Inter-industry linkages, knowledge-intensive services and the (digital) urban economy

- An empirical network analysis for 45 industries in Germany -

DRAFT

Abstract

Forward and backward linkages between industries are of utmost importance for the creation of agglomeration economies, the basic centripetal force behind successful economic clusters – be it in manufacturing or services – and linkages thus profoundly influence spatial structures of nations. Although the enormous significance of linkages is undisputed, existing knowledge about the effects of inter-industry linkages on the development of cities and regions is rather limited. Empirical research is usually hampered by the lack of detailed data and by methodological difficulties in analyzing the complex linkage structures of numerous different industries simultaneously. Under these conditions local economic policies, for example, often support certain industries without adequate knowledge of their linkages. Presently, it are the digital industries that range high in many urban policy strategies although their interrelations with other industries are anything but clear.

The paper summarizes an empirical analysis that is aimed at tracing the influence of inter-industry linkages on spatial structures, especially with regard to metropolitan regions, and puts a special focus on the interrelations of the fast growing digital industries. It also addresses the unresolved question how the "output of agglomerations" can generally be characterized, when seen from the perspective of inter-industry linkages.

In regard of the data and methodological problems, the analysis selects 45 mostly knowledge-intensive and relevant 'urban' industries out of a total of 72 industries for which input-output data are given in the official German statistics. It uses *Cytoscape*, a software tool for numerical analysis and graphical visualization of complex network relationships, to create a network of *nodes* resp. industries and *edges* resp. their linkages.

The ensuing network reveals how inter-industry relations contribute to the structuring of the German space economy and consists of industry clusters and groups as well as single industries. These components can be related to spatial phenomena in the real world like manufacturing regions or metropolitan centers of knowledge-intensive business services (KIBS). It is elucidating to see how far the single industries of the four broader sectors (manufacturing, transaction, cultural industries, transportation & logistics) do or do not correspond with the clusters of the network. Correspondence as well as divergence between assignments of industries to clusters and to sectors derive from specific linkages and those have spatial repercussions.

Digital industries prove to be highly connected to many transaction industries, like the financial industry, publishing and certain advanced producer services, reinforcing the high concentrations of such industries in metropolitan regions. Both digital and transaction industries are likewise connected by input-output linkages to certain other industries like public administration, education, accommodation & food and air transport, where the latter two are associated with travel and tourism activities. Some industries enumerated here in addition have strong links to the cultural sector. It appears these intensely interwoven industries together form a 'mega-cluster' that covers large segments of activities performed in a typical urban agglomeration.

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1. Industries and linkages, cities and regions

As in most Western countries, numerous cities and regions in Germany face a rapid structural change in their economic base. In these processes of change, globalization and digitization open new chances and, at the same time, pose new threats to many regions. In highly urbanized regions, structural change is particularly pronounced. Many manufacturing industries continue to loose shares of regional employment or gross value added, while certain service industries gain in significance. In view of rather slow nationwide growth, policy makers seek to foster the development of sections of the economy that might provide a sustainable economic base for their cities and regions. Various industries are almost always part of the mix that seems to promise prosperity, especially in metropolitan areas and most can be characterized as *knowledge-intensive* (NIW/ISI/ZEW 2010), such as:

- cultural industries (e. g. audio visual media, broadcasting and amusement),
- high technology manufacturing (e. g. manufacturing of electrical equipment, machinery or chemical industry),
- advanced business services (e. g. consulting, legal advice or advertising),
- research & development (engineering and sciences),
- and, now attracting most attention, digital industries (e. g. computer programming, information services and telecommunication).

From a theoretical point of view, one decisive stimulus for industries to concentrate in space, be it in cities or geographical clusters, is the existence of *agglomeration economies* – cost savings that firms can obtain in their transactions concerning goods and services, workers and ideas. The magnitude of these economies is closely related to the intensity and configuration of buyer and supplier relationships that exist between the firms resp. industries in question. Emphasizing the outstanding significance of linkages for the economic dynamics of big cities, Michael Storper (2011:13) demands, that we must "be better able to characterize the output of these agglomerations and stop looking for cars, carpets and widgets." As Storper stresses, the „outputs of these places are not final products but intermediate inputs such as information, planning, designing and deal-making that cross over many different final output sectors."

However, quite little is known about the precise structure of inter-industry relationships of knowledge-intensive industries, especially when industries from different sectors are to be considered. Let alone the structure of linkages to and between other industries that are not classified as knowledge-intensive. For example, in metropolitan areas the linkages between knowledge-intensive industries and industries related to tourism, to air transport or to public administration are manifold, yet little studied

One reason for the limited knowledge about these inter-industry linkages resp. intermediate inputs is that empirical research is complicated by the fact that the possible number of input-output relationships increases exponentially with an increase in the number of industries under observation. Many studies thus include only relatively few selected industries or focus on certain sectors like manufacturing or services or subgroups thereof. In addition, comprehensive recent and detailed data on input-output linkages are difficult and very costly to obtain. A problem that is multiplied if data for different regions are required.

In face of these obstacles, this exploratory paper investigates inter-industry linkages on the basis of a complete input-output matrix for Germany containing inter-industry supplies for all 72 industries. Out of those, the most relevant ones for urban development are selected by qualitative and quantitative criteria. The basic linkage structure of these 45 industries is explored and presented as a network of clusters and industries. The network is created utilizing *Cytoscape* (3.5.1), a sophisticated tool for the mathematical analysis and graphical visualization of complex network relationships. This network in turn has geographical ramifications that are discussed for various sectors and industries and related to spatial arrangements found in the 'real world'.

In the next, second section of the paper, the impacts of inter-industry linkages on agglomeration economies are briefly described from a theoretical point of view. A discussion of the empirical limitations of the approach presented here follows. The third section presents the design of the study, consisting of the selection of industries and their classification into sectors, the definition of indicators and the explanation of methods for analysis and

(graphic) presentation. In the fourth section, the results are put forward for each sector defined before and some single industries. The fifth section summaries the results and draws some conclusions for regional economic policy and for further research.

2. Theoretical background and empirical constraints

Since the foundational work of Alfred Marshall (1890), the main sources of the spatial concentration of industries, economies of agglomeration, are seen by economists (Ellison et al. 2010, Storper 2013) as rooted in three fundamental processes or mechanisms. Duranton and Puga (2002) condensed them into the terms sharing, matching and learning.

- Spatial proximity of firms to their suppliers lowers transport cost and high demand allows suppliers to take advantage of increasing returns to scale. Firms *sharing inputs* provided by local suppliers have thus significant cost advantages. Concurrently they can benefit easily from frequent face-to-face contacts that allow the emergence of "untraded interpendencies" (Storper 1995). Thereby exchange is facilitated, which is especially important under conditions of high uncertainty and complexity.
- With concentrations of many firms of one industry in a certain city or a geographical cluster, a large pool of qualified labor comes into existence, lowering search cost and increasing the probability to find suitable workers for specific jobs. The *matching of jobs and workers* is significantly eased and the larger pools of labor allow more flexibility for employers to adjust the size of their workforce to their needs.
- Proximity of firms also enhances the flow of ideas between people and firms which in turn promotes innovation and technological progress. These effects relate to technological *learning* and localized knowledge spillovers that are more probable to occur in dense clusters of specialized industries.

All three mechanism are deeply intertwined with input-output linkages. While the first one explicitly refers to buyer supplier relationships, the second and third mechanism have an indirect relation to input-output linkages. The size of a local labor pools depends not only on the degree of concentration of one industry in a region, but also on the co-location of other industries, that are linked by input-output relationships to that industry, because highly connected industries or industries from the same sector will – in general – have more similar labor requirements than unconnected industries or industries from different sectors. A similar correlation between the strength of economic effects and industrial linkage structures probably exists in the case of learning and knowledge spillovers. The more industries are connected via input output relationships, the more learning effects and knowledge spillovers will usually occur (Porter 1990).

Obviously, the questions such as how agglomeration economies come into existence and why and where industries concentrate relate to many current debates about spatial development. For example to the debate about how advanced producer services determine the functions and relative importance of global cities (Taylor et al. 2011). Or to the debate how the creative industries or 'creative class' contribute to the innovative capacities of cities and spur their economic growth (Markusen 2007, Storper/Scott 2009, Florida 2012). As to the question how research & development (R&D) and technologically advanced manufacturing industries propel the development of certain regions (Scott 1993, Sternberg 2000). While in all these cases the development of the 'propulsive' industries (high-level business-services, creative industries, high-technology sector) is researched in depth, input and output linkages of these industries are generally looked at only very selectively. To analyze the whole spectrum and structure of important linkages is beyond the scope of these analyses, especially as concerns linkages to industries that are considered as not knowledge-intensive or belong to other sectors than those in focus

Differing from such approaches, an explicit inter-industry and cross sector perspective is taken by cluster-based investigations as presented by Ketels/Protsiv (2014). For "traded" – as opposed to "local" – industries the authors investigate the important exchanges including employment and skill use factors and the spatial dimen-

sion of their interrelations. The authors identify ten dynamic "emerging industries" (e. g. advanced packaging, digital industries, experience industries) and 37 "cluster categories" (e. g. Automotive, business services, distribution) composed on basis of the deeply subdivided two digit NACE[1] classes. The main objective of these highly detailed analyses is, to offer support for "designing smart specialization and cluster strategies" (p. 1) to national and regional policy makers. While linkages play their well-deserved role in this work, the complex networks of inter-industry exchanges are presented in a rather schematic way, by either basic graphic or purely quantitative means. Furthermore, these methods do not allow a simultaneous presentation of input-output linkages *within* and *between* clusters, i.e. the complete network of all (important) linkages.

That said, is has to be acknowledged that the following exercise in investigating inter-industry linkages, which tries to overcome some of the shortcomings of the various approaches described before, likewise has a number of limitations.

First of all, the values for input-output linkages are measured solely nationwide, although they will have – in some cases a large – regional variation in reality. This problem is due to the fact that the necessary statistics are regularly available only for national data. Regional data were so far prepared for selected case studies (e. g. for federal states) and oftentimes with an narrower range of industries than applied at the national level. The results given below, therefore, represent merely the basic input-output linkage structure of industries in Germany.

Moreover, even the nationwide data used subsequently offer only a limited subdivision of (in total 72) industries. For some industries (e. g. for the sciences or computer programming) a further subdivision would be particularly desirable.

And it should be noted that in the space economy of the country, metropolitan regions now dominate over other (e. g. rural) regions. With 70.4% of the total German population located in and 72.8% of nationwide GDP originating from metropolitan regions, they clearly prevail in the country's space economy (IKM 2012). National input-output data will, therefore, have a 'metropolitan bias'.

The paper primarily looks at the *output structure* of industries, which implies naming of the most important industries using these goods or services as intermediate inputs. This will make clear that there are many similarities in the output structure of industries belonging to a certain sector, but also that there are striking differences in some cases. One might equally look mainly at input structures, but a constant shift between both perspectives would be rather confusing in a comparison of many industries and sectors.

Possibly it should be pointed out that the spatial properties of the network graph, above all the distances between industries or their clustering, do not have an immediate spatial significance. Industries situated close to each other in the graph are not necessarily located close to each other in reality. However, proximity in the graph signals comparatively strong linkages and these will reinforce – everything else being equal – tendencies for the industries in question to lower exchange cost for both physical transportation and transactional activities by choosing locations with relatively short distances between them.

Thus the network structure has *spatial implications* and these will be discussed subsequently for all sectors and important industries. In this way it will become clear that the structures of the network, its clusters and the placement of industries, do correspond in part to spatial configurations that exist in reality. Depending on what empirical information is available in secondary sources, some examples and various indicators (e. g. regional specialization and concentration ratios, results of clustering research) will be cited for this claim, mostly referring to Germany.

