a two-sided 90% confidence interval, which we take to cover, for each distance, *d*, the range of densities consistent with no localization of the function in question. The robustness check reported in Column (2) of Table A5 indicates that 1,000 repetitions are enough. Increasing the number of repetitions to 2,000 does not change the classification of industries into domestically fragmenting, domestically localizing or other industries notably.

For the measure of colocalization of two functions in (2), we construct a similar counterfactual reference that indicates how the density distribution for the colocalization of the two functions may have looked like in 1992 (or 2007), if firms had had no incentives or disincentives for colocating them, given the size distributions of the two functions across establishments. We randomly resample each of the two functions independently of each other 1,000 times in the same way as described above[31] and estimate from these 2 x 1,000 random distributions 1,000 counterfactual weighted bivariate K densities in the same way as we estimate the actual bivariate K density (see equation 2). From this, we construct a two-sided 90% confidence interval, which we take to cover, for each distance, *d*, the range of densities consistent with no colocalization of the

[31] We actually use the same counterfactual distributions as those constructed for the references for the univariate measures of localization (see above).

two functions in question.

Significance of changes in localization or colocalization over time

To assess the significance of the changes of localization or colocalization over time, we construct a counterfactual reference that indicates how the density distribution for the localization (or colocalization) may have changed between 1992 and 2007, if there had been no incentives or disincentives for colocating establishments performing this function (these functions) at both points in time. This counterfactual reference should account not only for the changes in the location patterns of the industry as a whole. It should also account for the changes in the locational patterns of each function that are due to changes in their size distributions or optimal lot sizes. We do, for example, not want to conclude that a function became more localized just because its industry as a whole became more localized, or because the optimal lot sizes for individual functions increased over time. We construct the confidence interval for the change of an estimated K density over time from the differences between corresponding counterfactual K densities for 2007 and 1992. These counterfactual K densities are constructed independently of each other for each point in time in the same way as those for the levels of localization or colocalization (see above).[32] If the difference between estimated K densities for 2007 and 1992 lies above the upper bound of the 90% confidence interval of the distribution of these 1,000 counterfactual differences at short distances, we will say that the respective function became more localized (or the two functions became more colocalized) over time. And if it lies below the lower bound of this confidence interval, we will say that the function became more dispersed (or the two functions became more codispersed) over time.

[32] This approach is conceptually very similar to that used to evaluate changes in inequality measures over time (see, e.g., Mills and Zandvakili 1997).

Appendix 3: Additional tables

Table A1. Industry classification

Industry	NACE	Shares in total manufacturing			
		Establishments		Employment	
		1992	2007	1992	2007
Food processing, Beverages, Tobacco	10-12	0.206	0.088	0.164	0.094
Textiles	13	0.016	0.023	0.016	0.012
Leather, Apparel	14-15	0.038	0.027	0.017	0.010
Wood	16	0.052	0.018	0.065	0.020
Paper, Paper Products	17	0.008	0.019	0.010	0.020
Printing	18	0.052	0.029	0.056	0.027
Basic Chemicals, Petroleum	19. 20.1	0.004	0.018	0.008	0.030
Chemical Products	20.2-20.6, 21	0.013	0.056	0.016	0.045
Rubber Products	22.1	0.004	0.011	0.005	0.011
Plastic Products	22.2	0.024	0.031	0.035	0.048
Glass, Ceramics	23.1-23.4	0.008	0.016	0.008	0.013
Other Nonmetallic Minerals	23.5-23.9	0.034	0.019	0.035	0.016
Basic Metals	24	0.010	0.039	0.018	0.048
Structural Metal Products	25.1	0.087	0.040	0.147	0.066
Fabricated Metal Products	25.2-25.9	0.035	0.043	0.042	0.047
Machinery and Equipment n.e.c.	28.1-28.3, 28.9	0.042	0.049	0.061	0.088
Metal Forming Machinery and Machine Tools	28.4	0.066	0.107	0.053	0.075
Computers and Peripheral Equipment	26.1-26.2	0.004	0.006	0.005	0.006
Consumer Electronics	26.4	0.019	0.031	0.019	0.041
Electrical Equipment	27	0.009	0.016	0.009	0.020
Magnetic/Optical Media, Optical Instruments	26.3, 26.7, 26.8	0.014	0.024	0.014	0.029
Measuring, Testing, Navigation, Electromedical Equipment	26.5, 26.6	0.086	0.084	0.093	0.061
Motor vehicles	29	0.018	0.112	0.016	0.121
Ships, Railway Locomotives & Rolling Stock, Other Transport Equipment	30.1, 30.2, 30.4, 30.9	0.006	0.013	0.004	0.006
Air and Spacecraft, Related Machinery	30.3	0.001	0.009	0.002	0.013
Furniture	31	0.083	0.037	0.051	0.021
Other Manufacturing	32, 33	0.063	0.036	0.031	0.014
Total Manufacturing		1	1	1	1

