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Making a Global Gas Market: Territoriality and Production Networks in Liquefied Natural Gas

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abstract

Energy markets are an important contemporary site of economic globalization. In this article we use a global production network (GPN) approach to examine the evolutionary dynamics of the liquefied natural gas (LNG) sector and its role in an emerging global market for natural gas. We extend recent work in the relational economic geography literature on the organizational practices by which production networks are assembled and sustained over time and space; and we address a significantly underdeveloped aspect of GPN research by demonstrating the implications of these practices for the territoriality of GPNs. The article introduces LNG as a technological reconfiguration of natural gas that enables it to be moved and sold beyond the continental limits of pipelines. We briefly outline the evolving scale and geographic scope of LNG trade, and introduce the network of firms, extraeconomic actors, and intermediaries through which LNG production, distribution, and marketing are coordinated. Our analysis shows how LNG is evolving from a relatively simple *floating pipeline* model of point-to-point, binational flows orchestrated by producing and consuming companies and governed by long-term contracts, to a more geographic and organizationally complex production network that is constitutive of an emergent global gas market. Empirically the article provides the first systematic analysis within economic geography of the globalization of the LNG sector and its influence on global gas markets, demonstrating the potential of GPN (and related frameworks) to contribute meaningful analysis of the contemporary political economy of energy. Conceptually the article pushes research on GPN to realize more fully its potential as an analysis of network territoriality by examining how the spatial configuration of GPNs emerges from the organizational structures and coordinating strategies of firms, extraeconomic actors and intermediaries; and by recognizing how network territoriality is constitutive of markets rather than merely responsive to them.

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Spatially dispersed production networks are widely acknowledged as a significant organizational form within the global economy. The territorial configuration of global production networks (GPNs) and value chains, however, remains an underdeveloped analytical theme in the economic geography literature. As a consequence, the relationship between network territoriality and practices of network coordination is not well understood. A better understanding of the territoriality of production networks, and how territoriality emerges from the coordinating strategies of firms, extraeconomic actors, and intermediaries, is necessary if economic geography is to provide richer analyses of their geoeconomic/geopolitical consequences and the mutually constitutive character of spatial and organizational form. In this article, we use a GPN approach to examine the evolutionary dynamics of the liquefied natural gas (LNG) supply chain and its role in an emerging global market for natural gas.

Energy markets are an important contemporary site of political-economic change, shaped by a combination of economic policy goals (e.g., market liberalization and supply competition), geopolitical and geoeconomic shifts in power (with associated concerns about energy security), and environmental objectives (e.g., climate change mitigation and urban air quality). An earlier generation of geographic researchers recognized the significance of energy markets and the importance of understanding their structural and dynamic features in accounting for the geographies of economic activity. Manners (1964), for example, placed market demand at the center of his survey of *The Geography of Energy* and its influence on economic development; the eight editions of Odell's (1970) classic *Oil and World Power* highlighted the role of oil markets in shaping geopolitical relations during one of the most turbulent periods in the sector's history; and Chapman's (1989) *Geography and Energy: Commercial Systems and National Policies* examined the organizational and spatial structure of electricity, oil, and gas markets. However, despite the enduring importance of energy markets, it is only recently that they have again become a focus of attention within geography (for a recent review, see Calvert 2016). International markets for natural gas are currently undergoing profound change. Gas consumption worldwide has grown 25 percent in the last decade, with projections of a *Golden Age of Gas*

buoyed by surging shale gas production in the United States, large conventional gas discoveries (e.g., offshore East Africa, eastern Mediterranean, and Australia), and fuel switching in power and urban transport sectors. In many national contexts, the shift toward gas has been facilitated by energy market deregulation, major infrastructural investment (e.g., in pipelines and import terminals), and environmental regulation that valorizes the lower particulate and greenhouse gas emissions of gas relative to coal or oil (International Energy Agency [IEA] 2011, 2014). However, the most significant process transforming international gas markets—and the focus of this article—is the increasing integration of geographically discrete markets for gas and, for the first time, the prospect of a global gas market emerging similar to that for oil. Central to this process has been a growing seaborne natural gas trade, in the form of LNG, which increasingly enables gas to be moved and sold beyond the continental limits of pipelines. As we show, however, growth in LNG trade is accompanied by a deeper process of integration associated with cross-border production networks for making, selling, and transporting LNG—what is commonly referred to as the LNG supply chain. These GPNs for LNG stretch from upstream gas extraction to downstream gas consumption via intermediate processes of gas processing, liquefaction, shipping, and regasification. We show how the territorial form of these production networks is evolving, along with the organizational practices through which they are held together, and how the manner of their evolution is bringing a global gas market into being.

The contributions of the article, therefore, are threefold. The article provides the first systematic analysis within economic geography of the globalization of the LNG sector and its influence on global gas markets. In doing so, it demonstrates the potential of GPN to contribute meaningful analysis of the contemporary political economy of energy. Second, this article critically extends recent work in the relational economic geography literature on the organizational practices by which production networks are assembled and sustained over time and space. We agree with Murphy (2012, 211) that GPN/global value chain (GVC) research has yet to develop fully an “empirically informed exposition of how different production network configurations develop through the actions of agents,” and we see value in his call for a “process-sensitive approach” attuned to the “process(es) through which network linkages are established, sustained, and reorganized over time and space” (ibid.). The article responds to this call, examining how LNG production networks are scaled and sustained by focusing on the practices that hold together different network actors. Third, by foregrounding the concept of territoriality, we address an underrealized potential of the GPN approach for examining the implications of network practices for the territorial configuration of GPNs. We concur with Coe and Yeung (2015, 35) that, to date, “the territoriality of global production networks is elusive and under-developed.” By paying attention to the spatial configuration of LNG production networks, we are able to show how, in the case of natural gas, GPNs are constitutive of markets—market making—rather than merely responsive to them.

