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Disentangling agglomeration and network externalities: Conceptual typology illustrated by the geography of globalized producer service firms

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Abstract

Agglomeration- and network externalities are fuzzy concepts. When different meanings are (un)intentionally juxtaposed in analyses of the agglomeration/network externalities-menagerie, researchers may reach inaccurate conclusions about how they interlock. Both externality types can be analytically combined, but only when one adopts a coherent approach to their conceptualization and operationalization, to which end we provide a combinatorial typology. We illustrate the typology by applying a state-of-the-art bipartite network projection detailing the presence of globalized producer services firms in cities

in 2012. This leads to two one-mode graphs that can be validly interpreted as topological renderings of agglomeration and network externalities.

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Keywords: Agglomeration externalities, Network externalities, world city research, network analysis, fuzzy concepts

1. Introduction

One of the main debates in regional science in the last decades concerns the choice of 'appropriate' spatial units and the relevance of 'interaction' between these spatial units. Are cities, regions, or other types of agglomerations the crucial geographical units of analysis if we want to understand economic development or is it better to focus on the interactions between these units – i.e. networks of regions, cities and agglomerations – to fathom this conundrum? Testimony to the relevance of this discussion, which is now over 25 years old, is that it is addressed in some of the most heavily cited papers in the spatial-economic sciences in the 1990s and the 2000s (e.g Amin and Thrift 1992; Bathelt et al. 2004). Yet, the argument sometimes seems to be a needle stuck in its groove, with conclusions becoming somewhat repetitive in spite of obvious progress in methods and data quality (e.g. Ducruet et al. 2011; Camagni et al. 2015; Liu et al. 2015).

There appears to be a consensus in the literature that both agglomerations and their inter-connections matter, separately as well as conjointly. However, in spite of this consensus, which takes on the form of a ‘stylized fact’, actual research on how (much) and why this matters generates a fair dose of controversy. For instance, scholars still puzzle over the causal direction between the development of agglomerations and inter-agglomeration networks (Rozenblat 2010; Neal 2011, 2012a; Pain et al. 2015). Similarly, it remains unclear whether interaction patterns between the two remain stable over time. Furthermore, the findings are differently interpreted: is the importance of 'networks' in the equation the result of the business cycle (Neal 2012a; Camagni and Capello 2015), or rather structurally related to new technological paradigms (Castells 1989, 2000; Camagni 1993; Neal 2011)? Although these are all pertinent questions and debates, they risk becoming unproductive once there is ambiguity regarding the research object (van Meeteren et al. 2015): as soon as polyvalence arises in terms of how we understand what an ‘agglomeration’ or what a ‘network’ is, and how these are spatially articulated, the debate becomes muddled. Adding to the confusion is that these fundamentally academic questions tend to get adopted by policy makers as they start considering urban size and/or urban network connectivity as policy goals to allocate scarce public resources (van Oort et al. 2010; Rodriguez-Pose and Fitjar 2013; Pain et al. 2015).

The debate about agglomeration externalities, network externalities, and their interactions is held across disciplinary boundaries, but as a research problem it most pertinently speaks to regional science. As the problem is both policy-laden and multi-disciplinary, regional science’s explicitly interdisciplinary focus can help build a common vocabulary to debate the issue at hand (Isard 1960). The issue that needs to be tackled if such a vocabulary is to be developed is 'observational equivalence' (Overman 2004): how can we know which aspects of this 'stylized fact'– namely, that agglomeration and network externalities both matter – explain our observations? McCann (2007, p.1218) makes the case for tackling observational equivalence by applying 'quantitative approaches using the methodological rigor and internal consistency' that he associates with regional science. Although we concur with McCann (2007) that a more rigorous and consistent application of methods would foster a better understanding of what Johansson (2005) has aptly called the 'menagerie of agglomeration and network externalities', observational equivalence can never be resolved across studies by rigorous and consistent methods alone as long as the underlying concepts remain fuzzy. As put forward by Markusen (1999, p. 702), a fuzzy concept

> 'posits an entity, phenomenon or process which possesses two or more alternative meanings and thus cannot be reliably identified or applied by different readers or scholars. In literature framed by fuzzy concepts, researchers may believe they are addressing the same phenomena but may actually be targeting quite different ones.'

As the conceptual frameworks that exclusively address agglomeration or network externalities are already fuzzy among scholars and disciplines, attempting to combine both perspectives compounds the issue, as one may have to choose between incompatible building blocks. The prime purpose of this paper is to make the case for a coherent approach to the conceptualization and subsequent empirical operationalization of combinations of agglomeration and network externalities. Rather than formally testing the relative importance of both perspectives and their interaction in an econometric exercise, the empirical focus is on exploring how such a coherent conceptual approach might look like in practice. To this end, we present a topological perspective on agglomeration and network externalities that can be discerned in intra-city and inter-city complexes of globalized producer services firms.

The remainder of this paper is organized as follows. Based on a review of the fuzziness of the notions of agglomeration and network externalities (Section 2), we argue that existing juxtapositions can – in addition to their commonsensical referents as cities and city-networks – be understood through three different dimensions (which coincide with different disciplinary traditions): an industrial-organizational dimension (market versus network), a spatial-economic dimension (gravity-type versus archipelago-economy type interactions), and a geometrical dimension (topological versus projective geometry). Rather than advocating a 'correct' combination, Section 3 emphasizes that undue juxtapositions may lie at the basis of much of the confusion in the literature. A meaningful combination of the different approaches thus requires a coherent framework. In Section 4, by means of illustration, the utility of the typology is explored through developing one possible combination of agglomeration and network externalities. Through elaborating the topological perspective on both externality types, we infer some of the decision-making rules used by globalized firms to choose where to locate their branch offices. We apply Neal's (2014b; 2014c) stochastic degree sequence model to data detailing the relative importance of 175 producer service firms' branch office locations in 526 cities in 2012, as presented in Taylor and Derudder (2015). This produces two one-mode graphs that can be interpreted as topological renderings of agglomeration and network economies, respectively. The relevance of this approach is subsequently demonstrated by discussing a number of tangible examples. Section 5 draws conclusions.

2. Agglomeration and network externalities as fuzzy concepts

2.1 Cities and networks of cities: theoretical selection criteria

Building a theoretical framework that combines agglomeration and network externalities requires compatible building blocks. However, before we are in a position to identify these, we need to specify how to benchmark the available options. Two considerations are important here: (1) the degree of empirical correspondence with a geographical observable research object ('cities' within 'networks of cities'), and (2) the level of analysis (firms versus the wider geographical environment impinging on these firms).

When we think of the world as a 'network of agglomerations', a commonsensical geographical association of a multitude of connected cities is invoked. Although it would be an empiricist or a 'naive objectivist' (Sayer 1992, p. 44) fallacy to assume that such a commonsensical observation automatically corresponds geographically and theoretically to a research object, we nevertheless agree that a practically adequate degree of correspondence between a commonsensical sign/signifier and its theoretical referent is important (Sayer 1992, pp. 55-84; Gregory 1994, p. 12). Thus, a first important selection criterion of our conceptual building blocks is whether a degree of reference to the commonsensical notions of 'city' and 'network of cities' can be retained.