1 **N**omenclature Générale des **A**ctivités Économiques dans les **C**ommunautés **E**uropéennes: Statistical classification of economic activities in the European Community

3. Design of analysis

3.1 Data compilation, industries and sectors

The input-output tables provided by the *Federal Statistical Office of Germany* are calculated in various steps from different statistical sources (Statistisches Bundesamt 2010). They are a secondary statistic using a multitude of basic statistics. One outcome is a symmetric (72x72) input-output matrix that shows for all "product groups" how much of their output is "included as intermediate consumption in the branches of homogeneous production" (Destatis 2017). In this explanation the term "product groups" not only includes (groups of) tangible goods but also activities usually defined as 'services'. And the term "intermediate consumption" relates to the inputs that branches receive from other ones. For simplicity these branches of homogeneous production and product groups will both be denoted as *industries* subsequently.

The number of 72 industries is, however, too large for this overview analysis and many industries are of little importance for the development of large cities, because they are usually not located in cities (like mining and agriculture). Some industries that usually do not enlarge the export base of cities (Simmie 2002) can also be excluded from further analysis. This concerns primarily social services or industries that provide basic public utility infrastructure and such goods or services (e. g. water, electricity). A number of industries was therefore excluded from further analysis.

After this selection 45 industries remained, of which the majority are in general categorized as *knowledge-intensive manufacturing* or *knowledge-intensive business services resp. KIBS* (Muller/Doloreux 2007, NIW/ISI/ZEW 2010). In order to allow general conclusions 37 of the 45 industries were classified into four relatively homogeneous *sectors* (Manufacturing, transaction, culture and transportation & logistics), presuming that a sector should be composed of at least three industries. Eight industries were not assigned to a certain sector. They are marked as 'Other industries' in the graph and some of them are fused into small groups.

In detail the following *categorization of industries* was applied (Tab. 1):

- Thirteen industries were assigned to manufacturing based primarily on the simple and widely accepted criterion that these industries mainly produce tangible goods. The ***manufacturing sector*** here includes all seven industries considered as knowledge-intensive manufacturing (e. g. the machinery, pharmaceutical or the computer, electronic & optical products industry). In addition, some industries were included that produce partly design-intensive fashion goods in small batches (e. g. apparel) or might otherwise be important for urban economies.
- In contrast to the manufacturing sector, the classification of service industries and many other basic questions concerning services are - after decades of discussion – still controversial (see e.g. Akehurst 2008). For classifying services a criterion cross cutting with knowledge-intensity will here applied by differentiating economic activities according to the *function* that they fulfill. This implies primarily a differentiation whether an activity is devoted to a *transaction*, the linking of steps in a value chain performed by different economic agent, or to the *transformation* of the condition of a person (e. g. medical treatment or teaching) or an object (e. g. car repair or artistic painting). From this view, firms or industries conducting mainly "transaction activities" (Furubotn/Richter 1997) constitute the ***transaction sector***. It includes industries like retail, wholesale, finance, but also publishing, advertising, law, accounting and consulting (Wallis/North 1986, Engelbrecht 1997, Stein 2002). In the given examination, 16 industries are assigned to the transaction sector. In general, these industries provide activities that serve economic organization and coordination.
- The ***cultural sector*** is represented by three industries: (1) audiovisual media, music publishing, (2) arts, culture & gambling and (3) sport, entertainment & recreation. This sector has attracted much attention in

recent decades for spurring innovation, growth and prosperity in urban regions, even in those that are or were heavily industrialized.

Table 1: **Industries, sectors and groups**

No.	**Industry** (Official denomination)	**Industry** (Short form in text)	**Abbre-viation**
1	Food products, beverages, tobacco products	Food & tobacco	FTo
2	Textiles,wearing apparel,leather,leather products	Textiles, apparel & leather	TAL
3	Paper and paper products	Paper	PaP
4	Printing services, rec. sound,image,data carriers	Printing	Prn
5	Chemicals and chemical products	Chemical	Che
6	Pharmaceutical products	Pharmaceutical	Pha
7	Metal products	Metal products	MeP
8	Computer, electronic and optical products	Comp., electr. & optical prod.	CEO
9	Electrical equipment	Electrical equipment	ElP
10	Machinery	Machinery	Mch
11	Motor vehicles, trailers and semi-trailers	Motor vehicles	MoV
12	Other transport equipment	Other transport equipm.	OTE
13	Furniture and other manufactured goods n.e.c.	Furniture	Fnt
14	Wholesale,ret.trade,repair of motor veh.,motorcyc.	Trade & repair of mot. vehic.	TrM
15	Wholesale trade serv.,exc. motor veh. a. motorcyc.	Wholesale	WhT
16	Retail trade serv.,exc. motor veh. and motorcycles	Retail	ReT
17	Land transp.serv. a. transport serv. via pipelines	Land transport	LTr
18	Water transport services	Water transport	WTr
19	Air transport services	Air transport	ATr
20	Warehousing and other services for transportation	Warehousing	WST
21	Postal and courier services	Postal & courier serv.	PoC
22	Accommodation and food services	Accommodation & food	AcF
23	Publishing services	Publishing	Pbl
24	Audio-visual media, music publishing, broadcasting	Aud.-vis., music publ. & broadc.	AVM
25	Telecommunication services	Telecommunication	Tel
26	Computer programming, consultancy, inform.services	Computer programming & inform. serv.	CPI
27	Financial services	Finance	Fin
28	Insurance and pension funding services	Insurance	Ins
29	Services related to financial a.insurance services	Services to fin. &.insur.	SFI
30	Real estate services	Real estate	ReE
31	Legal, accounting, management consultancy services	Law, accounting & consulting	LAC
32	Architectural & engineering serv., techn. testing	Engineering	EnT
33	Scientific research and development services	Sciences	Sci
34	Advertising and market research services	Advertising	Adv
35	Other prof., scientific,techn., veterinary services	Professional services	PSS
36	Rental and leasing services	Rental & leasing	ReL
37	Employment services	Employment serv.	EmS
38	Travel agency, tour operator,other reserv.services	Travel agencies	Trv
39	Invest., security, admin., support services n.e.c.	Admin. support serv.	Adm
40	Public administration and defence services	Public administration	PAD
41	Education services	Education	Edu
42	Human health services	Human health	HuH
43	Arts, culture and gambling services	Arts, culture & gambling	ACG
44	Sporting, amusement and recreation services	Sporting, amusem. & recreat.	SAR
45	Services of membership organisations	Membership organisations	MeO

Categorization of industries into sectors and groups (by colour)

Manufacturing	Transaction	Cultural industries
Science, R&D, Human Health	Transportation & logistics	Other industries

The remaining eight service industries of which the first five are knowledge-intensive are marked as ***´other industries´***. They mostly apply completely different technologies and offer very diverse outputs made available from equally diverse inputs. But a few that provide rather homogeneous goods and services for similar uses can be further grouped together:

- The two industries in the field of ***engineering and sciences*** are (1) *architectural and engineering services and technical testing*, representing predominantly applied technological sciences and research for innovative products and processes and (2) *scientific research and development services*, representing mainly basic research in natural sciences and humanities, including social and cultural sciences.
  The two ***digital industries***: (1) *Telecommunication*, mainly supplying the infrastructures for global communication and (2) *Computer programming & information services*, including e. g. internet providers, programming and online-services for communication, search and entertainment. The latter industry incorporates the actual core of the ongoing digitization processes with continuously innovated software and an ever expanding variety of new business models, often with worldwide reach.
  Another knowledge-intensive industry is ***human health,*** covering all kinds of firms providing medical treatment, yielding a total output almost as large as the one of the computer, electronic and optical products industry.
- Three *'other industries'* are not considered as knowledge-intensive, yet, they are – for various reasons – considered to be important for the development of cities, and have been included here. Similar to human health, *public administration* and *education* are not ruled primarily by the rules of competition, but under public ownership and control to a large extent or highly regulated. Still, both can provide important stimuli for urban development. The location of institutions of the public sector can lead to growth effects in urban areas, so can educational institutions. Important impulses can result from the *accommodation & food services* industry as well, where the second term stands for all kinds of food services. This industry includes services of hotels, restaurants, bars and catering firms for local business, inhabitants and for visitors of cities and is thus closely connected to national and international tourism, that seems an ever increasing source of growth in many cities.

Finally, there are five industries forming the ***transportation & logistics sector.*** It entails the three industries providing services of transport via (1) land, (2) water and (3) air. And two further ones: (4) warehousing & other transport services and (5) the postal & courier services industry. These five industries consist of enterprises handling the transport of people, goods and other objects (e. g. letters, contracts or documents) between locations from the regional to the global level. The level of their activities are an indicator for the "gateway functions" (BBSR 2011:21) of urban and metropolitan areas.

Industries assigned to one of the four sectors (manufacturing, transaction, cultural industries, transportation & logistics) are depicted with colored nodes in the graph, all other industries have no filling. It should be noted that the aggregation of industries to sectors is important for the interpretation of the results – but does not influence the the results themselves, because the structure of the network depends solely on the strength of linkages between single industries. There is, accordingly, no single correct way to read the network graph.

3.2 Indicators and methods

To describe the structure of input-output relations of industries and their importance in the economy *three main indicators* are applied.

- The *five strongest output linkages* of one industry (e. g. No. 1) to other industries (e. g. No. 6, 18 or 41) are used to create a network of inter-industry relationships, representing the interlocking of the selected 45 industries. In

order to concentrate the analysis on the most important linkages and keep the network decipherable, a restriction to five linkages that are not smaller than 200 Million (MM) Euro was applied (Tab. 2).

- The *percentage of output* delivered from one industry (e. g. No. 3) to one of the whole set of other industries of the official input-output tables (No. 1, 2, 4, ..., 71, 72) shows, how these deliveries relate to total inter-industry output of an industry, resp. how 'dependent' industries are on each other.
- But firms of one industry (e. g. No. 7) do not only deliver to firms of other industries, but also to firms of the same industry (No. 7). This output is called *internal demand* in the following. The *percentage* of internal demand to total inter-industry output relates to the 'roundaboutness of production' within that industry and shows how elaborated the intra-industry division of labor is. If this percentage is comparably high, the shares of output delivered to other industries will be logically comparably low.

In addition to the five (absolutely) strongest output linkages the *absolute amount of internal demand* is also considered. It is related to the importance of an industry in the German production system and the distribution of internal demands of the industries included is rather unequal (Tab. 3, p. 25). It is – measured in Euro – by far largest in the motor vehicle industry (85 653 MM) and the chemical industry (60 612 MM) and smallest for membership organizations (11 MM) and accommodation & food (37 MM). In general, internal demand is relatively large in manufacturing and far smaller in the transaction sector. Though, some transaction industries also show an high internal demand, such as law, accounting & management consulting (20 256 MM) and finance (18 891 MM).

In order to analyze the structure of all linkages for the selected 45 industries simultaneously with mathematical methods and provide a graphic representation of the inter-industry network (Fig. 1), the software package *Cytoscape 3.5.1* has been used. Cytoscape is a continuously improved software platform for researching and visualizing complex networks and offers a large variety of tools, layouts and apps (Shannon et al. 2003). In Cytoscape a network is basically constructed from two elements: nodes and edges.