Table A2. Correspondence between functions and occupations

Function	Occupations
Headquarter services	Corporate managers, entrepreneurs; CEOs; heads of business organizations; economic and social scientists; Members of Parliament, ministries, or other public administrations
R&D	Engineers; chemists; other natural scientists
Production	Farmers; Miners; skilled manufacturers of stone, ceramic, chemical, wooden, textile, leather, metal, electrical or mechanic products; skilled manufacturers of food or beverages; assemblers; skilled construction workers, (unskilled) laborers; maintenance workers

Table A3. Shares of establishments and workers by functions

Function	Establishments		Employment	
	1992	2007	1992	2007
Headquarter services	0.235	0.224	0.035	0.045
R&D	0.109	0.126	0.038	0.057
Production	0.873	0.829	0.575	0.530
Rest (not included)	.	.	0.352	0.369

Table A4. Point estimates of the threshold distances, d_{jk}^*, for localization and colocalization

	Localization							Colocalization					
	All	Production		HQ		R&D		Prod.–HQ		Prod.–R&D		HQ–R&D	
	92 (0)	92 (1)	Δ (2)	92 (3)	Δ (4)	92 (5)	Δ (6)	92 (7)	Δ (8)	92 (9)	Δ (10)	92 (11)	Δ (12)
	Fragmenting industries												
Structural Metal Products	235	135	–72	78	–66	58	–54	118	–71	70	–62	69	–63
Basic Metals	105	77	–76	86	–84	70	–70	87	–84	77	–76	81	–83
Fabricated Metal Products	141	0	–46	0	0	0	0	0	–29	0	–17	0	0
Machinery and Equipm. nec	0	36	–67	193	–61	55	0	348	–96	341	0	208	–61
Chemical Products	78	26	–14	54	–36	39	–22	76	–76	71	–37	72	–44
Plastic Products	–48	–106	–18	17	0	0	0	0	–32	0	0	18	0
Magnetics, Optics	34	0	0	24	0	26	0	24	–26	22	–24	31	–13
Other Nonmetallic Minerals	–59	0	0	65	0	95	–92	35	0	87	–5	89	–89
Food, Beverages, Tobacco	–369	0	0	40	–24	47	–8	30	–6	28	0	48	–29
Rubber Products	16	9	0	24	0	31	0	28	0	28	0	32	–12
Wood	–54	0	0	66	–8	42	0	38	0	36	0	67	–16
Measuring, Testing, etc.	30	–63	0	26	–21	23	–15	0	0	0	0	31	–27
Other Manufacturing	41	–18	16	37	–34	45	–39	17	0	27	0	44	–42
	Integrating industries												
Metal Forming Mach., Machine Tools	166	–65	92	0	0	0	0	–50	106	–55	81	0	97
Consumer Electronics	113	–32	24	0	30	0	26	–29	20	–16	18	0	34
Leather, Apparel	23	–72	42	0	22	14	0	–56	0	0	46	0	35
Printing	34	–63	0	0	0	0	32	0	0	0	0	0	19
Furniture	145	137	18	42	0	32	–24	140	22	0	0	0	0
Electrical Equipment	0	0	0	10	0	13	0	0	8	0	0	35	32
Basic Chemicals, Petroleum	86	79	0	0	20	0	0	61	0	75	0	0	13
Motor vehicles	8	0	0	15	0	24	0	17	0	23	0	29	23
	Other industries												
Textiles	37	0	0	0	0	11	0	0	0	4	0	13	0
Paper, Paper Products	0	0	0	0	0	69	0	0	0	65	0	65	0
Glass, Ceramics	66	75	–53	32	0	37	0	63	0	38	0	43	0
Computers	0	0	0	9	0	15	0	18	0	24	0	26	0
Air- and Spacecraft	48	0	0	43	0	39	0	100	0	92	0	48	0
Other Transport Equipment	18	–34	0	0	0	0	0	0	0	0	0	0	0

Notes: Threshold distances, d_{jk}^*, as defined in Section 3, resulting from weighted uni- or bivariate K density estimations. See Section 3 for a detailed description of the methodology. All: Industry as a whole (relative to total manufacturing), Prod: production, HQ: headquarter serviuces, R&D: research and development, "Δ": change 1992–2007.