The second consideration concerns the appropriate level of analysis our theoretical framework should adopt. According to Olsen (2002), the central misunderstanding between economic geography and geographical economics regarding externalities relates to whether the theoretical object refers to the perspective of the individual firm, or to the wider geographical environment in which firms are situated. The associated difference between 'internal' and 'external' agglomeration effects has been widely recognized in the literature (Parr 2002a), and can be understood as the difference between 'agglomeration economies' and 'agglomeration externalities' (Parr 2002a, 2002b). Since we are primarily interested in environmental-level effects that accrue *across* firms we adopt the definitional yardstick that 'externalities or spillovers occur if an innovation or growth improvement implemented by a certain enterprise increases the performance of other enterprises without the latter benefiting enterprise having to pay (full) compensation' (Burger et al. 2009, p. 140).

2.2 Agglomeration externalities

Over the years, many scholars have formulated different city-scale externality categorizations that suited their respective research questions at that moment. The resulting typologies crosscut one another and tend to have different geographical referents (Gordon and McCann 2000). We first analyze the two canonical taxonomies and associated ideas regarding their geographical footprint: the typology initially put forward by Ohlin, Hoover and Isard (Isard 1956), and the one initially put forward by Marshall (1920 [1890]). This is followed by a discussion of a number of notable alternative categories: MAR externalities, Jacobs externalities, and a family of 'complexity externalities'.

We commence with Isard’s (1956, p. 172 *paraphrased*) elaboration of the Ohlin/Hoover taxonomy. It concerns a tripartite classification of agglomeration economies consisting of (1) large-scale economies, which refer to scale advantages for the individual firm at an individual location; (2) localization economies, which refer to the benefits accruing to a single industry at a single location; and (3) urbanization economies accruing to all firms in all industries at a single location. Here we disregard the first type since we are interested in economies outside the boundaries of the firm (i.e. externalities, see Moulaert and Djellal 1995; Parr 2002a). Note that in Isard’s formulation the taxonomy is not mutually exclusive: localization economies are a subset of urbanization economies. Moreover, there is vagueness in this definition regarding the geographical scale of the phenomenon, where each effect refers to a nondescript ‘location’. Although Burger et al. (2008), following McCann (1995), argue that localization economies tend to have a smaller geographical scale than urbanization economies, Isard's ‘nested’ definition does not warrant such a claim solely based on geographical properties. For instance, a specialized amenity only relevant for particular sectors such as a port might have a spatial range that is far beyond a specific city (Parr 2002b). Moreover, too tight a focus on industrial sectors might obscure observations of sector emergence or coalescence (Neffke 2009). However, defining agglomeration externalities solely for specific sectors does give advantages when operationalizing the concept empirically. For instance, Duranton and Overman (2005) find that locational clustering associated with a localization economy mostly takes place at small scales under a distance of 50 km even though the intensity and degree of effect will most likely differ across sectors (McCann 1995).

The Ohlin-Hoover-Isard typology cuts right across the other canonical typology put forward by Marshall (1890 [1920]), which discerns agglomeration externalities based on ‘labor market pooling’, ‘input sharing’, and ‘technological spillovers’ (Rosenthal and Strange 2003). Although Marshall mentions these externalities in a treatise of specialized sectors, which are therefore sometimes considered a specification of localization economies (Rosenthal and Strange 2003; Burger et al. 2009), there is no inherent mechanism that restricts Marshall's three mechanisms to specific sectors: a shared, or thick, labor market can cut across sectors, as do shared inputs (e.g. infrastructure) and information spillovers. The Marshall typology has been fruitfully applied in work that engages with the spatial dimension of agglomeration externalities, as the three mechanisms commonly allow for identification of spatial thresholds (Rosenthal and Strange 2003). For instance, labor market pooling tends to adhere to the spatial scale of functional urban areas based on commuting patterns, while the technology spillovers based on close-knit interaction is generally present solely on a very small neighborhood-level scale (Larsson 2014). By contrast, inter-firm interactions might define a larger scale outside the bounds of the administrative city, which are nevertheless geographically constrained (Phelps et al. 2001). Hence, agglomeration-externality fields, defined with whatever typology, consist of various mechanisms operating at different scales. This makes the ‘agglomeration’ a unit with a variable geometry, where certain effects overlay several cities while others are confined to more local environments (Lang and Knox 2009).

Over time, authors have made additions and/or proposed alternatives to these canonical typologies. Without the pretention of being exclusive, we mention a few others that have come to play a major role in theorizing the relation between agglomeration and network externalities. First, there is the MAR versus Jacobs externalities debate which concerns the question whether related or unrelated industries foster knowledge-based competitiveness (Glaeser et al. 1992; Henderson 1997; Neffke 2009). MAR-externalities (named after contributing theorists Marshall, Arrow and Romer) are a specification of localization externalities that attribute knowledge and innovation-related externalities to intra-industry dynamics (Glaeser et al. 1992). Jacobs (1969) externalities, in turn, theorize innovation to be the result of interaction between diverse industries. Furthermore, some authors propose another urbanization-externality mechanism that refers to a specific kind of uncertainty reduction for firms located in that region. Parr (2002a, 2002b) calls these 'economies of complexity', while McCann (1995) describes them as a family of 'hierarchy-coordination' effects and Moulaert and Djellal (1995) as 'economies of overview'. Although all of these conceptualizations, henceforth addressed as 'overview externalities', differ slightly in their elaboration, they have one crucial feature in common: they posit that large cities, on account of their knowledge- and/or size-related possibilities of recombining and retooling assets across markets and sectors, offer enhanced benefits to firms located in that city.

2.3 Network externalities

In its most basic guise, the concept of a 'network' refers to an observable pattern of 'linkages' between 'nodes', the ensemble of which can be directly or indirectly examined using the tools of graph theory. Although interest in ‘networks’ in geography and regional science dates back to at least the 1960s (e.g. Nystuen and Dacey 1961; Haggett and Chorley 1969; see Poorthuis 2015 for a recent overview), we can observe a surge in interest in the concept since the 1990s: references to ‘urban networks’ have grown dramatically in the scientific literature (Neal 2013a), and these networks are currently explored within many social but also natural science disciplines (e.g. Bettencourt and West 2010). Research now extends over many scales of analysis from the intensely local formation of social networks (e.g. Hipp et al. 2012) to the global formation of transnational economic networks (e.g. Alderson and Beckfield 2004).

It is not easy to identify why ‘networks’ and ‘network analysis’ have entered our collective analytical toolkit, as very different kinds of interlocking processes seem to have played a role in its popularization. For instance, urban network research commonly but patchily refers to the relevance of information and knowledge being routed through branch location networks of enterprises (Pred 1977; Rozenblat 2010; Taylor and Derudder 2015), the densification of telecommunications, airline and high-speed rail networks fostering increased but uneven time-space convergence (Janelle 1969; Castells 1989, 2000; Veltz 1996; Zook and Brunn 2006), and the vastly increasing depth and spatial extent of trade and investment networks in an increasingly globalized and urbanized economy (Dicken 2011). Observing these processes, scholars were increasingly interested in determining how, why and which economic interactions were affected by uneven patterns of time-space convergence. Moreover, they tried to make sense of relations that remained spatially proximate in the face of the ostensibly declining relative importance of distance (Amin and Thrift 1992; Bathelt et al. 2004). Altogether, these developments converged in a research agenda concerned with the generic phrase 'urban networks'.