- In the given examination, industries are depicted as *nodes* of the network. The size of these nodes is proportional to the (absolute) size of internal demand of an industry. Nodes of industries assigned to a certain sector are colored as noted in Table 1, nodes of the *´other industries´* have no filling.
- Input-output linkages are depicted as *edges* (arrows) in the network. The width of edges is proportional to the absolute size of linkages. As mentioned above, only the five strongest links – exceeding 200 MM Euro – are mapped for each industry
- For *structuring the network*, the *Prefuse force directed layout*[2] is utilized, in which the size of linkages resp. edges function as weights that determine the positioning of an industry. The stronger input-output relations between industries are, the closer these industries are located in the network.

2 See: http://www.prefuse.org/

Table 2:

Five strongest output linkages (> 200 MM Euro) of 45 industries to other industries*

(Alphabetical order)

From	to	Output	From	to	Output	From	to	Output	From	to	Output
AcF	ATr	447	EmS	MoV	3011	MeP	MoV	12371	ReL	WhT	3256
AcF	PAD	311	EmS	Mch	2634	MeP	Mch	11918	ReL	ReT	2895
AcF	WhT	276	EmS	MeP	1934	MeP	OTE	2632	ReL	WST	1610
AcF	MeO	221	EmS	WST	1714	MeP	ElP	2138	ReL	LTr	1432
ACG	Pbl	1607	EmS	FTo	1623	MeP	Fnt	1350	ReL	Fin	1041
ACG	AVM	1021	EnT	Mch	1698	MoV	Mch	3564	ReT	FTo	6441
ACG	SAR	609	EnT	ElP	1688	MoV	TrM	1734	ReT	HuH	5690
ACG	PAD	270	EnT	Che	1626	MoV	LTr	683	ReT	AcF	3211
Adm	WhT	4919	EnT	LTr	1445	MoV	Sci	369	ReT	MoV	2228
Adm	ReT	4150	EnT	PAD	1332	MoV	WST	307	ReT	CEO	2093
Adm	PAD	4023	Fin	ReE	20431	OTE	PAD	1928	SAR	PAD	2944
Adm	Fin	3325	Fin	SFI	3491	OTE	ATr	467	SAR	MeO	489
Adm	HuH	2849	Fin	ReT	2191	PAD	LAC	2857	SAR	Fin	330
Adv	FTo	3506	Fin	HuH	2052	PAD	ReE	2241	SAR	Edu	221
Adv	ReT	1823	Fin	Ins	2006	PAD	Adm	1489	SAR	FTo	202
Adv	Che	1358	Fnt	HuH	994	PAD	EnT	1477	SFI	Ins	20988
Adv	MoV	1111	Fnt	CEO	303	PAD	FTo	1323	SFI	Fin	6390
Adv	WhT	986	FTo	AcF	7198	PaP	FTo	2529	TAL	MoV	362
ATr	Mch	570	FTo	HuH	3166	PaP	Prn	1876	TAL	Fnt	262
ATr	CEO	507	FTo	PAD	2135	PaP	Che	1315	Tel	Pbl	1585
ATr	PAD	494	FTo	Che	1233	PaP	WhT	1218	Tel	Fin	1280
ATr	MoV	292	FTo	Edu	264	PaP	ReT	950	Tel	PoC	1123
ATr	Fin	253	HuH	Sci	256	Pbl	PAD	2036	Tel	Trv	908
AVM	Adv	3819	Ins	SFI	2635	Pbl	Edu	2007	Tel	PAD	889
AVM	AcF	431	Ins	LTr	2577	Pbl	LAC	1651	TrM	MoV	13733
AVM	LAC	271	Ins	PAD	1617	Pbl	ReT	1206	TrM	WST	3203
AVM	ACG	213	Ins	ReT	1273	Pbl	ACG	1145	TrM	PoC	2683
CEO	ElP	1161	Ins	WST	1087	Pha	HuH	1326	TrM	ReT	2232
CEO	Tel	1130	LAC	Fin	10077	PoC	ReT	9209	TrM	LTr	1880
CEO	Fnt	625	LAC	ReE	8861	PoC	WhT	3319	Trv	ATr	2058
CEO	PAD	540	LAC	EnT	7987	PoC	Tel	1685	Trv	LTr	961
CEO	Mch	532	LAC	Adm	6984	PoC	Mch	1388	Trv	SAR	689
Che	PaP	943	LAC	Mch	4585	PoC	LTr	1171	Trv	AcF	363
Che	MoV	895	LTr	WST	13429	Prn	Pbl	3317	Trv	ACG	261
Che	TAL	689	LTr	WhT	11663	Prn	ReT	1941	WhT	FTo	10666
Che	Pha	636	LTr	Edu	6156	Prn	Fin	919	WhT	Mch	6952
Che	Adm	526	LTr	MoV	2495	Prn	LAC	709	WhT	MoV	5221
CPC	Fin	4095	LTr	ReT	2179	Prn	PAD	588	WhT	HuH	4157
CPC	Pbl	2075	Mch	MoV	4954	PSS	LAC	1234	WhT	ElP	3892
CPC	Tel	2010	Mch	MeP	1161	PSS	Pbl	1096	WST	WhT	30166
CPC	WhT	1675	Mch	OTE	641	PSS	Fin	904	WST	LTr	13469
CPC	Sci	1586	Mch	ElP	559	PSS	Ins	624	WST	PoC	6043
Edu	PAD	1871	Mch	FTo	535	PSS	TAL	622	WST	FTo	5073
Edu	Sci	1282	MeO	ReT	1251	ReE	ReT	17838	WST	MoV	3342
Edu	Fin	763	MeO	HuH	641	ReE	Fin	7528	WTr	WhT	844
Edu	MoV	646	MeO	LAC	584	ReE	AcF	6283	WTr	WST	275
Edu	CPC	619	MeO	WST	337	ReE	LAC	5996			
ElP	Mch	3449	MeO	FTo	312	ReE	WhT	4965			
ElP	MoV	2849									
ElP	OTE	366									
ElP	Fnt	338									
ElP	AcF	295									

** See table 1 for abbreviations.*

4. The network of inter-industry linkages and clusters

The first impression of the graph is that the inter-industry linkages span an absolutely puzzling network (Fig. 1). Although a number of industries are disregarded and only the five strongest linkages were mapped, the network still cannot be fully grasped as a whole. This is partly due to the limitations of the graphic representation, especially in a small graph. But also to the highly developed social division of labor in modern economies, which is at least partly reflected in the network.

Nonetheless, linkages between industries create a certain structure in the network that is in no way random, but can be explained in economic terms and has repercussions on the location of industries in space. The network structure is described in the following sections with some general observations (4.1) that are complemented by a discussion of the properties of certain sectors and industries (4.2-4.4). As a special case, the transportation & logistics sector will be dealt with in the last section (4.5).

4.1 Industries of the same sector cluster together – in general

As can be expected, linkages between industries of the same sector are in general stronger than linkages between industries from different sectors. Therefore, most industries of the manufacturing sector, the transaction sector and the cultural sector each form more or less dense clusters in the network.

Manufacturing: Highly interlinked and clustered

This holds especially true for manufacturing. Almost all manufacturing industries are grouped together in the lower right part of the network. The center of that cluster is formed by knowledge-intensive – industries, except for the last one: motor vehicles (MoV), chemicals (Che), electrical equipment (Elp), machinery (Mch), computer, electronic & optical products (CEO) and food & tobacco (FTo). These are all very important industries in the German production system and they are heavily interlinked - mainly between themselves, but also with many other manufacturing industries. In particular with the paper & products (PAP), pharmaceutical (Pha), metal products (MeP), furniture (Fnt), other transport equipment (OTE) and textiles, apparel & leather industry (TAL) . These industries form an outer circle around the center.

The linkage structure of the *machinery* industry can serve as an example for interconnections in manufacturing. Most of its output (67%) is supplied to other firms of the machinery industry itself. The second largest share of supplies (11%) is directed at the motor vehicle industry. The industries that follow demand much smaller shares from machinery: repair of machinery (3%), metal products (2.6%), other transport equipment (1.4%) etc. All in all 90% of machinery output is directed at manufacturing, the rest to other sectors. Many manufacturing industries show a similar structure of linkages.

This high interconnectedness of manufacturing firms and industries creates incentives for firms to locate relatively close or in spatial clusters, leading to specialization tendencies towards manufacturing in certain regions or cities. Of course, the strength of these incentives depends on many factors, like the quantity and complexity of exchange relations and does not exclude worldwide sourcing, e. g. for standardized products.

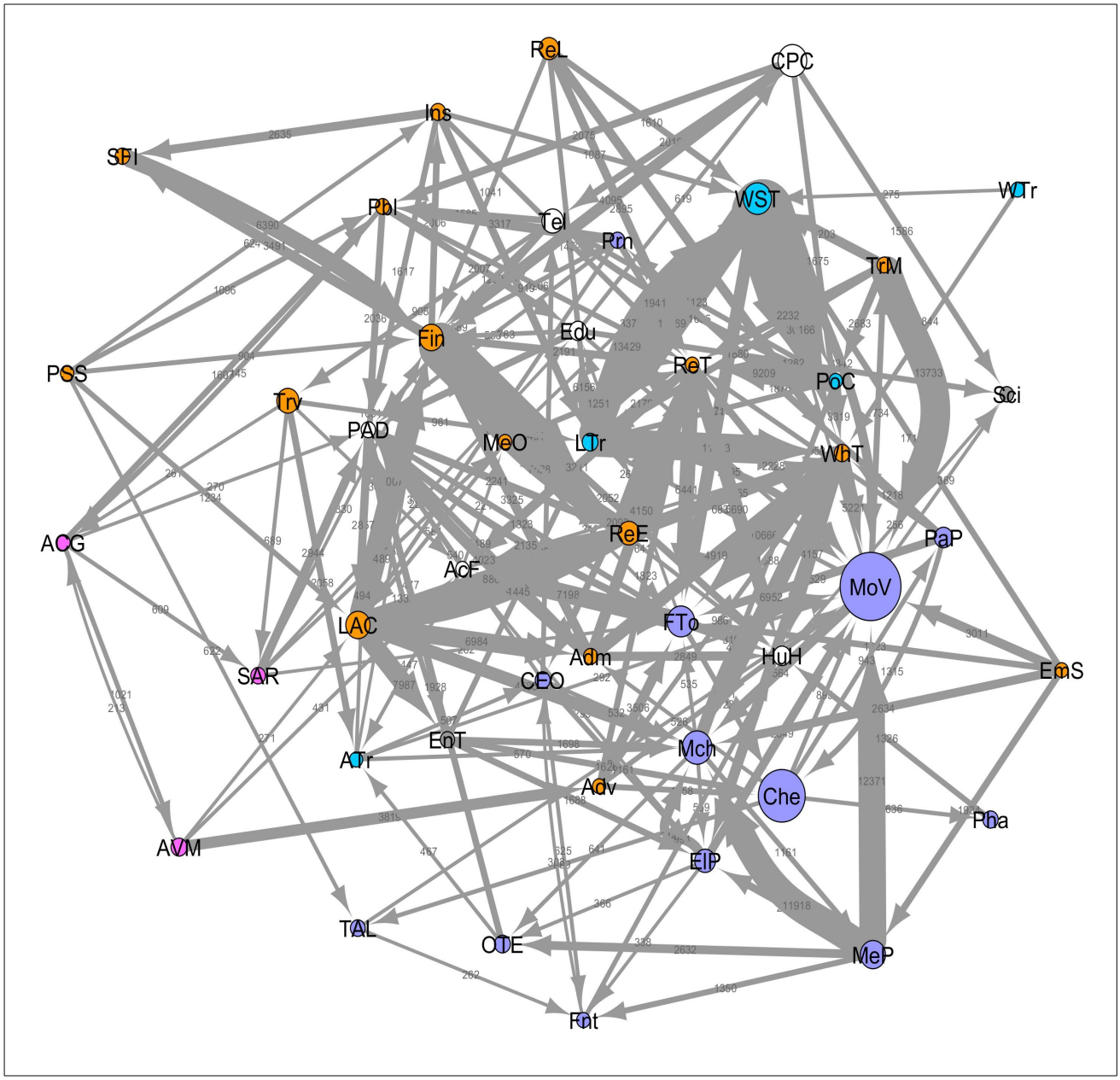
In what kind of urban setting then can pronounced specializations in manufacturing be expected? To find out what the dominating sectoral specializations of Germany's largest 71 cities[3] are, Burdack and Hanewinkel (2016) compared their gross value added (2009) for four large sectors:

- Manufacturing,
- Trade, catering and logistics,
- Producer services, finance and renting,
- Other private and public services.