Table A5. Localization and colocalization of functions by industries in West Germany 1992 and 2007

	Localization						Colocalization					
	Production		HQ		R&D		Prod.–HQ		Prod.–R&D		HQ–R&D	
	92	07	92	07	92	07	92	07	92	07	92	07
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Fragmenting industries												
Structural Metal Products	+		+	+	+		+	+	+		+	+
Basic Metals	+		+		+	+	+	+	+	+	+	+
Fabricated Metal Products		–										
Machinery and Equipm. nec	+		+	+	+	+	+	+	+	+	+	+
Chemical Products	+		+	+	+	+	+	+	+	+	+	+
Plastic Products	–	–	+			+		–			+	+
Magnetics, Optics			+	+	+	+	+		+		+	+
Other Nonmetallic Minerals			+	+	+	+	+	+	+	+	+	+
Food, Beverages, Tobacco			+	+	+	+	+	+	+	+	+	+
Rubber Products	+		+	+	+	+	+	+	+	+	+	+
Wood			+	+	+	+	+	+	+	+	+	+
Measuring, Testing, etc.	–	–	+	+	+	+					+	+
Other Manufacturing	–		+	+	+	+	+	+	+		+	+
Integrating industries												
Metal Forming Machinery, Machine Tools	–			+		+	–	+	–			+
Consumer Electronics	–			+		+	–		–	+		+
Leather, Apparel	–			+	+	+	–					+
Printing	–	–		+		+		–				+
Furniture	+	+	+	+	+	+	+	+				+
Electrical Equipment			+	+	+	+		+		+	+	+
Basic Chemicals, Petroleum	+	+		+		+	+	+	+	+		+
Motor vehicles		+	+	+	+	+	+	+	+	+	+	+
Other industries												
Textiles					+				+		+	
Paper, Paper Products		–			+	+			+		+	+
Glass, Ceramics	+	+	+	+	+	+	+	+	+	+	+	+
Computers		+	+	+	+	+	+	+	+	+	+	+
Air- and Spacecraft		+	+	+	+	+	+	+	+	+	+	+
Other Transport Equipment	–											+

Notes: Results of weighted uni- or bivariate K density estimations. See Section 3 for a detailed description of the methodology. Prod: production, HQ: headquarter services, R&D: research and development. "+" indicates statistically significant localization or colocalization, "–"statistically significant dispersion or codispersion. No entry indicates that there was no significant (co-) localization or (co-) dispersion.

Table A6. Robustness of the classifications of industries

	Baseline	Robustness checks (if deviating from baseline)					
	(0)	(1)	(2)	(3)	(4)	(5)	(6)
Distance intervals (m)	500	100	500	500	500	500	500
# repetitions for counterfactuals	1000	1000	2000	1000	1000	1000	1000
bandwidth (km)	20	20	20	10	15	25	30
Structural Metal Products	FRAG						
Basic Metals	FRAG						
Fabricated Metal Products	FRAG						
Machinery and Equipm. nec	FRAG			OTHER			
Chemical Products	FRAG						
Plastic Products	FRAG			LOC			
Magnetics, Optics	FRAG						
Other Nonmetallic Minerals	FRAG						
Food, Beverages, Tobacco	FRAG						
Rubber Products	FRAG					OTHER	OTHER
Wood	FRAG						OTHER
Measuring, Testing, etc.	FRAG						
Other Manufacturing	FRAG						
Metal Forming Mach., Mach. Tools	LOC						
Consumer Electronics	LOC						
Leather, Apparel	LOC						
Printing	LOC						
Furniture	LOC						
Electrical Equipment	LOC						
Basic Chemicals, Petroleum	LOC					OTHER	OTHER
Motor vehicles	LOC						
Textiles	OTHER						
Paper, Paper Products	OTHER						
Glass, Ceramics	OTHER			LOC		FRAG	FRAG
Computers	OTHER						
Air- and Spacecraft	OTHER						
Other Transport Equipment	OTHER						

Notes: FRAG indicates fragmenting and LOC localizing industries. Column (0) reports the classification of industries suggested by the baseline estimation (see Table 1). Empty cells for the robustness checks in Columns (1) to (6) indicate no difference to the classification in the baseline estimation.

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