Whatever the lineage of the ‘network’ concept, it is clear the concept is now commonly deemed useful for making sense of cities and regions. To be analytically sensible, any network perspective implies that the object of inquiry can be fruitfully related to that perspective (Neal 2014a). In the case of externalities, for instance, an economic perspective could highlight utility considerations about the costs and benefits of being connected to a network. Network externality perspectives thus tend to focus on the extent to which benefits of one entity being connected to the network spill over to the other entities. Katz and Shapiro (1985) provided a first formulation of network externalities in which they examine goods where ‘the utility that a user derives from consumption of the good increases with the number of other agents consuming the good’ (Katz and Shapiro 1985, p. 424). For example, they discuss telephone and ICT infrastructure (cf. Capello and Nijkamp 1995) where ‘the utility that a given user derives from the good depends upon the number of other users who are in the same “network”’ (Katz and Shapiro 1985, p. 424).

Camagni (1993) and Capello (1996, 2000) have proposed a similar notion of ‘network externalities’ to understand the economic benefits associated with inter-city interactions. They emphasize that benefits accrue on the level of the city production function as inter-city networks deliver ‘synergies’, and ‘complementarities’ (Camagni et al. 2012; cf. van

Oort et al. 2010): where connections between cities lower transport costs and times, and as information between places travels first and foremost through the people communicating through these networks, all sorts of asymmetries between cities emerge based on their level of connectivity to other cities (Neal 2011). These asymmetries can often be related to infrastructure, for example with the classic (spatially uneven) lowering of costs and increased utility when a place is connected to an infrastructure network (Zook and Brunn 2006; Ducruet et al. 2011). However, most applications of network externalities engage with knowledge asymmetries. Overview externalities, for instance, thrive on localized knowledge asymmetries that are theorized to induce agglomeration of economic activity (Amin and Thrift 1992; Moulaert and Djellal 1995; Bathelt et al. 2004; Liu et al. 2015; van Meeteren and Bassens 2015).

Similar to agglomeration externalities, the problem of observational equivalence looms large when specifying a network externality mechanism. That two different phenomena can be meaningfully represented in a network does not mean they automatically refer to the same object. The question thus remains to what extent inter-governmental collaborations, inter-firm networks, airline and maritime networks, etc. add up to a generalized 'urban networks' concept (Nystuen and Dacey 1961). How much 'isomorphism' or' 'homology' between networks do we need to identify before two different phenomena are considered part of the same urban network (e.g. Choi et al. 2006; Tranos et al. 2014)?

3. A combinatorial typology for agglomeration and network externalities

3.1 Three disciplinary perspectives on the menagerie

Despite the varied building blocks used for understanding agglomeration and network externalities, scholars from several scientific disciplines have attempted to meaningfully combine them. Given the variety of possible starting points sketched above, compounded variation and hence fuzziness is to be expected. Nevertheless, we argue that the different disciplinary positions and the main dimensions they highlight do not preclude meaningful classification and subsequent comparison of 'agglomeration' and 'network' and different axes of analysis have been proposed to that aim. We discern three different perspectives (Table 1): an industrial organization perspective, a spatial-economic perspective and a geometrical perspective. We do not have a preference for any of these axes of analysis. Rather, the disciplinary perspectives are different ways of carving-up the same empirical reality into different scientific objects. The merit (or the lack thereof) of each of these combinations needs to be assessed on its own terms. They cannot assumed to be generalized notions of the agglomeration/network externalities-menagerie. The typology serves to emphasize that any juxtaposition will benefit from a conscious combination of the different axes of analysis, as it decreases fuzziness without disregarding the contributing disciplinary traditions.

Table 1. Combinatorial typology of agglomeration and network externalities

Axis of analysis	Agglomeration	Network
Commonsensical association	City	Network of Cities
Industrial organization perspective	Public good	Club good
Spatial-economic perspective	Gravity-type interaction	Archipelago economy-type interaction
Geometrical perspective	Projective geometries, e.g. Euclidian geometry	Topology

3.2 The industrial organization perspective

Many different conceptualizations of networks could have been used to complement the perspective on agglomeration externalities in regional science. However, it is the analysis of city networks based on industrial relations and transaction cost theory that initially grabbed the attention of economic geographers and regional scientists (Camagni and Capello 2004; Grabher 2006). This 'industrial organization perspective' is the first dimension through which we will unpack the agglomeration/network menagerie. The industrial organization perspective on networks emerged out of dissatisfaction with the ideal-typical dichotomy of 'markets' (unplanned coordination) and 'hierarchies' (completely planned coordination) in theories of the firm (Richardson 1972; Powell 1990). Industrial organization theory claims that stable 'network' relations between firms are an important backbone of the economy, and are even becoming more important as the industrial system becomes more flexible: buyer-seller relations are governed by trust and stability rather than by price competition alone. Therefore, being part of a network of interlocked firms enhances the efficiency of the economic system as a whole (Powell

1990). From the perspective of the firm, being part of the industrial network is a 'club good' rather than a public or private good, where semi-excludability and the right balance in number and quality of participants determine the economically optimal outcome (Buchanan 1965). Being embedded in a network conveys certain advantages to participants (Granovetter 1985): it opens up the network externalities to those who are part of the club (Capello and Nijkamp 1996). In analogy to this industrial organization perspective on the level of firm networks, an up-scaled distinction has been proposed for city networks as a club good (Capello 1996, 2013; Camagni et al. 2015). In this perspective, being part of an inter-city network conveys network externalities to the participating cities that complement the endogenously created agglomeration externalities. Again, a crucial aspect of this conceptualization is the excludability, or the 'club good' character of the network externalities: only some cities can participate (Capello 1996). As a corollary, agglomeration economies are non-excludable and hence 'a market' (Johansson and Quigley 2004): by being located in the city, by simply 'being there' (cf. Gertler 1995), a firm can reap the advantages. Cast in Bathelt et al.'s (2004, pp. 40-41) metaphorical language of 'local buzz and global pipelines', the local 'buzz' is ubiquitously accessible to all locally-present firms, but cities' participation in the 'global pipelines' requires some sort of conscious effort.

Although the industrial relations perspective provides important insights as to why certain inter-city relations are present and others not (e.g. it would clearly be useful to explain the above-average connections between major international financial centers such as New York and London), two inconsistencies appear when we try to project this perspective on the commonsensical definition of cities and inter-city networks. The first inconsistency is that many of the clubs we intuitively think of when considering the externality literature are profoundly local: whether it is Granovetter's (1985) diamond traders or industrial districts and clusters (see Powell 1990 for an overview), many of the archetypical networks to which the theory applies are in fact intra-urban. Second, in urban economics there is a modeling tradition that explicitly conceptualizes agglomeration externalities as a club good (Rosenthal and Strange 2003). In this tradition, in order to isolate the effect of presence of agglomeration externalities, location in a particular city is modeled as membership of a club. In other words, every city is conceptually 'nodalized': assumed to be a monocentric nodal region with its own hinterland (Nystuen and Dacey 1961; Parr 2002, 2014). If a firm wants to accrue the agglomeration-externality, it has to bear the operating costs of presence in that nodal region, which indeed can be modeled through an analogy of paying club membership fees. These two inconsistencies show that a conceptualization of the agglomeration-network menagerie singularly based on the governance analogy of markets and networks is insufficient. A spatial-economic dimension, in which distance plays an instrumental role, has therefore been put forward as well (Camagni and Capello 2004).