3 Cities with more than 100 000 inhabitants.

Figure 1: **Network* of input-output linkages of 45 industries**

(Five strongest linkages (Million Euro) / Size of nodes proportional to absolute internal demand of industries)



**) Network Analysis: Cytoscape 3.5.1 (Layout: Prefuse force directed)*

According to these calculations, highest regional specializations in manufacturing can be observed in only 14 cities (marked blue in Fig. 2, below). Among those only four (Essen, Duisburg, Mannheim, Gelsenkirchen) have more than 250 000 inhabitants, whereas ten cities have less inhabitants – most of them far less. Such as Leverkusen with 160 000, Wolfsburg with 121 000 or Erlangen with 104 000 inhabitants. Obviously, large segments of production networks in manufacturing, find most favorable locational conditions mainly in or around these second or third tier cities, not in the much larger cities of the country where a specialization in one of the other three sectors exits. Similar spatial configurations of manufacturing can be found e. g. in Denmark and Italy (Schmitz/Musyck 2016, Giuliani/Rabellotti 2017), countries in which *industrial districts* are located primarily in less dense regions. Such spatial distributions of manufacturing are reminiscent of Jane Jacob's (1969:82) statement, relating to the "inefficiencies" of "big cities", such as traffic congestion, waste disposal, limited space etc. and where she concludes: "Factories move to the outskirts and the suburbs, and to small and distant towns, often for reasons of efficiency."

Transaction sector: Cluster with strong linkages – and satellites

Most industries of the transaction sector also cluster together. They are ordered into the upper left, where they form an own core in the network (Fig. 1). The impression for the transaction sector is, however, more diffuse than for manufacturing, since some of its industries supply more to manufacturing than to other transaction industries. This is the case not only for *administrative services* (Adm) and employment services (EmS) – both usually employing rather low qualified work - but equally for *advertising* (Adv), where higher qualifications are required (see below).

Yet, the clear majority of transaction industries are part of a highly interconnected cluster with the financial industry (Fin) in its middle, being surrounded by publishing (Pbl), insurance (Ins), membership organizations (MeO), retail trade (ReT), real estate (ReE), law, accounting & consulting (LAC) and travel agencies (Trv) and others.

Within this cluster the so-called FIRE complex is clearly discernible (Tab. 4). The FIRE complex embraces, in general, the ***F****inance*, ***I****nsurance* and ***R****eal* ***E****state* industry. It figures prominently in urban research, mainly because of the strong growth and the pronounced labor market inequalities that come with it in global cities (Sassen, 2009), In the German case, *services in finance and insurance* (SFI), including activities like stock exchanges, fonds management and insurance brokerage, are classified as an own industry and have to be included into that complex as well.

- On the one hand, these industries are highly interconnected by inter-industry supplies. The financial industry, for example, delivers by far the largest share (25%) of its services to real estate and significant shares to the other industries of the FIRE complex. Insurance delivers the largest share of its output (10.6%) to services to finance and insurance. Real estate delivers about 6% to financial firms, which represent the second largest group of clients after retail firms.
- On the other hand, the FIRE complex is characterized by comparatively high shares of internal demand – at least when compared to other transaction industries. In the finance industry, 23% of output is provided to finance itself. For Insurance and pension fonds, internal demand amounts to 15% and for real estate to 11%. These figures point at a quite detailed division of labor within these industries.

At the same time the data show, as indicated before, that a number of other transaction industries have equally strong interconnections with the industries of the FIRE complex (Tab. 4).

- Most important is probably the industry of *law, accounting & consulting* firms (LAC). These specialized firms represent the core of managerial, economic and legal knowledge that drives change and globalization in market economies (see e. g. Taylor et al. 2011). The financial industry is the single most important customer for these firms, demanding 9.4% of their expertise. Another 8.3% of output are directed at real estate and 3.8% at the insurance industry.
- The rather diverse industry of *professional services* (PSS) is also closely connected to many of the aforementioned transaction industries. It embraces e. g. graphic designers, photographers and translators. The largest share of its deliveries (9.3%) is directed at law, accounting & consulting, the second largest (8.2%) at publishing, the third largest (6.8%) at the financial industry.

- Another very interesting industry in this cluster of the transaction sector is *publishing*, which is sometimes erroneously regarded as part of the manufacturing sector, although transactional activities (searching for marketable authors and subjects, evaluating manuscripts, organizing production and distribution processes etc.) absolutely prevail in this business. The clients of this industry are rather widespread. The two highest shares of output of publishing are directed at the public domain and education, receiving 7.9% and 7.8% respectively. But third in

the ranking by shares is already law, accounting & consulting (6.4%). Other transaction industries also receive sizable shares of publishing output, e. g. retail (4.7%), administrative services (4.4%) and membership organizations (2.6%). In total 40% of publishing output is directed at other transaction industries, only 10% at manufacturing.

- A similarly widespread structure of clients can be detected for *membership organizations* that do lobbying and provide support, information and other mainly transactional knowledge to their members. The largest share of that industry's output is required by retail (15%), the second largest by human health (8%). Total manufacturing demands about 17%. The transaction sector in total demands 40%, of which - besides retail – mainly two industries demand large shares: the one is law, accounting & consulting receiving 7 percentage points (p.p.) and the other finance receiving 4 p.p. Thus, the linkages of membership organizations to other transaction industries are not that pronounced, but still prevailing compared to other sectors.

Table 3: **Input-Output structure of the transaction sector, including the FIRE complex and other interlinked industries** (Shares of output in %)

	TrM	WhT	ReT	Pbl	CPI	Fin	Ins	SFI	ReE	LAC	Adv	PSS	ReL	EmS	Trv	Adm	PAD	MeO
TrM	**5,15**	0,71	**6,33**	0,29	0,11	0,25	0,18	0,15	0,07	0,62	0,17	0,26	**1,91**	0,03	0,06	0,48	**2,53**	0,05
WhT	0,69	**4,09**	**1,77**	0,27	0,40	0,16	0,06	0,04	0,10	0,33	0,11	0,19	0,06	0,03	0,01	0,85	**2,28**	0,27
ReT	0,56	0,98	**1,43**	0,66	0,30	0,24	0,11	0,11	0,18	0,83	0,23	0,50	0,11	0,12	0,02	1,21	**3,19**	0,56
Pbl	0,77	**2,10**	**4,68**	**6,82**	**2,88**	**2,36**	**1,54**	1,00	1,04	**6,40**	**1,39**	**2,62**	0,71	0,95	0,23	**4,43**	**7,89**	**2,59**
CPI	0,41	**2,60**	**1,93**	**3,22**	**43,53**	**6,36**	**1,42**	0,54	0,49	**1,57**	0,55	0,50	0,66	0,49	0,39	0,82	**1,95**	0,13
Fin	1,05	**2,13**	**2,69**	0,42	0,80	**23,15**	**2,46**	**4,28**	**25,04**	**1,72**	0,30	0,53	0,68	0,31	0,21	0,89	**1,84**	**1,43**
Ins	1,06	**1,58**	**5,11**	0,42	0,28	**4,02**	**14,49**	**10,57**	0,35	1,04	0,17	0,30	**3,52**	0,17	0,03	1,02	**6,49**	0,80
SFI	0,00	0,00	0,00	0,00	0,00	**21,26**	**69,84**	**8,43**	0,00	0,00	0,00	0,00	0,07	0,00	0,00	0,00	0,02	0,00
ReE	**3,19**	**3,63**	**13,02**	0,63	0,36	**5,50**	**2,07**	0,80	**10,52**	**4,38**	0,54	0,50	0,43	**1,53**	0,19	**1,96**	**3,57**	0,52
LAC	0,85	**3,29**	**3,96**	0,73	1,11	**9,40**	**3,75**	**1,87**	**8,26**	**18,89**	0,56	**1,90**	0,82	0,41	0,32	**6,51**	1,31	0,28
Adv	**4,83**	**5,48**	**10,14**	**3,87**	0,00	**2,78**	**1,99**	0,06	0,07	**1,15**	0,60	0,26	1,23	**1,46**	0,97	0,64	0,79	0,05
PSS	0,73	**1,96**	**2,08**	**8,22**	0,10	**6,78**	**4,68**	**4,27**	**3,44**	**9,26**	1,34	**3,32**	0,71	0,57	0,05	**3,70**	**3,01**	0,48
ReL	0,65	**6,06**	**5,38**	0,90	**1,41**	**1,94**	0,92	**1,46**	0,19	0,37	0,16	0,18	**22,11**	0,01	0,63	**1,44**	1,32	0,63
EmS	0,30	0,88	0,98	0,27	**2,22**	0,23	0,07	0,00	0,43	0,95	0,16	0,12	0,51	0,49	0,09	**3,24**	0,02	0,02
Trv	0,09	0,35	0,62	0,00	0,14	0,10	0,07	0,00	0,00	0,36	0,06	0,08	0,03	0,02	**74,86**	0,25	0,75	0,07
Adm	0,94	**8,05**	**6,79**	**3,26**	0,43	**5,44**	**2,68**	**1,73**	**3,11**	**2,85**	0,48	0,87	1,30	0,32	0,38	**3,38**	**6,58**	0,24
PAD	0,62	1,18	**1,98**	0,32	1,08	0,92	0,43	0,08	**5,34**	**6,80**	1,16	**1,61**	0,65	0,57	0,03	**3,55**	**4,84**	1,25
MeO	**2,32**	**3,29**	**14,97**	1,35	0,95	**3,67**	1,29	0,39	0,17	**6,99**	0,71	1,17	0,44	0,38	0,44	**2,19**	**1,71**	0,13

Values larger than 1.39 (=average across all industries) printed in boldface. Source: Destatis (2017), own calculations.