3.3 The spatial-economic perspective

A second way to distinguish between agglomeration and network externalities is by observing that the former attenuate with distance (e.g. Gordon and McCann 2000; Parr 2002a, 2002b; Rosenthal and Strange 2003; Johansson 2005). Since this attenuation effect is traditionally modeled in a gravity-type model, Camagni (1993) has suggested naming this kind of interactions 'gravity-type interactions'. It is argued (e.g. Castells 1989, 2000; Camagni 1993; Batten 1995; Veltz 1996) that the technological possibilities offered by consecutive information- and communication-technological revolutions have made different kinds of interactions between localities more prevalent: those where distance does not matter anymore. Castells (2000, p. 14) describes this mechanism as 'the technological and organizational possibility of organizing the simultaneity of social practices without geographical contiguity.' Noteworthy examples of such interactions mentioned by Camagni (1993) are financial city networks where transactions are virtualized, tourist cities connected through cultural or historical 'itineraries', or innovation networks between connected industrial sectors. Rodriguez-Pose and Fitjar (2013), following Veltz (1996), suggest the term 'archipelago-economy interaction' for inter-city interactions where distance does not matter (cf. van Meeteren and Bassens 2015). Camagni (1993; Camagni et al. 2012; cf. Batten 1995) proposes to reserve the term 'city networks' for relations between cities of such an archipelago-economy interaction type. Taken together, this suggests we can define the spatial-economic dimension of both types of externalities as follows: agglomeration externalities are defined as externalities that attenuate with distance, while networks are externalities where the effect of distance has become negligible. This distinction has been fruitfully applied in empirical research (e.g. Bentlage et al. 2013; Camagni et al. 2015, Pain et al. 2015).

It is important to note that 'gravity-type interactions' and 'archipelago-economy type interactions' are ideal-typical poles on a continuum where the exception – that of global financial networks – might be dictating the rule. For instance, many of the city-network externalities described in the literature on polycentric urban regions (Hall and Pain 2006; Meijers and Burger 2010; Van Oort et al. 2010) do attenuate with distance. The fact that the cities of the Randstad are on average 55 kilometers apart is causally significant. And even Castells (1989, p. 110) mentions that a three-hour plane ride to Silicon Valley was an important distance threshold facilitating the emergence of new industrial spaces in the American west in the 1980s. Of course, if a plane is the only available mode of transport, by virtue of the networked structure of the air-travel system, one could still make this cost/time attenuation endogenous to an urban network analysis (Zook and Brunn 2006; Matisziw and Grubesic 2010). This kind of analytical move, which involves assuming that an urban concentration can be treated as a point location (Parr 2002b, p. 727), i.e. nodalization, is widespread in research on agglomerations in networks. For instance, any study abstracting a dichotomous 'proximity' variable to indicate agglomeration is in fact nodalizing, albeit often implicitly (e.g. Amin and Thrift 1992; Bathelt et al. 2004). Moreover, once 'geographical proximity' is substituted for more sociologically defined proximities (Torre and Rallet 2005; Boschma 2006), research loses its geographical anchor altogether. However, as Parr (2002b) notes, the larger our study area, the more questionable the nodalization assumption becomes and the more an appreciation of distance attenuation might be relevant (van Meeteren, 2013). Therefore, whether abstracting locations into a nodal region is a valid reduction of rich geographical information is ultimately an empirical question.

3.4 The geometrical perspective

The issues of information reduction, geographical description, and comparability bring us to the heart of the geometrical issues involved in denoting agglomerations and networks. That two different phenomena can be meaningfully represented in a network does not mean they automatically refer to the same thing. This is why Burger et al. (2014a, 2014b) insist that urban networks are multiplex, i.e. the effects and reach of urban networks differ from network to network. Multiplexity in this sense is the conceptual analogue of the 'variable geometry' in agglomeration externalities. Both agglomeration- and network-externality effects have a geographical instability to them. Nevertheless, different sets of agglomeration or network effects are often tied together by appealing to geographic referents (cities and networks of cities). By appealing to a geographic referent, we refer to the geometrical properties we associate with the city and network form. In the case of a city, a specific place and configuration on the earth's surface is invoked which we associate with Euclidian geometry: the specific projective geometry that is fairly accurate for describing distances up to 250 miles and resonates with our commonsensical perception of space and objects located in that space (Harvey 1969, p. 224). In the case of a network, we appeal to topological geometry: a more basic geometry that focuses on connectedness (Bunge 1966; Harvey 1969).

Regional scientists are not the only scholars trying to make sense of externalities. Importantly, there has been a recent surge of interest in measuring the importance of externalities by physicists seeking to 'solve' the city mathematically using network analysis. Bettencourt and West (2010), for instance, have observed universal scaling in cities, and argue that the degree of scaling can be analytically derived from the topological properties of branching distribution networks. However, in our view, these kind of attempts to devise a unified 'theory' of cities clashes with the insights of Sack (1972), who has made the case that it is logically impossible to derive social substance from a theory or model that merely consists of geometrical properties. There is, therefore, no such thing as spatial laws that have economic or sociological validity on their own terms. The fact that we can fruitfully model different spatial interactions with a geometrical model derived from an analogy with the laws of gravity does not mean there is a 'universal law of gravity that applies to socio-spatial systems', giving people a propensity to attract (Lukermann 1958). The underlying monist idea that theories of physics can explain both human and non-human worlds is scientifically contentious (Barnes and Wilson 2014). Similarly, the fact that we can model different social phenomena as networks (infrastructure, information networks, office networks) does not automatically imply that there is a 'social law of networks'. At best, a network model or a gravity model with a good fit provides analogies that inspire a scientist to construct theories drawing on a *substantive* mechanism that subsequently proves practically adequate for a research endeavor (Barnes 1996; Mair 1986); non-substantive models are insufficient as an explanation on their own terms (Sheppard 1978). Hence, irrespective of the analytical rigor and exciting innovation in research on 'typical' network structures such as 'small world networks' and 'scale-free networks' (Ducruet and Beaugitte 2014), ultimately these typical networks need to be backed up by a plausible social-scientific theory or mechanism in order to count as explanation (Neal 2013b, 2014a; Taylor and Derudder 2015). Consequently, geometry should be considered primarily as a language that we can use to describe spatial forms (Harvey 1969, p. 192). Different geometries allow us to describe different properties of the same object while they similarly render other properties out of view. Thus, from a geometrical perspective, describing an object as ‘a network’ or ‘an agglomeration’ is merely a choice of language based on its presumed efficacy for a particular application (van Meeteren and Bassens 2015).

This brings us to the key question of what geometrical language suits what kind of research problem. Harvey (1969, p. 218) expects 'topological theorems to be applicable to geographic problems if the geographical problem itself can be realistically and successfully be stated in terms of connectedness’. Therefore, if connectedness is the focus, describing the city and the network of cities as nested networks is a viable research strategy (Rozenblat 2010; Neal 2013a). When the choice of geometry is primarily a choice of language, ‘nodalizing’ becomes a translation from projective geometry in topology (Bunge 1966). However, such a seemingly efficient topological perspective also has drawbacks. Topological perspectives tend to reduce the amount of information in the description compared to a projective geometry such as Euclid’s, even though techniques for reducing such information loss are emergent (Hoff et al. 2002). Specifically, the distribution of objects that are difficult to describe in terms of connectedness can inadvertently be rendered out of view. Conversely, projective geometry is particularly helpful to map properties of objects that are best captured by a notion of a ‘field’. A Field denotes a sphere of influence in a two dimensional area between a center and its periphery. Fields are 'theoretically continuous distributions with a very rapid fall-off near their center and a very slow, almost asymptotic fall-off at their outer ranges' (Haggett

1965, pp. 40-41). Analyses of potential of population and accessibility (Stewart and Warntz 1958; Sheppard 1979), with subsequent applications such as deriving potential markets (Harris 1954) and prices (Warntz 1957) are renowned applications of field analysis. Many topics associated with spatially attenuating phenomena – labor markets, central place market areas – concern in fact field properties (Phelps et al. 2001) and are hence difficult to fully grasp with topological perspectives.

3.5 Towards a consistent combination of agglomeration and network externalities

In this and the previous section, we have reviewed the intricacies associated with a coherent approach to the conceptualization and subsequent empirical operationalization of (combinations of) agglomeration and network externalities. In addition to the confusion that may arise from an incoherent combination of conceptual dimensions in Table 1, effective combinations are often further compromised by limitations induced by the available data sources. One obvious way in which data-based inconsistencies can be sidestepped is by using a single dataset. In the next section, therefore, we present an example that achieves this particular kind of consistency: we analyze 'cities as networks within networks between cities' (Neal 2013b after Berry 1964) by using a bipartite dataset detailing the co-presence of branch locations of globalized producer services firms in and across world cities. This allows us to simultaneously operationalize agglomeration and network externalities using the identical dataset and method.

Cast in our typologies discussed, this implies we will make the following choices in our combinatorial typology. First, by opting for graph analysis on the city and city network levels, we abstract both into topological language. Hence, we assume that in this case, both the city and the network of cities are best described as nodalized. On the level of inter-city interactions we assume that archipelago-economy interactions sufficiently capture the dynamic while for the inter-firm interactions we assume a co-location dummy of proximity sufficiently accurate to speak about potential agglomeration externalities (subject to a significance test). Whether our interactions on the city or network levels are public (market) goods or club (network) goods depends on the barriers of entry to the producer services economy. Since this would require an institutional analysis of this particular sector, we cannot make definite statements on that matter.

4. A topological rendering of the APS economy

4.1 GaWC measures of the APS economy

Our empirical illustration is based on an examination of the producer services economy as explored in world city network analysis. In world city network analysis, advanced producer services (APS) firms are conjectured to be crucial facilitating actors in the global economy (Taylor and Derudder 2015; Bassens and Van Meeteren 2015). It is the office networks of APS firms that relay business knowledge, i.e. overview externalities, between well-connected cities in the global economy. These global networks are assumed to be embedded at the city scale in a strong localization economy where the information is locally decoded, recombined and transmitted (Amin and Thrift 1992, Moulaert and Djellal 1995; Bathelt et al. 2004). Hence, the APS economy is an exemplary case where externalities associated with both the city and city-network levels come together. We first explain the basics of our data and method, after we illustrate results in the next section through a discussion of selected examples.

Data are derived from the research carried out in the context of the Globalization and World Cities (GaWC, http://www.lboro.ac.uk/gawc) research network. GaWC was formed in the late 1990s to advance our understanding of the changing worlds of cities under conditions of contemporary globalization. Its core business has been to more narrowly focus on one conspicuous topic in research on globalized urbanization: the external relations of world cities. Following early inventories of world cities based upon their *level* of advanced producer services (Beaverstock et al. 1999), most of GaWC's quantitative research has been premised upon the application of the 'interlocking *network* model'. The interlocking network model (INM) essentially provides an empirical specification of Allen's (2010, p. 2898) observation that 'city powers are mobilized through inter-city networking in financial and business services.' To this end, a universe of producer service firms located in world cities is defined. The elemental measure is a service value v_{ij} with information on the importance of the presence of firm j in city i. These observations can be arrayed as service value matrix V. In the most recent 2012 GaWC data gathering, the data comprises standardized measures of the relative importance (ranging between 0 if a firm has no presence, and 5 for the global headquarters of a firm) of the branch locations of 175 service firms in 526 cities (for more details, see Taylor and Derudder 2015).

In network analysis, the service value matrix V is commonly termed a two-mode network (Liu and Derudder 2012; Neal 2012b). In contrast to one-mode networks, where actors are directly linked, a two-mode network is characterized by connections between two separate sets of nodes. In this case, V is a network connecting cities with firms, respectively. In the initial specification, there is no direct linkage within the same set of nodes: we simply know which firms are in what cities, and which cities house what firms. However, it is possible to infer two one-mode networks from the two-mode dataset by applying a 'projection function'. The INM is essentially such a projection function (for alternatives, see Neal 2014a; Hennemann and Derudder 2014). The two-mode to one-mode projection function entails applying a method converting the service value matrix V into a relational matrices R of firm and city interactions, and ultimately draws on seeking out co-presences of firms in and across cities. In most GaWC research, the focus has been on deriving inter-city networks (systematic analysis of the location of branch offices of a firm in specific sets of cities), but the same logic can be applied to intra-city networks (systematic analysis of the presence of branch offices of specific firm networks in a city) (Neal 2008).

The crux of the interlocking network model projection function is (1) the definition of city-dyad connectivity CDC_{a-b} between cities *a* and *b* and (2) the definition of firm-dyad connectivity FDC_{i-j} between firms *i* and *j* based on V:

$$CDC_{a-b} = \Sigma_i v_{ai}.v_{bi} \qquad a \neq b \quad (1)$$

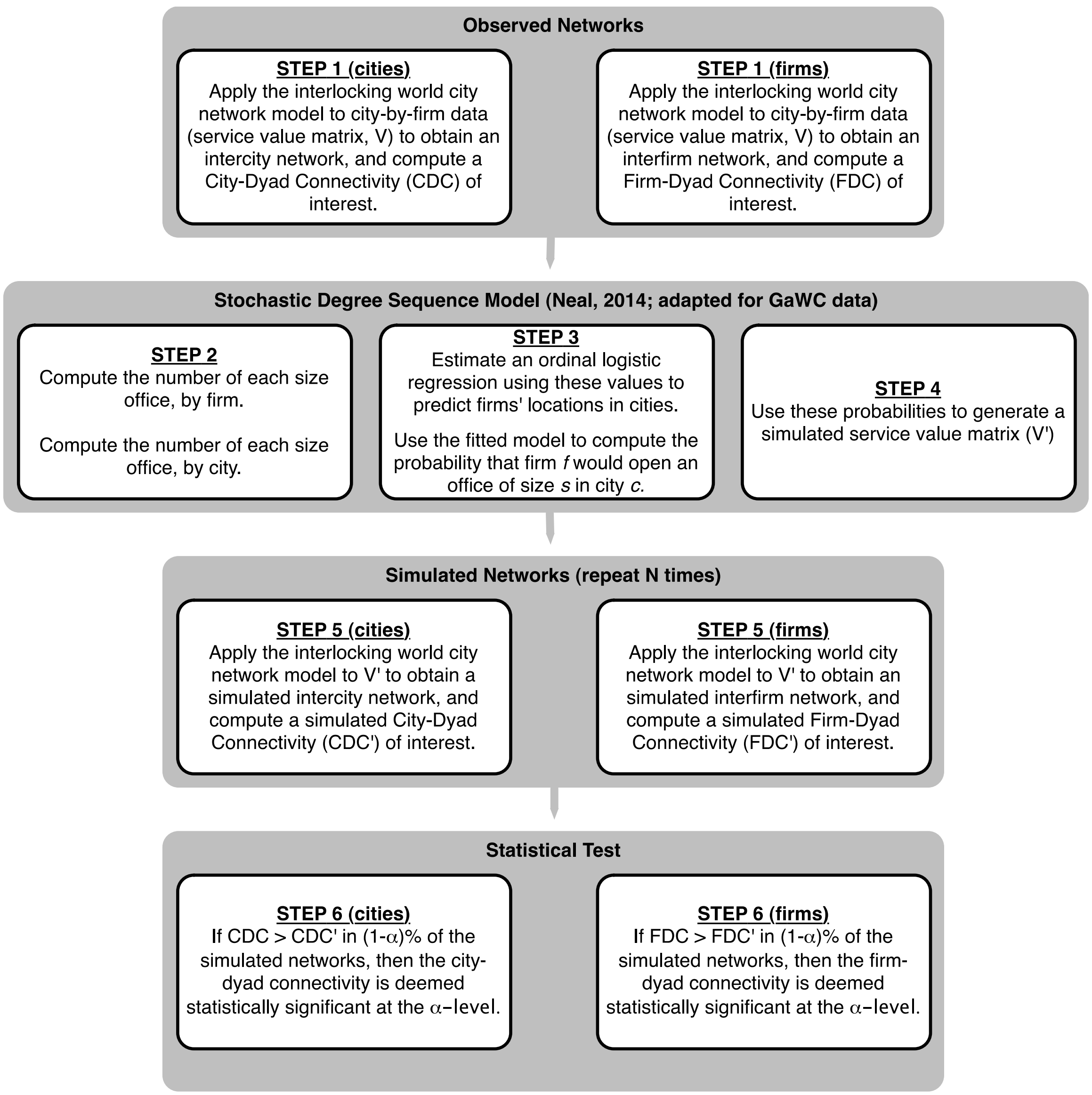
$$FDC_{i-j} = \Sigma_a v_{ai}.v_{aj} \qquad i \neq j \quad (2)$$