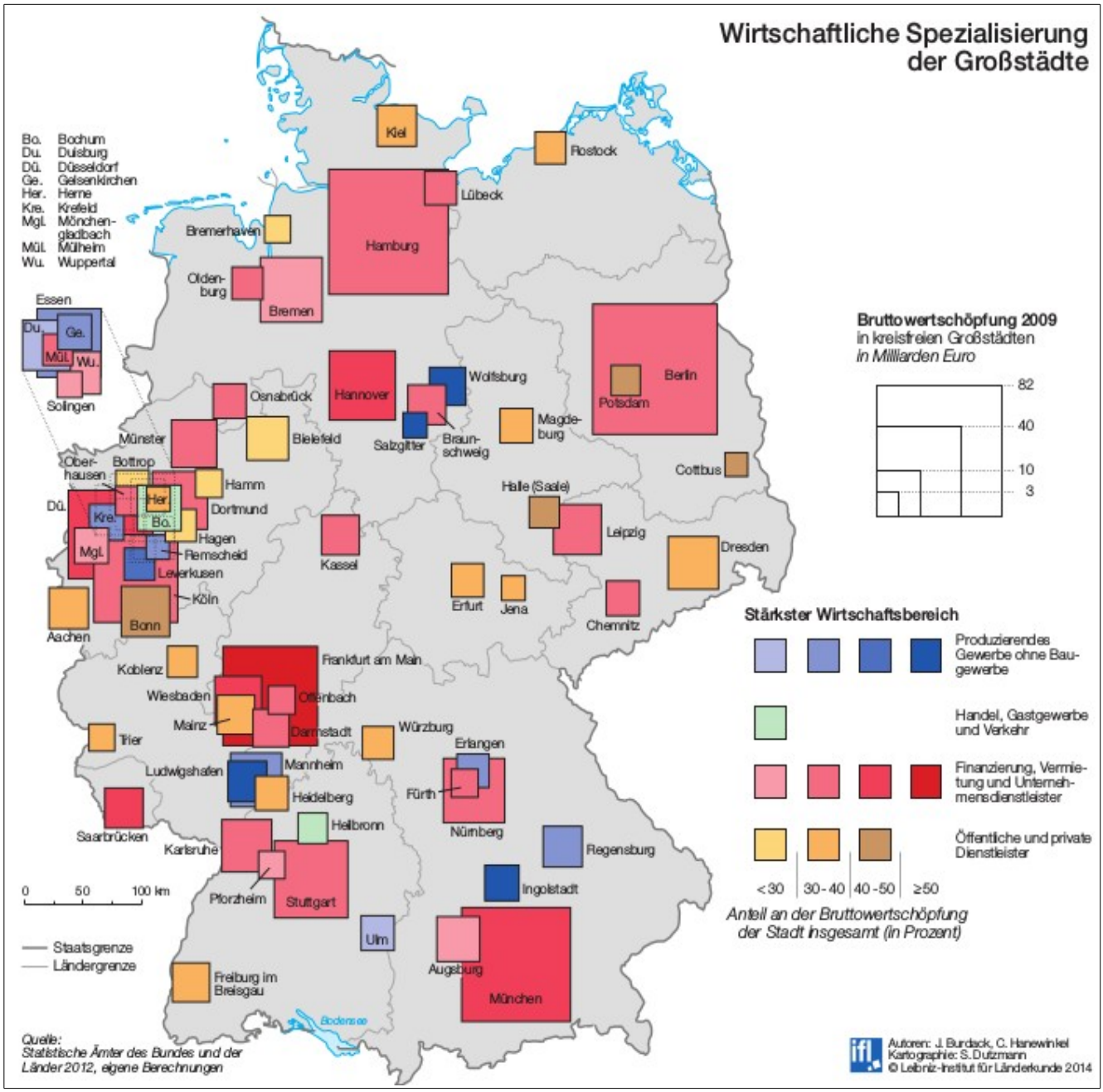
With these manifold and substantial linkages between a large number of transaction industries – of which only the strongest ones were mentioned here – it is clear that firms belonging to them have strong incentives to locate in close vicinity. Especially since much of their exchange raises complicated economic and legal issues, often concerning huge amounts of assets. Such transactions are eased in common by frequent face-to-face contacts of the people in charge (Storper/Venables 2004). The less these exchanges are standardized and the more higher qualified personal is necessary to prepare, execute and control these exchanges, the more spatial proximity comes into effect. Typically, such firms constitute the economic core of central business districts in large cities or dominate the whole economy of many metropolitan areas.

Even in Germany, with its relatively strong manufacturing sector, the transaction sector is the dominating sector in most of the 71 largest cities of the country. This can be seen by examining the analysis of economic specialization of large cities from Burdack/Hanewinkel (2015) in Fig 2.They classified these cities according to their

specialization in one of four sectors. Their sector *Producer services, finance and renting*[4], represents important parts of the transaction sector, though not the whole sector as defined here. The specialization in transactional activities is yet prevailing in 32 of the 71 cities (red marking).

Another 23 cities are specialized in *Other Private and public services*[5] (marked brown), 14 in manufacturing[6] (marked blue) – as mentioned above – and two cities in *Trade, catering & logistics*[7] (marked green). Thus not only the most populous cities – Berlin, Hamburg, Munich and Cologne with about 3.5 million to one million inhabitants – but also most of the other relatively large ones (with more than 250.000 inhabitants) and a number of smaller cities are specialized primarily in transactional activities.

Figure 2: **Economic Specialization of large cities**
Absolute size and relative share of gross value added of largest economic sector (2009)
(Billion Euro / Percent of total value added)



Source: Burdack / Hanewinkel (2016)

4 Finanzierung, Vermietung und Unternehmensdienstleister
5 Öffentliche und private Dienstleister
6 Produzierendes Gewerbe ohne Baugewerbe
7 Handel, Gastgewerbe und Verkehr

From the data it is obvious that activities of organization and coordination as performed in the transaction sector represent the dominating sector in most larger urban economies in Germany, not other services or manufacturing.

Cultural industries: Small sector with selective strong links – internally and externally

The three industries of the cultural sector likewise form a definite cluster, situated on the left side of the network. *audiovisual media, music publishing* (AVM) and *arts, culture & gambling* (ACG) have strong links to each other and the latter industry, also to *sport, entertainment & recreation* (SAR).

At the same time, cultural industries supply large shares of their output to transaction industries. The audiovisual media industry e. g. delivers 42% of its output to transactions industries of which advertising demands 34 p.p. alone. Almost half (47%) of the output of this cultural industry is internal demand. It stays within the industry itself and is exchanged between its highly specialized and often small firms. Arts, culture & gambling delivers 33% to the transaction sector, thereof 27 p.p. publishing. Sports, entertainment & recreation has very strong ties to public administration, being placed within the transaction cluster in the network and demanding 40% of the output of the sports industry. None of the cultural industries has any strong interconnection to manufacturing.

Thus the cluster of cultural industries is placed adjacent to the cluster of transaction industries, which underlines the importance of relationships between these two sectors, that also intersect with links to the public domain. With close links to transaction industries, which prefer locations in metropolitan regions in particular for higher level activities, and their own locational prerequisites (e. g. a developed cultural infrastructure, large pools of creative workers, large local audiences) most segments of cultural industries are irresistibly drawn into highly agglomerated regions.

In the most populous metropolitan areas of the United States, for example, the regional specialization in the group "Arts, Design, Entertainment, Sports and Media" is by far larger than in all other 21 occupational groups (Markusen 2007). The location quotient reaches an value of 1.87, far ahead of subsequent values e. g. for occupations in the legal professions (1.47), protective services (1.30) or in business and financial operations (1.26). Lagging far behind in regional specialization in these largest metro areas is the group life, physical and social sciences (1.04), which is virtually non-existent.

In Germany large metropolitan regions similarly have the highest specializations in "Cultural economy and media" functions (Volgmann 2013). Measured by a location quotient for 2010, based on a composite index, Munich (1.50) is definitely most highly specialized and followed by Hamburg (1.23), Leipzig (1.20) and Berlin (1.19) – which is catching up rapidly in these functions – plus, with a rather low value, the region Rhein-Ruhr (1.04). The remaining eight metropolitan regions all show location quotients below the value of 1, which means they are not specialized in cultural and media functions. And, in the five regions enumerated before, the location quotient for cultural economy and media function is higher than the quotient for most of the other eight "metropolitan functions", including e. g. "innovative functions" as indicated by "Private sector Research & Development".

Exceptions to the rule: Employment services and printing as examples

While the first three points of this section showed that the clusters of the network graph mainly consist of industries belonging to the same sector (manufacturing, transaction sector, cultural industries), it is obvious that there are clear exceptions to that rule. Some examples for the manufacturing and transaction sector are discussed subsequently.

As concerns the *manufacturing cluster* it was already pointed out that some of its industries show strong links to transaction industries, especially to administrative services, advertising and employment services. *Advertising*, for

example, delivers most of its output (20%) to the food & tobacco industry, 8% to the chemical and another 6% to the motor vehicle industry. In total 52% of the output of advertising is directed at manufacturing industries, 36% to (other) transaction industries, of which retail requires 10 p.p. alone.

The case of *employment services* (EmS) is even more significant, since the important links of this industry are exclusively focused on manufacturing industries. They show no strong relationship to other transactions industries, resulting in a placement of these services far distant from the transaction cluster. In total 60% of the output of employment services is directed at the manufacturing sector, only 9% to other transaction industries. This large percentage of demand diverted to manufacturing is probably to be explained by the extensive use of temporary and mostly cheap labor that characterizes a number of manufacturing industries and was eased in Germany over the past decade by the weakening of labor regulations. The motor vehicle industry e. g. demands more than 10% of the output of employment services alone, by far the largest share among all industries. Clusters of automobile manufacturing firms will thus attract many firms offering employment services.

Turning to the *transaction cluster*, it is discernible that the aforementioned looser connections of its industries are related to the fact that a number of 'other industries' (e. g. education) are closely integrated into this cluster. These industries will be dealt with below. But there is also a manufacturing industry that is placed in the transaction cluster. This is *printing industry* (Prn) representing another example for a deviation between assignment to cluster and sector. The largest share (20%) of printing output, e.g. cultural products like books or newspapers, is shipped to publishing. The second largest share is directed at retail (12%), followed by finance (6%) and law, accounting & consulting (4%). All in all, 54% of printing output is demanded by transaction industries, which is about double of what is demanded by manufacturing. This output comprises, above all, the analogous products or 'hardware' that transaction industries – even in the digital age – need for dealing with all the information that they process: products such as catalogs, advertising brochures, information and promotion material, company and economic reports etc., either printed on paper or stored on data carriers.

With such close links to transaction industries, parts of the printing industry will have strong incentives to locate close to important customers of the transaction sector. In particular, when batch sizes of orders are small, production and delivery time has to be short or when specifications of contracts are complicated, like for high quality products. Certain firms of the printing industry will thus be over-represented or develop better in or close to urban and metropolitan areas.

4.2 Digital industries: Partly clustered – and overlapping with the transaction cluster

Looking at the placement of the two digital industries *telecommunication* (Tel) and *computer programming & information services* (CPI) near each other in the upper right of the network, it is obvious that they are closely interlinked. This is mainly due to the fact that the telecommunication industry is the third largest customer of the computer programming & information services industry, receiving 6.4% of its output.

Sometimes, the *computer, electronic and optical products industry* (CEO), is also classified as digital. According to this network analysis, however, it seems that this industry is rather a part of the manufacturing cluster. About 65% of its output is absorbed by manufacturing industries.

In contrast, especially telecommunication and to a lesser extent computer programming might be viewed as part of the transaction cluster, as is shown by their placement in the graph. A closer look at the linkages of these industries reveals the causes for this classification.

The *Telecommunication* industry delivers its products and services to customers in a wide range of industries. Among those – rather unexpectedly – customers from publishing receive the largest share (5%) of its output. Another 4% of demand comes from finance and 3.4% from postal and courier services. In total, demand for telecommunication output originates to a large extent (26%) from the transaction sector. Only a small fraction

(6%) originates from manufacturing. Almost half (46%) of telecommunication output is delivered to customers of the industry itself.

This industry mainly supplies hardware and services for communication and obviously the need for communication is much larger in industries that are specialized on the organization and coordination of economic processes than in industries that primarily manufacture tangible goods.

A similar pattern, the wide spread of customers across industries and the prevalence of demand from the transaction sector (see also Tab. 4), is recognizable for *computer programming & information services*, which embraces besides programming important parts of the 'internet economy', e. g. activities like web hosting, data and internet services.

Among customers of this industry, those from finance clearly receive the largest share (6.4%) of output, which seems amazing at first sight. The ranking of the next most important industries is also quite different from common perceptions: Publishing receives 3.2%, telecommunication 3.1% and wholesale 2.6%. And again, a large percentage (44%) of the industry's output is directed at firms of the industry itself.