Neal (2013c, 2014b, 2014c) has pointed out that results produced by an application of (1) and (2) to the GaWC data, for instance as discussed in Taylor and Derudder (2015), have above all a comparative appeal. For example, inter-city connections are often benchmarked against the New York-London dyad, which is by far the strongest inter-city connection in absolute terms. However, Neal (2014c) argues that a potentially more appropriate comparison for substantiating claims of strong connectivity would be to ask whether London and New York are more highly connected than could be expected based on their massive service complexes, which imply that strong connections in an absolute sense are in fact almost a given. Similarly, systematic co-presence of branch locations of 'The Big Four' in accountancy in cities is to be expected given their blanket-type location strategies (Taylor et al. 2014; Taylor and Derudder 2015, chapter 5). As a consequence, the question becomes whether, say, KPMG-Deloitte tend to be *unusually* frequently co-located in cities given their massive office networks. As argued by Ellison and Glaeser (1997), we can only assuredly speak of externalities when we have significant confidence that the co-presence of firms is due to interaction between those firms and not the result of mere chance.

To address this issue for externalities described in topological language, we draw on the application of Neal's (2014b) stochastic degree sequence model (SDSM) to GaWC data as elaborated in Neal (2014c). The SDSM allows testing the statistical significance of a network statistic (e.g. CDC and FDC) in an observed network (e.g. those produced by the INM) in a sample of random networks that were generated by the same processes responsible for the observed network's development (e.g. firms' site selection strategies). In Figure 1 we summarize the steps involved in applying the SDSM to these data, and here we briefly review these steps so that readers are able to interpret the findings reported below. In the first step, the observed firm and city networks are constructed from a service value matrix, V, using equations (1) and (2) from the interlocking network model. This yields two one-mode networks in which the strength of the linkage between a pair of cities (firms) is a function of the number of firms maintaining offices in both locations (number of cities hosting offices of both firms), weighted by the size of those offices. The second step involves computing the row and column marginals of V, which here are used as indicators of firms' capacity to expand and city's capacity to serve as markets. In the third step, a logistic regression is estimated that predicts the size of each firms' office in each city as a function of these marginal values, then uses the fitted model to compute, for each firm-city pair, the probability that firm *f* would open an office of size *s* in city *c*. In the fourth step, these probabilities are used to generate a simulated service value matrix, V′, which has stochastically identical marginals to V.

Step five involves applying the interlocking network model again, this time constructing simulated firm and city networks from the simulated service value matrix. The generation of a simulated service value matrix, and the subsequent construction of simulated firm and city networks, is repeated many times (in the results that follow, we use 10,000 replications). The final step compares a network statistic from the observed network to the distribution of the same statistic from the simulated networks. For example, a statistical test of the strength of a given city dyad connection (CDC) compares the value of the CDC in the observed network to the values of the simulated CDCs in the simulated networks. If the observed CDC is larger than almost all of the simulated CDCs, then the city-dyad connection is deemed statistically significant.

Figure 1. Outline of the Stochastic Degree Sequence Model



4.2 Results

Our discussion of results is purposively partial: the highlighted cases are illustrative examples, and therefore by no means an inclusive discussion of CDC and FDC patterns around the globe. Rather, our aim of this is to empirically verify the conceptual model of the combinatorial typology and its consistent empirical operationalization by discussing some examples. Figures 2 and 4 display the complete city and firm networks obtained by applying the SDSM to the GaWC data, while figures 3 and 5 display the ego networks for selected specific cities and firms within these networks. All of these figures show a pair of cities (a pair of firms) as linked if their corresponding CDC (FDC) is significant at the $\alpha = 0.001$ level using the SDSM test. We use a conservative threshold for statistical significance here because it yields sparser networks, which facilitates their visualization and interpretation. Substantively, this threshold means that there is a less than one-tenth of one percent chance the links shown were forged between the cities (firms) by chance. Additionally, all of these networks use a spring embedding layout, which highlights the topological rather than topographical relationships among the nodes.