In total 22% of the computer programming & information services' industry output are directed at the transaction sector, which is double the share (11%) directed at manufacturing. There, the machinery industry demands the largest share, which however only amounts to 2 p.p., showing the wide distribution of customers across industries that produce tangible goods.

One might assume that computer programming & information services are closely interrelated with engineering, because this branch uses computing and digital technologies intensively. But engineering demands only 1% of computer programming output. One reason is probably that many engineering firms provide programming and related services to a large extent in-house. Even the institutions of the sciences (see below) demand a much larger share (2.5%).

Computer programming, telecommunication and the ever-growing and diversifying field of information services provide the software for information processing, worldwide communication and exchange, nowadays highly important in almost every industry. For transaction industries, however, these information related activities coalesce largely with their core competencies, on which they are specialized, be it

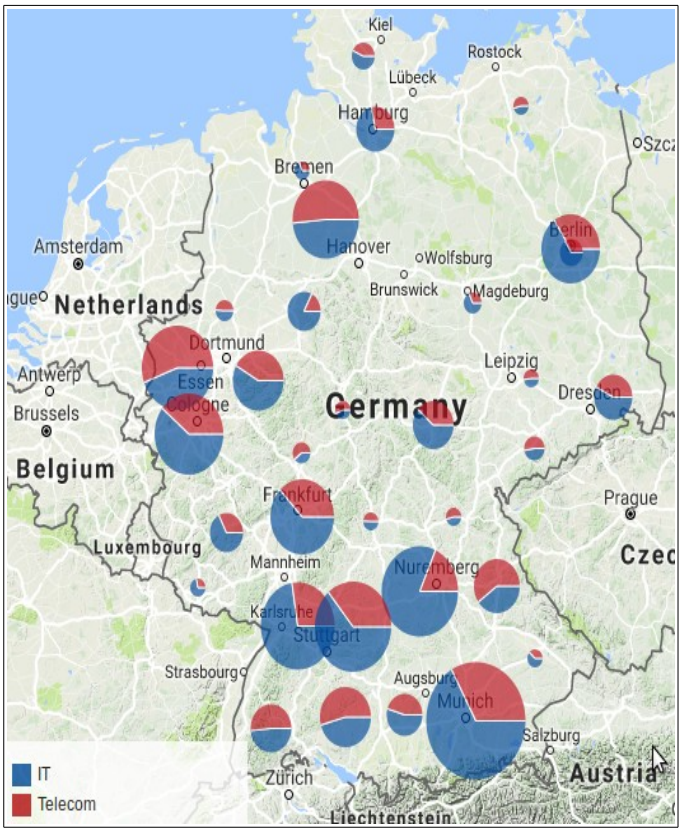
- trading (in consumer or capital goods, data or information),
- brokerage (e. g. for stocks, raw materials or valuable art objects),
- intermediation (e. g. of car rides, rental apartments, prepared food or employment – from click jobs to jobs for top executives)
- or whatever kind of transactional activity like searching, comparing, evaluating, auctioneering etc. (Stein 2015).

This explains why the ties between transaction industries and the digital industries are so close. In fact, large parts of digital industries perform basically transactional tasks (cf. AT Kearney 2010). In the financial industry with its globally integrated markets, banking and other financial activities are only possible with huge inputs from computer programming and telecommunication, especially in activities like brokerage, payment processing or high frequency trading. In the latter, making millions of profits with transactions that take fractions of seconds and concern fractions of cents is only possible with enormous resources of computer hard- and software. Not surprising then that the financial industry figures so prominently among clients of the two digital industries. Digitization is definitely of high and growing importance for technological and production processes as well, for example, in automated and networked manufacturing or for self driving vehicles. In these processes, however, digital technologies serve as means to an end. In the examples it is the manufacturing of tangible goods and the transportation of humans or cargo. Digitization in these processes cover a far smaller part of the value chain than in their use for transaction activities.

In recent developments of digital applications like the *blockchain* technology, a large range of transactional activities is fused completely into distributed computerized procedures (EPRS 2017). One of the most widely spread applications today is the virtual currency *Bitcoin*, but there are other applications for trade in diamonds or other valuable goods like energy and securities. Presently, there is an intensive search for further applications as in the *Hyperledger Project*, supported by the Linux Foundation and leading companies from finance, banking and the IT sector.[8]

The close links of digital industries with many transaction industries will contribute to a high degree of co-location between them. According to the 'Cluster Observatory' for the European Union, for instance, the most important 28 clusters of the (rather widely defined) "digital industries" are located in or very close to major metropolises of the respective twelve nation states where large segments of transaction industries are also concentrated (cf. Ketels/Protsiv 2014:49).

Figure 3: **Distribution of employment in digital industries in Germany**



In Germany digital industry clusters are distributed slightly more dispersely, but still the largest concentrations of employment exist in large metropolises, as the Cluster Observatory shows. Stuttgart and Munich stand out with 163 600 and 156 400 employees in digital industries, followed by Karlsruhe (111 900), Cologne (92 900), Nürnberg (83 600) and Berlin (67 400). Again, this distribution of employment in digital industries shows strong similarities with the distribution of employment in the transaction sector.

In a city like Berlin, that was and became national capital once again and that still attracts numerous firms of the transaction sector, especially many from advanced producer services, the linkages between firms from these industries and digital industries support a process that one might label as "digital metropolization", the rapid structural change in favor of these industries (Stein 2014, 2015).

(Source: Ketels/Protsiv 2014)

4.3 Science, research & development and human health: Special linkages – special placement

Science, research & development: Sciences on the fringe, R&D close to main clusters

Besides digital industries, activities of research and development – above all in the fields of technology and natural sciences – appear to provide a secure basis for future metropolitan economies. This is mainly because many institutions (e. g. universities, research institutions or high tech firms) carrying out research and development (R&D) are located in metropolitan areas and it is these activities that can result in the emergence of innovative

8 See: https://www.hyperledger.org/about

products or production processes that foster regional economic growth. In the present study *engineering , architectural services & technical testing* and the *sciences* represent these activities.

The *human health* industry is also discussed in this context, since its has relatively close links to the sciences and otherwise very special input-output relationships.

In general, *engineering* (EnT) output is delivered to a wide range of industries, but industries from manufacturing prevail among the customers. In the graph of the inter-industry linkages, engineering is placed on the left fringe of the manufacturing cluster, indicating its relatively close ties to the production of tangible goods. To be accurate, 39% of its engineering output is demanded by manufacturing, only 15% by transaction industries.

The three largest output shares are all delivered to manufacturing industries, demanding almost equal portions of engineering services: to the machinery (4.73%), electrical equipment (4.70%) and chemical industry (4.5%). All three high technology industries need large inputs continuously from engineering to develop and manufacture new products.

The share of engineering output that the sciences demand is relevant (2.8%), but not very high. Even the public sector receives a larger share of supplies (3.7%) from engineering. Hence, the economic links between applied science (engineering) and basic research (the sciences) are not very strong, when measured this way. Engineering services are mainly required by various high-tech manufacturing industries, but a number of other industries also utilize such expertise.

While up until now the perspective was on how output of industries is distributed over other industries and sectors (the rows of the input-output matrix), the perspective is reversed for the *sciences* (Sci). By definition, the sciences in the data base do not appear as a supplier of output to other industries. All output from the sciences is regarded as internal demand. But the sciences do appear as a recipient of outputs from other industries, so that inter-industry linkages in this case will be looked at from that side. For which industries then are the sciences an important customer? To answer this question, one has to examine the column for sciences in the input-output matrix.

Starting with the two large sectors, it is obvious that sciences are relatively unimportant for both. Only 0.4% of total output of manufacturing is supplied to the sciences, in the transaction sector it is 1.1%. Among single industries included, education shows the by far the strongest linkages, delivering 8.3% of its output to the sciences. The next strongest interlinked industries are: Publishing (3.3%), air transport (3.0%), employment services (2.8%) and engineering (2.8%).

With such a diversity of linkages, the placing of sciences on the right border of the network comes as no surprise. There are no particularly strong ties to engineering or manufacturing, as one might assume, but rather to industries belonging to or being situated within the transaction cluster. Among those education stands out, showing a rather close relation between knowledge creation and dissemination, that probably works in favor of urban regions. Otherwise, clear spatial consequences of this linkage structure of the sciences, limited by the data to the input side, can hardly be derived. They might be easier to deduct if the sciences would be subdivided into different domains like social sciences and natural sciences.

The spatial effects resulting from input-output relations of engineering can be better described. As outlined before, there are – most importantly – very strong links to manufacturing, mainly to high technology industries. In many cases economic exchange between these industries developing and producing innovative high-tech goods will be small in scale – especially in early phase of production cycles – and will have complicated specifications. Thus, it will be relatively costly per unit. To lower such costs, firms will tend to cluster in space, contributing to the unequal distributions of these industries across national territories.

A look at the spatial distribution of employment in R&D in Germany that may be used as a proxy for employment in engineering and high tech manufacturing, reveals that this category of employment is in fact distributed very unequally (Stifterverband 2016) over the 96 spatial units of Germany. When measured in relation to total employment, R&D personnel is above all strongly over-represented in the South of the country:

- In the South of Germany nine more or less highly agglomerated regions attain shares of R&D employment larger 20%, three of those more than 30% (Stuttgart, Darmstadt/Starkenburg, Ingolstadt and Munich). Five other regions in the South still report values above 15%.
- In the North only one region (Braunschweig/Wolfsburg) reports more than 30% R&D employment. And there are only two other regions with values above 15%. In the East of Germany there is not a single region that falls into any of these categories.
- And, in Germany's largest two and highly agglomerated cities, Berlin and Hamburg, the share of employment in R&D is only between 5 and 10% of total employment. Similar values are reported for many rural regions of the country.

R&D employment is then obviously much less important in these large metropolises, than in a whole range of less agglomerated mainly Southern cities and regions. The strong linkages of R&D to manufacturing, that is concentrated primarily in smaller cities and less agglomerated regions (see 4.1), appear to be of prime importance for this spatial distribution.

Human health: Specific linkages favor the emergence of health complexes

Human health (HuH) is the ultimate industry (considered here) that is characterized as knowledge-intensive. It shows a very high share of internal demand. About 75% of its output are delivered to the human health industry itself, indicating a highly developed division of labor with many specialized firms. Beyond that only the sciences require a larger share of supplies from human health (2.5%) and these supplies (256 MM) are the only ones that exceed the 200 MM threshold, that was applied in the analysis.

In the graph human health is located in the manufacturing cluster, which seems questionable. However, there is an extremely strong linkage to the pharmaceutical industry (Pha) that supplies a huge amount (1 326 MM) and the by far largest share its output (22%) to human health and thereby 'draws' it into the manufacturing cluster. Given the high internal demand of the pharmaceutical industry (67%) and the absence of any other appreciable interlinked industries besides the sciences, receiving 1.3% of pharmaceutical output, these three health related industries can be seen as a sub-group in the network with very specific properties.

Looking at the real word, numerous 'health complexes' in metropolitan areas can be found which are formed by institutions from human health, the pharmaceutical industry and the sciences & academia. As, for example in Germany, where Berlin and its surroundings are home to numerous such institutions. These include e. g. the *Charité* – supposedly Europe's largest University Hospital – and about 130 other hospitals, ten research institutes of various scientific institutions (e. g. Max-Planck and Leibniz Institutes) conducting research in life sciences, about 30 pharmaceutical firms and many other companies and institutions[9]. Similar complexes exist in other countries, like the *Massachusetts General Hospital* with the *Harvard Medical School* in Boston (USA), the *Pierre and Marie Curie University* with its three teaching hospitals in Paris (France) or the *Imperial College Healthcare* with medical partner institutions in London (UK).

Such complexes are very important for employment creation in their regions and the health related industries they consist of are highly interlinked and dependent on each other. They probably enjoy extensive agglomeration economies and allow significant knowledge-spillovers to occur. The linkages to industries beyond the health sector, however, seem to be comparatively weak.

9 Cf. http://www.healthcapital.de/gesundheitsregion-b-bb/daten-fakten/

4.4 Other industries: Public administration, education, accommodation & food: strongly linked to ´basic´ industries

While much research has recently been done about the locational changes in knowledge-intensive industries, far less attention has been devoted to other industries. Although some of these, like public administration, education, accommodation & food services, are also very important for urban development and offer employment for huge segments of the labor force. When exploring in how far the input-output relations of public administration and education might exert an influence on the fabric of the space economy, one should recall that locations in these realms are strongly influenced by central place structures. The locations are spread across national territories largely according to the distribution of the population, but higher level institutions are located primarily in higher ranking cities.

In the network, *public administration* (PAD) appears as a part of the transaction cluster. About 27% of its total output is delivered to diverse transaction industries, especially to law, accounting & consulting (6.8%), real estate (5.3%) and administrative services (3.5%). Much less of its output (19%) is directed at manufacturing, widely spread across many branches.

At the same time the public branch is an important - in one case absolutely dominant - consumer of inputs from other industries. The sporting, amusement, recreation industry (SAR) delivers an enormous 40% of its output to public administration. And education still delivers 12%, accommodation and food 9%, air transport 8% and publishing 8% to public administration. Demand from public administration consequently contributes significantly to output of many industries. The predominance of supplies to transaction industries, the strength of ties to cultural industries and to education result in its positioning close to the transaction cluster.

Recalling the reasoning that was put forward to define the transaction sector (Section 3.1), this position of public administration in the network of linkages seems consequential. The role of the public sector or the state is not only to provide 'public goods' like education and security but also to coordinate the interplay of many of different institutions: public (e. g. local and state, federal bodies), private (trade unions, employers associations, lobby groups), mixed institutions (parties, health insurances) and other ones. These coordinating functions of the public sector take place on a higher, societal level but are in essence similar to transaction activities of the private sector and in many cases connected to those. Relatively strong linkages between those two spheres can hence be expected. They materialize where a lot of firms and institutions of the industries involved are located, as for example, in many capital cities of federal states in Germany, like in Munich, Stuttgart or Hanover and also in the national capital, Berlin.

Education (Edu) is an extremely diverse field, since it encompasses all educational institutions, from kindergartens and ubiquitarily available basic public education to universities as well as private enterprises, teaching a large range of different capabilities. The interpretation of the linkage structure can, therefore, be only tentative.

As opposed to public administration that has only a share of 5% of internal demand, almost half (47%) of education services output is directed at other educational institutions. Externally, the by far largest share of output from education is demanded by public administration (12%). The next most important demand comes from: the sciences (8%), the financial industry (4.8%), the motor vehicle industry (4.2%) and computer programming & information services (4.0%). With its output being structured in this way, the placement of education in the upper part of the network is not without logic.

While the large shares for public administration and the sciences are not surprising, since education is a 'public good' and the state controls its provision, the sizable shares of the financial and motor vehicles industry come rather unexpectedly. The important role of computer programming is, however, not astonishing given the fundamental role that digitization presently plays. These shares reflect the importance of the sciences and the other

three industries in the German economy and their large demand for education, training and continuous adaptation to changing qualification needs.

The locational requirements of higher level educational institutions (e. g. a qualified and multilingual workforce, high level physical and communication infrastructure, cultural amenities) draw them into highly agglomerated regions. In addition, education can be viewed as a form of investment for future success of humans or companies and as such it is struck with high uncertainty and often transactional complexity as well. Therefore, economic exchanges between education and the industries demanding its output will be eased tremendously when they locate in close proximity.

Many metropolitan regions all over the world show by example, how higher level or specialized educational institutions and digital or financial industries function as drivers of the economic well being of their regions. Needless to mention the role that *Stanford University* played in the formation of Silicon Valley as a global center of the digital industries. Many academic institutions in New York City offer classes and grades that enable students to work in or for financial industries. So do the *Frankfurt School of Finance & Management* and the *House of Finance of the Goethe University* in Frankfurt (Germany).

As Figure 1 shows, the *accommodation & food* services industry (AcF) is placed on the lower fringe of the transaction cluster. Its importance for urban economies derives from its relation to tourism and travel, since traveling – whether for private or business purposes – creates an high demand for many services and goods. Of this industry's output, only 13% are directed at the manufacturing sector, but 37% at the transaction sector, where wholesale receives most (8 p.p.) of that share, followed by membership organizations (6 p.p.) and finance (5 p.p.). Among all industries, however, the largest demand for supplies from accommodation & food derives from air transport, receiving 13% of total output alone. Hence, these two industries are located rather close in the graph of linkages. Similar to demand from membership organizations and finance, the large demand from air transport results primarily from the needs of business people that travel a lot or consume food and accommodation services frequently. Adding to that, comes demand from growing numbers of tourists consuming such services occasionally. The second largest share of demand for accommodation and food (9%) derives from public administration, probably related to such services for public institutions.

Looking at the input side of accommodation & food, this industry has significant linkages to manufacturing, mainly and logically to food & tobacco, supplying an huge amount (7 200 MM) and the absolutely largest share of its output (16%) to accommodation & food services.

This industry is on the one hand highly connected to clients – be they firms, tourists or business people – from rather globalized segments of the economy like air transport, finance or other transaction industries. On the other hand accommodation & food services is tied closely to suppliers, located often in the same region because fast and reliable deliveries, e. g. for fresh food, are frequently required.

Metropolitan regions usually house a lot of firms of these industries and equally many trading firms in such areas. The interplay of these firms can create significant economic advantages, allowing e. g. greater degrees of specialization and more efficient service provision than in less denser regions. They contribute important shares to metropolitan economies and employ large numbers of workers. Though, most of them have comparatively simple qualifications (waiters, guards, cooks, cleaning personnel etc.) and rather low incomes, thereby, increasing polarizations tendencies in metropolitan regions.

It appears that it is a general feature of these ´other industries´ that they are rather strongly interlinked with some ´basic´ industries, the industries that are part of the export base of urban economies.

4.5 Transportation & logistics sector: Mostly highly interlinked industries – and air transport as a special case

The latter, the rather close connection to basic industries, holds true for several industries classified into the sector of *transportation & logistics,* too. These industries are grouped somewhat contiguous in the upper right part of the network and embrace: *Land transport* (LTr), w*arehousing & other services for transportation* (WST), w*ater transport* (WTr) and *postal and courier services* (PoC). They are in part highly connected to each other via output chains, such as land transport shipping most of its output (21% resp. 13 429 MM) to warehousing.

And these industries are also closely interlinked to a number of other industries, some from manufacturing (Motor vehicles, food & tobacco), but most from trade related industries: Retail, wholesale and trade & repair of motor vehicles. Thus, the second most important recipient of output from land transport is wholesale, receiving 19% of its deliveries, only a little less than warehousing.

Taken together these industries form an own subgroup crossing sector borders. It accounts for a huge amount of output from transportation & logistics industries, mainly dealing with the physical movement of goods, a lot of them bulk products. Many firms of these industries locate in less denser regions – in suburban areas or beyond – because they need of lot of space for their activities and good access to traffic infrastructure. And also, because the coordination needs with customers, i.e. transactional relations, are, in general, not very demanding when compared to many other inter-industry relations.

There is, however, one industry belonging to the transportation sector that shows a quite different output structure and is not part of that subgroup. This is *air transport* (ATr), delivering the two largest shares of its output to two manufacturing industries, to the machinery (9.7%) and the computer, electronic and optical products industry (8.7%). The third largest share (8.4%) is demanded by public administration, followed by the motor vehicle industry (5.0%) and finance (4.3%), where the latter share amounts to an output of 256 MM in absolute numbers. While these linkages are not large in absolute terms, compared to the transportation industries described before, they presumably represent higher per unit value inter-industry transactions.

With the great significance of high-technology and transaction related industries in its output structure, Air transport is located close to those industries in the left middle part of the network. High-tech industries today depend on inputs from production facilities distributed across the world and much of this input is of high value. The financial industry, being highly internationalized, and as it seems public administration too, have a large demand for air travel. Be it qualified personnel, important documents or valuable products that are transported via air travel, it is a fast and expensive way of transportation connecting cities and regions from all over the world. Many of these activities are located in or close to large metropolitan regions.

Table 3:

Internal output of industries

No.	Industry	Euro *(Million)*	Share* of output for own industry (%)
1	Food & tobacco	25.977	57,9
2	Textiles, apparel & leather	3.000	67,1
3	Paper	9.350	41,9
4	Printing	2.393	14,3
5	Chemicals	60.612	77,6
6	Pharmaceutical	4.011	66,9
7	Metal products	21.622	30,3
8	Comp., elec. & opt. prod.	3.253	30,7
9	Electrical equip.	13.725	41,8
10	Machinery	29.851	67,3
11	Motor vehicles	85.653	92,2
12	Other transport equipm.	4.935	55,0
13	Furniture	750	28,0
14	Trade & repair of motor vehic.	1.813	5,1
15	Wholesale	4.227	4,1
16	Retail	630	1,4
17	Land transp.	4.905	7,8
18	Water transp.	500	19,4
19	Air transp.	288	4,9
20	Warehousing	27.029	26,4
21	Postal & courier serv.	214	0,7
22	Accommod. & food	37	1,1
23	Publishing	1.759	6,8
24	Aud.-vis., music publ., broadc.	5.319	47,1
25	Telecommunication	15.105	45,7
26	Computer prog. & inform. serv.	28.031	43,5
27	Finance	18.891	23,2
28	Insurance	3.611	14,5
29	Serv. to fin. & insur.	2.533	8,4
30	Real estate	14.402	10,5
31	Law, account. & consult.	20.256	18,9
32	Engineering	2.163	6,0
33	Sciences**	1.110	100,0
34	Advertising	107	0,6
35	Professional Serv.	442	3,3
36	Rental & leasing	11.888	22,1
37	Employment serv.	141	0,5
38	Travel agency	16.168	74,9
39	Administrativesupp. serv.	2.064	3,4
40	Public administration	2.031	4,8
41	Education	7.324	47,3
42	Human health	7.658	75,3
43	Arts, culture & gambling	1.723	28,8
44	Sporting, amusem. & recreation	2.787	38,0
45	Membership organis.	11	0,1

**) As percenatge of total inter-industry output*
***) Per definition all output of sciences is 'internal' output*

Source: Destatis (2017), own calculations.

5. Summary and conclusions

The phenomenon that certain industries concentrate in certain regions is a basic feature of the space economy in developed countries, be it manufacturing industries in the industrial districts of North-Central Italy, cultural industries in Hollywood or advanced producer services in central business districts of many large metropolises across the world. In Germany auto manufacturing in Stuttgart, the cluster of cultural activities (e. g. media, art, entertainment) in Berlin and the financial sector of Frankfurt/Main provide examples of such specialized urban regions with a massing of specific industries. In all these cases it is not only the concentration of these dynamic industries with their intensive 'internal' – with the same industry – exchanges and relations but also the forward and backward linkages of these industries with many other industries that lead to the emergence of agglo me-

ration economies. These highly complex effects of inter-industry linkages and concomitant knowledge-spillovers are fundamental for urban and regional development but difficult to trace empirically because of methodological difficulties and since detailed and regionalized data are rarely available.