Figure 2. City Network

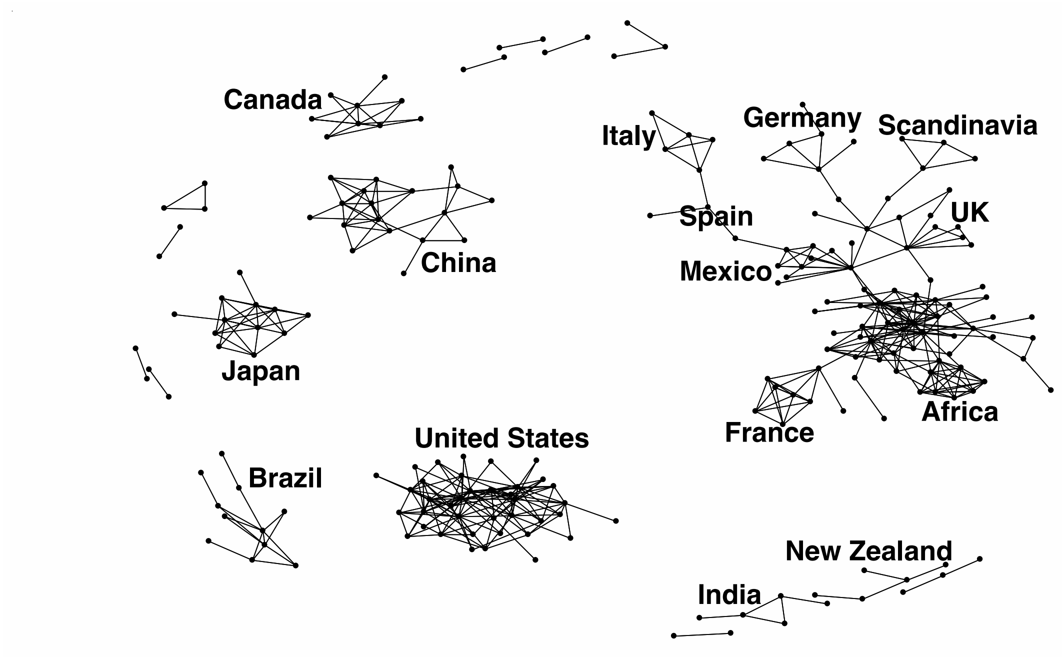


Figure 3. Ego networks of selected cities

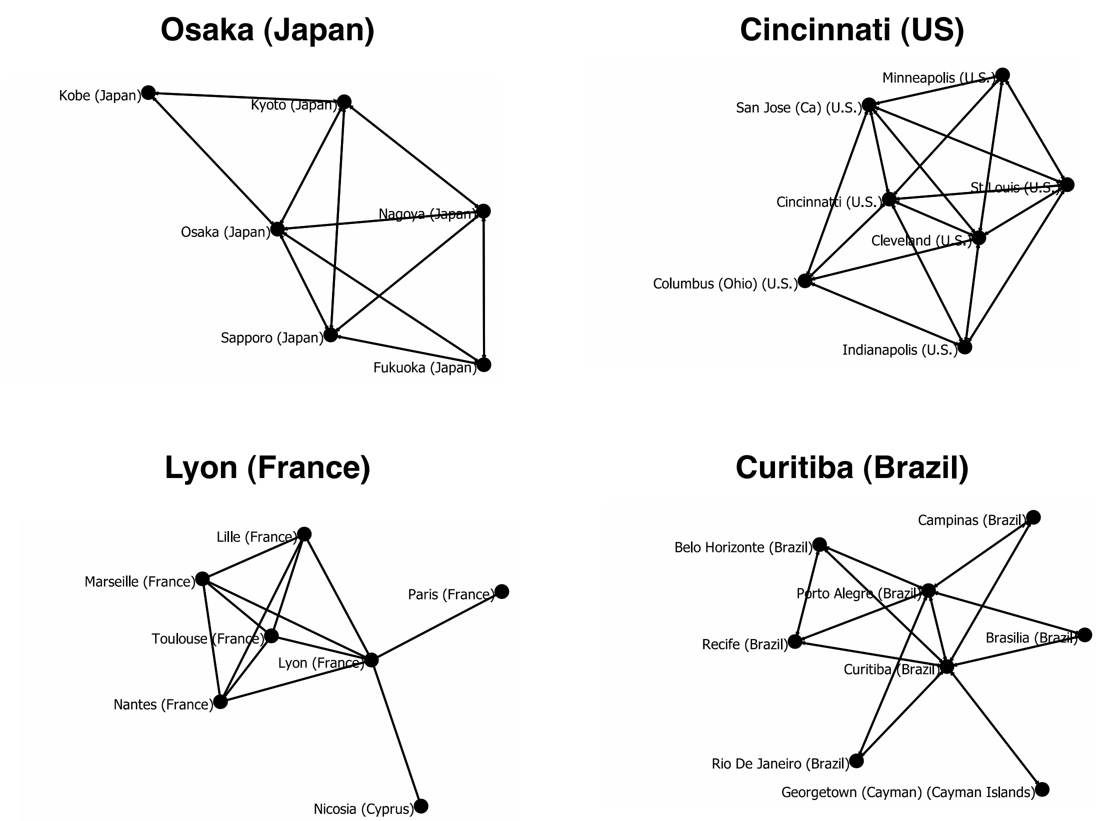


Figure 4. Firm Network

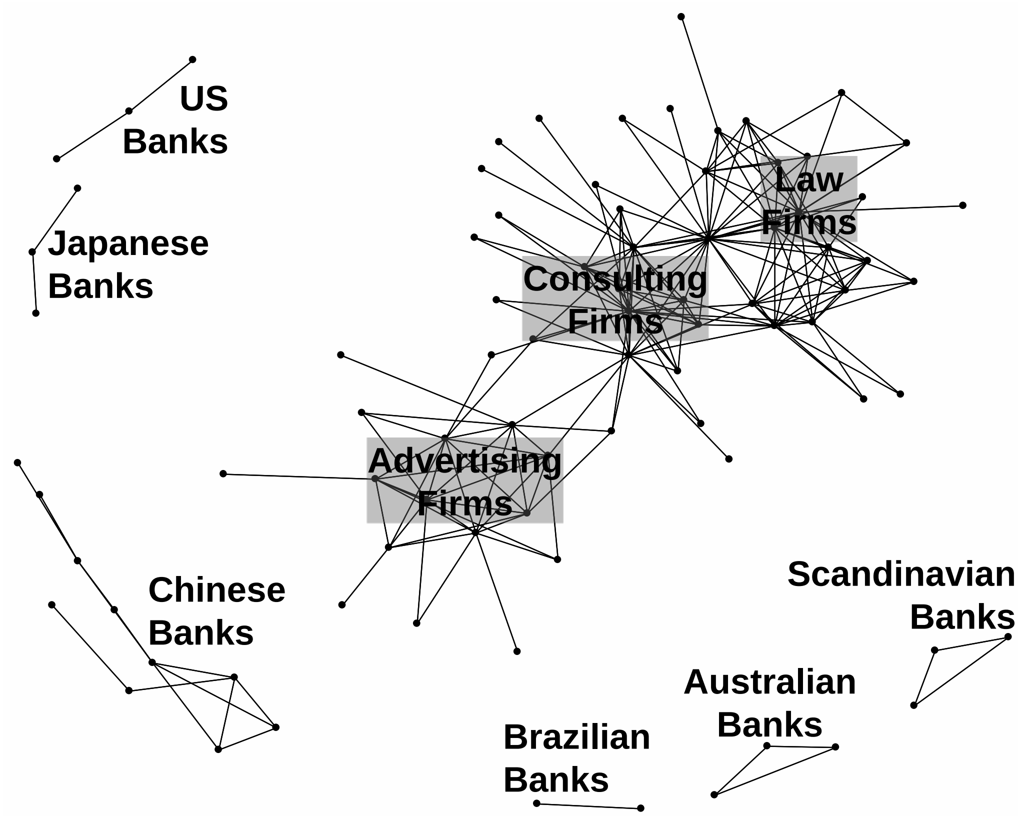
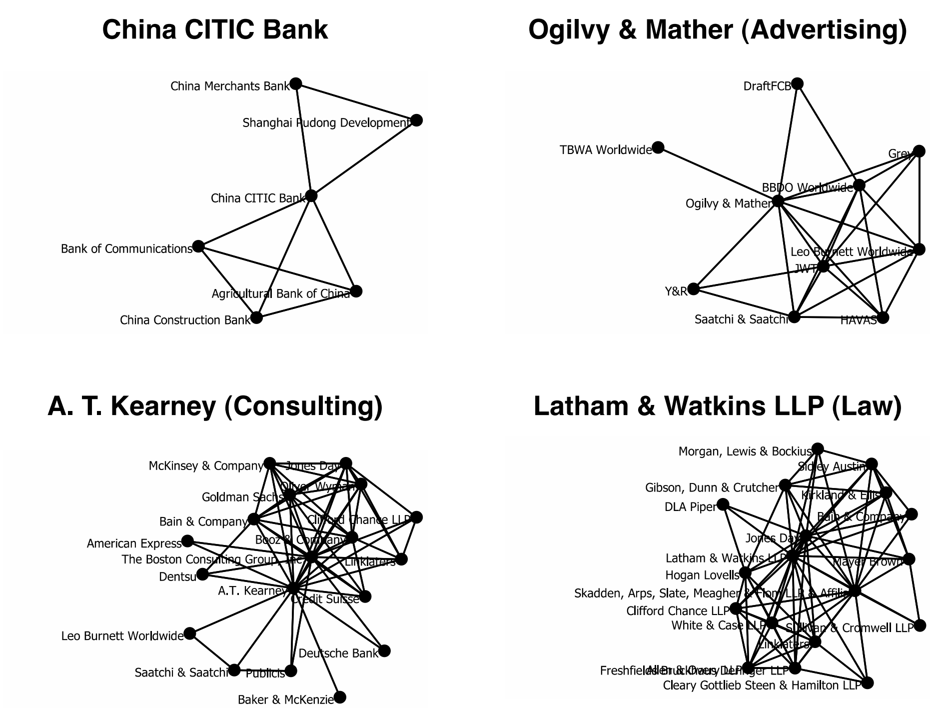


Figure 5. Ego networks of selected firms



In the city network shown in Figure 2, the nodes represent cities, but only groups of nodes are labeled. While this facilitates readability, it also highlights a key pattern in this network: the topology is organized primarily by regional tendencies in general and national borders in particular. Cities in the United States are linked only to other cities in the United States, and likewise for Chinese cities, Japanese cities, Brazilian cities, and so on. The large component on the right displays a small amount of cross-national interaction, suggestive of greater levels of integration in Europe, as well as lingering colonial influence in Mexico and Africa. However, even here nation-based groupings are still quite distinct: French cities are linked *mostly* only to other French cities. These patterns are confirmed, with greater detail, in Figure 3, which illustrates the network immediately surrounding four selected cities: Osaka, Cincinnati, Lyon, and Curitiba. These cities from different world-regions have networks large enough to be interesting, but small enough to be readily visualized, and clearly illustrate that this is the most basic pattern in Figure 2. The Cincinnati case, in particular, highlights that in nations with large numbers of major urban centers, the topological organization is first driven by national borders (Cincinnati is linked only to other US cities), but secondly by regional boundaries (Cincinnati is linked mostly to other cities in the US Midwest) (cf. Tobler 1970).

The patterns revealed in figures 2 and 3 provide clear evidence of *agglomerative tendencies* by advanced producer service firms. But to understand why requires reflecting on what linkages obtained using the SDSM mean. The linkage detected by the SDSM between Cincinnati and Cleveland indicates that firms with branch offices in Cincinnati have more (and larger) branch offices in Cleveland also than would be expected if these Cincinnati firms expanded their branch office networks based only on the attractiveness of candidate cities and the firm's own capacity to operate a new branch office. That is, these Cincinnati firms could have all sought to open offices in New York, or London, or Tokyo; they did not. Instead, they specifically and strategically sought out Cleveland as a branch office site, thereby establishing an intra-national, and indeed in this case intra-regional, agglomeration. Similar stories are told by the SDSM for each linked pair: firms' strategic site selections combine to yield the nationally-bounded agglomerations seen in Figure 2.

In the firm network shown in Figure 4, the nodes represent firms, but only groups of nodes are labeled. Again, while this facilitates readability, it also highlights a key pattern in this network: the topology is organized primarily by sector. Advertising firms are linked mostly to other advertising firms, while law firms are linked mostly to other law firms. Two notable exceptions are evident. First, consulting firms serve as a bridge between the advertising and legal sectors. Specifically, consulting firms are mostly linked to other consulting firms, but are also sometimes linked to advertising firms and sometimes to law firms, though rarely to both. This highlights the functional role of consulting firms in assisting multinational corporations to coordinate business services. Second, banks are not only topologically organized by sector (banks are linked only to other banks), but are also topologically organized by nation: Chinese banks are linked only to other Chinese banks. This likely signals unobserved institutional factors, but it is nonetheless noteworthy that no cross-national linkages are observed among banks. These patterns are confirmed, with greater detail, in Figure 5, which illustrates the network immediately surrounding one example firms in each sector: China CITIC Bank, Ogilvy & Mather (Advertising), Latham & Watkins LLP (Law), and A. T. Kearney (Consulting). The exclusively within-sector linkages are evident in the networks for the first three of these firms. In contrast, A. T. Kearney's network illustrates the linkages to other consulting firms (e.g. Boston Consulting Group, Bain & Company), but also to advertising (e.g. Leo Burnett, Saatchi & Saatchi) and law (e.g. Linklaters, Jones Day) firms.

The patterns revealed in figures 4 and 5 provide clear evidence of *network tendencies* by advanced producer service firms. Again, to understand why requires reflecting on what linkages obtained using the SDSM mean. The linkage detected by the SDSM between Ogilvy & Mather (O&M) and Saatchi & Saatchi (S&S) indicates that O&M has more (and larger) branch offices in the same cities as S&S than would be expected if O&M expanded its branch office network based only on the attractiveness of candidate cities and the firm's own capacity to operate a new branch office. That is, O&M could have sought to open offices in the same cities as A. T. Kearney, or Latham & Watkins, or China CITIC Bank; it did not. Instead, it specifically and strategically sought out to open offices in the same cities as S&S, thereby establishing an intra-sector network of advertising firms. Similar stories are told by the SDSM for each linked pair: firms' strategic site selections combine to yield the sectorally-bounded agglomerations seen in Figure 4.

5. Conclusions

The purpose of this paper has been to (1) identify the intricacies associated with a conceptually consistent approach to the combination of agglomeration and network externalities; and (2) explored how this can be adopted in empirical research. To this end, we presented a (combinatorial) typology of externalities commonly invoked in the regional science literature, after which we illustrated the remit of adopting this typology by applying a state-of-the-art bipartite network projection detailing the presence of globalized producer services firms in cities in 2012.

Our analysis of statistically highly significant links between firms-within-cities and between cities-through-firms serves a heuristic purpose: given a very specific selection of firms within a very specific selection of cities, our results have no deep-seated value in the context of the extensive literature that tries to make sense of specific empirical patterns of agglomeration externalities, network externalities, and how these interlock. Our results have above all an intuitive, commonsensical appeal: the finding that Chinese banks are strongly inter-linked, and law firms tend to seek out the same set of cities can hardly be called surprising. However, the major point of this analysis is that, as a conceptualization and subsequent empirical operationalization of the commonsensical notions of ‘a network of agglomerations’, both the agglomeration and the network dimension can be brought into close dialogue without the seemingly unavoidable noise of conceptual discrepancies, fuzziness, and data inconsistencies. The one-mode graphs presented in the different figures can be validly interpreted as conceptually and empirically consistent topological renderings of agglomeration and network externalities.

A subsequent analysis systematically examining how the patterns in figures 2-3 and those in figures 4-5 can be combined will therefore not suffer from the many hazards associated with undue juxtaposition of fuzzy concepts. It results in valid findings from the economic-geographic and geometrical perspectives that that can readily be hypothesized to be market, public or club goods in subsequent theorizing from an industrial organization perspective. The same could be done for alternative configurations of cities and firms for which there is a theoretically informed assumption. Similarly, the combinational typology will enable other methodological approaches to combine agglomeration and network externalities. For instance, an analysis could involve projective geometries, gravity-type interactions, and market-based exchange in order to construct meaningful and valid analyses of city and city-network effects that nevertheless denote different empirical referents than in our example. This highlights the purpose of this paper, which has been to draw attention to the importance of carefully attending to conceptual and empirical consistency. In our view, this will result in more precise statements on how agglomeration and network externalities interact, irrespective of the sector, scale, or processes being studied.

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