Presently policy makers in many urban regions focus on supporting local concentrations of knowledge-intensive industries, like high-tech manufacturing, advanced business services or digital industries, for fostering economic growth, mostly without fully understanding the complexities of inter-industry linkages and the resulting economic effects. The work presented in this exploratory paper is a first attempt to study and map inter-industry linkages for the German economy with an advanced program for network analysis and visualization. By applying *Cytoscape* (3.5.1.) to explore the structure and intensity of the most important input-output linkages of 45 industries, a network of clusters and industries is created that indicates, where major interrelations of industries exist that are favorable for the generation of agglomeration economies. In this way the paper also provides a deeper understanding of the social division of labor and how it presently changes through digitization and what spatial implications might ensue. In order to limit the complexity of the network, only the five strongest linkages are used that exceed the threshold of 200 MM Euro. Thus its structure, the interrelations of various sectors and single industries, can still be understood visually and interpreted. But to be sure, there is no single best way for creating and interpreting that network.

For the discussion of the results the 45 industries are grouped into three large main sectors (manufacturing, transaction and culture). In addition there are the smaller groups of industries: engineering and sciences, the two digital industries and human health. While the former industries are all considered as knowledge-intensive, the following industries also examined are not: public administration and education, accommodation & food services and the transportation & logistics sector, consisting of five single industries.

The following results for sectors and industries can be deducted from the network analysis:

- In general, there is a rather broad congruence between the assignment of industries to the sectors (manufacturing, transaction, culture and transportation & logistics) of the classification used and to the clusters that are identifiable in the network of inter-industry linkages. But there also clear divergences, concerning industries of one sector being closer interlinked with industries from another sector.
- Many industries in the ***manufacturing*** sector (e. g. motor vehicles, machinery and chemical industry) have relatively high shares of internal demand, indicating a pronounced division of labor. At the same time, they are particularly closely connected through input-output linkages, showing the close ties of many of these industries and the high significance of manufacturing in the German economy. Yet, there are also some transaction industries, mostly providing lower qualified services (e. g. employment services) strongly connected to manufacturing. Less strong linkages exist to industries that provide higher qualified services of the transaction sector, like law, accounting & consulting. This structure of linkages points at a comparably high importance of *localization economies* – benefits accruing from the location of firms of the *same* industry or sector, in many manufacturing industries.

  The strong interdependence of many manufacturing industries, their need for efficient and uncongested transportation infrastructure and extensive land resources, due to the predominance of single-storey buildings in production, draws most firms into less dense regions and smaller cities. Empirical examinations by Burdack and Hanewinkel (2016) show that it is in fact overwhelmingly second tier cities of the 71 largest cities in Germany that are specialized primarily in manufacturing. Obviously, the lower density environment of these 14 'smaller large cities' offers more favorable conditions for most manufacturing industries than the very large cities with their vast areas of densely populated or otherwise intensively used land.
- The same empirical examinations document that most of the very large cities of the country are specialized above all in industries that are clearly part of the ***transaction sector***. This applies to 32 cities specialized in producer services, finance and renting. Another 23 cities are specialized in other services, of which, some

would also have be considered as part of the transaction sector. In the network of linkages, transaction industries appear as a distinct cluster, though not as strongly interlinked as manufacturing and with important linkages to other industries and sectors.

The core of the cluster contains two industries of the FIRE sector – *finance* and *real estate* – but also law, accounting & consulting, wholesale and retail trade. Many other transactions industries are likewise interwoven with this core of the cluster, for example membership organizations, travel agencies, professional services, insurance and publishing. With these industries, the economic base of many inner cities of metropolitan areas, characterized by high concentrations of multi-storey or high-rise office buildings including e. g. company headquarters, is pretty much delineated. Many employees in most of these industries receive above average or very high salaries.

- Additionally a rather wide *mix of industries* is integrated more or less closely into the transaction cluster through input-output linkages. As opposed to manufacturing, where localization economies appear to be more significant, transaction industries are therefore probably more dependent on *urbanization economies* – benefits deriving from the size of a city and its common resources and from the location of firms from *different* sectors or industries. Among these industries, there is (a) public administration exhibiting very strong ties to different transaction industries, and also to sporting, amusement & recreation and to education. (b) Education, in turn – in contrast to public administration – has a rather high share of internal demand and is relatively closely linked to the sciences. Then there is (c) the accommodation & food industry, situated on the fringe of the transaction cluster, indicating important ties to some of its industries. So is (d) air transport, that is the single most important user of output from accommodation & food. These input-output linkages point at the needs of people that use consumer services during work or leisure time, as employees, business people or tourists. Metropolitan areas encompass huge concentrations of firms providing these services, many of them with rather low qualified and low paid employees.

  One industry belonging to manufacturing is also part of the transaction cluster. This is (e) the printing industry, which has very strong linkages to transaction industries, demanding altogether over half of its output. This output incorporates the printed 'hardware', mostly on paper, still essential in spite of ongoing digitization for the growing amounts of information processed in transaction industries. Parts of the printing industry, like firms producing time sensitive or high quality products in small batch sizes, will therefore be located close to their customers in metropolitan regions.
- The two ***digital industries*** are as well strongly interlinked with transaction industries, telecommunication even more than computer programming & information services as is signaled by its placement in the graph of linkages. Concurrently, both digital industries have rather high shares of internal demand and significant linkages to many other industries, since digitization and worldwide communication today play, of course, an important role in almost any process of value creation. The fifth largest share of telecommunication output, for example, is delivered to public administration. The corresponding share of computer programming & information output is delivered to the sciences.

  Far larger shares of output, however, are delivered from both digital industries industries to transaction industries: to the financial and the publishing industry, ranking highest in the list of the 5 most important customers of digital industries.

  Especially in the financial industry, it is evident that its business models evolve around the gathering, analyzing, dealing and making use of specific information (e. g. prices and trading conditions of stocks, bonds and securities). In other words: the core of their operations is *information processing*, the activity, that electronic technologies have revolutionized over the past decades and where technological progress continues to create new chances of inventing profitable businesses. Recently, for example, more and more applications of the blockchain technology have been implemented, enabling previously unconnected actors distributed across the world to conduct highly safe transactions of valuable items (e. g. Bitcoins, diamonds or energy) on the basis of

decentralized computer systems. In this case the execution of the transaction and the information processing are almost identical. It is logical then, that industries specialized in transactions, depend more and more on inputs from computer programming & information services and telecommunication. And that these industries choose locations in rather close vicinity, in particular when complicated exchanges frequently occur or when deals often require face-to-face contacts. In Germany, as in the whole of Europe, digital industries are mainly concentrated in the main metropolises, where the important parts of transaction industries are also massed together. Besides using mutual inputs and delivering outputs, firms of both spheres can benefit from significant agglomeration economies and knowledge-spillovers.

The two segments described before, the cluster of transaction industries and the additional mix of various industries, whose partly intense inter-linkages become only discernible on closer analysis, together form some sort of *mega cluster* in the upper part of the network of linkages, while manufacturing industries concentrate in the lower part. Most industries of this mega cluster have a strong affinity to metropolitan regions as concerns their locational requirements and in reality many of them are overly concentrated there. They encompass a large part of the "output of agglomerations" that Storper (2011), as cited in the introductory section, requires to be better identified.

- As is apparent in the graph of linkages, this mega cluster further shows significant ties to the ***cultural industries***, of which two are strongly connected to it and the third looser. Still, the three industries form an own little cluster and its strong output relations to some of the other industries of the mega cluster (e. g. to publishing or to public administration) will enforce factors that pull firms of these industries to locations in relative proximity of their customers and suppliers. This explains at least partly, why a lot of large metropolitan areas in Germany and other countries are very highly specialized in cultural activities.
- Among knowledge-intensive industries ***engineering*** and the ***sciences*** play a specific role. Many cities and regions promote especially these activities, expecting significant regional growth effects, primarily through positive effects on innovations in other industries, in particular high-tech manufacturing. And, as a matter of fact, close to 40% of engineering output is demanded by manufacturing. Ties between these industries are very intense. Besides these linkages engineering output shows a wide distribution across other sectors and many industries.

Ties to the sciences appear comparatively weak, even public administration demands more engineering output. This might, however, be due to the fact, that the sciences in the given data set are not differentiated, at least, between social and natural sciences. On the input side a relatively strong link exists between engineering and law, accounting & consulting, an important transaction industry.

Yet, in total, the output linkages of engineering to manufacturing dominate and pull this industry close to the manufacturing cluster. One can conclude that this dependency between engineering and manufacturing hampers in many cases efforts to re-industrialize urban regions, which have lost their industrial base, through the promotion of R&D activities. Manufacturing firms need a large net of specialized suppliers that usually cannot be built up from scratch. Expectations that publicly supported regional R&D will automatically lead to an increase in regional manufacturing jobs will thus often be futile.

In Germany very high shares of R&D employment, which is strongly related to engineering and high-tech manufacturing, are mainly found in the South of the country. In the federal states of Baden-Württemberg and Bavaria some regions with large cities, but also many regions with middle-sized and smaller cities, exhibit particularly high levels of R&D-employment. In these cities and regions, the intensive exchange between engineering and manufacturing industries supports regional specializations in manufacturing and sustainable competitive advantages for numerous high-tech industry clusters. On the other hand, in the two largest German cities, in Hamburg and especially in Berlin, R&D shares are comparatively low and manufacturing industries play, apart from some exceptions (e. g. smaller high-tech or design-intensive and ´non-basic´ rather locally oriented industries), a minor role.

- But Berlin, similar to more metropolitan areas in Germany and beyond, provides an example for another complex of heavily interlinked knowledge intensive industries. It evolves around ***human health*** that demands about one fifth – hence a very large share – of the output produced by the pharmaceutical industry and thereby 'pulls' human health into the manufacturing cluster of the graph. Both industries are, in addition, relatively closely linked to the *sciences* and have high shares of internal demand. Under these conditions, dense regional health complexes can come into existence, as is the case in Berlin. Such complexes consist of numerous companies and firms from these three industries, including hospitals, universities and research institutions, benefiting from cooperation with each other. Albeit, selected strong linkages within such complexes seem to coexist with rather diffuse and weak linkages beyond them.
- Many knowledge intensive industries mentioned so far in this summary require above average or relatively high qualifications for a large part of their workforce and pay corresponding wages. The opposite is true for some activities subsumed under the label ***other industries***. One of those is accommodation & food services, some other ones (e. g. land transport or warehousing) belong to *the transportation & logistics sector*. Many industries of transportation & logistics are strongly interlinked with each other and jointly with trade related industries they form a subgroup in the network of linkages. Because of the huge spaces and well equipped infrastructure that many of these industries need they are often located in less denser areas or regions.

  But this subgroup does not contain air transport. Air transports delivers the largest shares of its services to some high tech industries and, somewhat surprising, to public administration and the financial industry. On the input side, it is the single most important user of services from accommodation & food. That industry is also strongly linked to public administration and some transaction industries. Accordingly, air transport and accommodation & food are situated at the fringe of the transaction resp. mega cluster described above. These linkages point at firms in or close to metropolitan areas where large airports are located and many other firms serving the needs of companies from knowledge intensive industries, like transporting valuable items or people – like business people, but also tourists – and delivering other personal services that these people consume.
- For further research it would be particularly useful if regionalized data were available and also, for a number of industries (e. g. digital industries and the sciences), further subdivisions would be highly desirable. With such data input-output structures of different regions could directly be compared, numerically and visually. In general, linkages between manufacturing industries will be stronger in industrial regions, than was shown in this analysis. The same holds probably true for linkages between transaction industries in metropolitan areas. But, as was shown, there are many deviations from this simple characterization. And it is worth studying the real linkage structure of industries since they have deep repercussions on spatial structures and development.

Literature

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