The remainder of the article is organized into four sections. The next section contextualizes the article’s conceptual and empirical contributions via a review of recent work in GPN. Following that, we provide a brief introduction to the LNG sector and outline our methods and approach. The penultimate section presents our analysis of geographic and organizational change in LNG production networks. We identify three organizational trends reshaping the spatial configuration of LNG production network, and show how they are eroding the dominance of a long-established business model in LNG (what we refer to as the floating pipeline). We examine contract terms and other *network development practices* (Murphy 2012) associated with these organizational

changes, and explain how they introduce significant sources of geographic flexibility and uncertainty into the LNG production network. The final section concludes by considering the wider implications of the article's analysis of organizational and geographic shifts in LNG production networks.

Unfinished Business: Extending Territoriality, Materiality, and Network Practices within GPN Research

4 Contemporary social science has a rich set of heuristics for understanding the political economy of globalization and, in particular, for examining how spatially distributed economic activity is functionally coordinated. Some derive from studies of international trade and take the commodity as their analytical unit; others emerge from industry studies and focus on issues of value chain management, innovation, and sectoral governance; still others highlight the dialectical interplay of territorial and network coherence, and allow for a broad range of *economic* actors beyond the firm. As readers of this journal will know well, economic geographers have played a significant role in developing a broad family of relational approaches for understanding the interconnectedness, organization, and coordination of industrial sectors that includes work on global commodity chains (GCCs, e.g., Hughes and Reimer 2004), GVCs (e.g., Ponte and Gibbon 2005) and GPNs (Coe 2012). The GPN approach is the most spatially sensitive member of this family with its embrace of multiple geographic scales, recognition of a plurality of economic actors extending beyond the firm, and attentiveness to the unevenness of regional development outcomes. A GPN approach focuses on the relationship between the geographic extensification of economic activities and the activities' organizational integration and coordination. It was initially developed as a tool for understanding changes in the geographic organization of manufacturing and services at the world scale, and examining the implications for regional development of the internationalization of economic activity (Henderson et al. 2002; Coe et al. 2004; Dicken 2015). Consistent with its materialist origins, the GPN approach seeks to understand how existing interactions—around price formation or product design, for example—are outcomes of the distribution of power within a production network and, furthermore, how these interactions are generative of new organizational and geographic forms. Production networks, then, are understood as “organisational platforms through which actors in different regional and national economies compete and co-operate for a greater share of value creation, transformation, and capture though geographically dispersed economic activity” (Yeung and Coe 2015, 30). The point here is not simply that production networks are dynamic over space and time, but that network spatio-temporality is an emergent property and arises from interactions among a network's constituent parts.

The GPN approach's capacity for understanding the mutually constitutive character of spatial configuration and network organization makes it well suited to analyzing economic sectors whose organizational and geographic structures are in a state of flux. So far, the center of gravity of the GPN research framework has been manufacturing, where it has been adopted to understand functional and geographic integration in a range of sectors from aircraft (Bowen 2007) and automobiles (Isaksen and Kalsas 2009) to textiles (Tokatli, Wrigley, and Kizilgün 2008) and wood products (Murphy 2012; Gibson and Warren 2016). However, recent work has taken GPN into less familiar terrain, to examine producer services such as temporary staffing (Coe, Johns, and Ward 2011), freight forwarding (Bowen and Leinbach 2006; Rodrigue 2006), the creative sector (Johns 2006; Yoon and Malecki 2010), and extractive

industries (Bridge 2008; Steen and Underthun 2011; Bridge and Le Billon 2013; MacKinnon 2013). These studies have expanded the sectoral reach of GPN research but have also highlighted some of its conceptual limits and opportunities for further development. We are drawn to GPN's spatially sensitive relational approach and its advantage in this regard over GCC and GVC approaches: we think GPN's geographic sensitivity has the capacity to generate novel insights about the evolution of the LNG sector that make an original contribution to energy studies. However, we also think GPN's potential as a distinctively *geographic* mode of analysis is underdeveloped and can be enhanced by attending to three conceptual elements: GPN's account of territoriality, understanding of materiality and material transformation, and interest in network practices. The case of LNG foregrounds these limitations, while at the same time suggesting how attending to them can advance research utilizing GPN and other relational approaches.

Territoriality

The spatial reordering of manufacturing at the global scale provided the initial impetus for early work on *global shift* and the exercise of *global reach* in fragmented economic networks (Dicken 1986). However, explicit attention to the spatial configuration of networks has more recently taken a backseat in GPN research in preference for more parsimonious modes of explanation and theory-building in relation to network organization and processes of strategic coupling between leading global firms and local actors (e.g., Lee, Heo, and Kim 2014; Mahutga 2014). We think the concept of territoriality is an underdeveloped conceptual resource for more closely examining the territorial configuration of networks and the value activities of which they are comprised. In general terms, territoriality describes “the process by which individual and collective social actors define, bind, reify and control space toward some social end” (Steinberg 1994, 3). The concept draws attention to the way in which particular geographies (i.e., a specific territorial configuration, combining elements of both geographic reach and interaction with place) are integral to the exercise of economic and political power (Brenner et al. 2003). Territoriality initially piqued interest within political geography as a way of thinking about the practices that produce and maintain territory (see, e.g., Taylor 1994; Paasi 1998). Its capacities for de-naturalizing spatial form, and for linking spatial form with strategic practice, subsequently encouraged its application within a wider range of political-economic accounts. The potential for economic geography of theorizing “the territoriality behind territory” was noted early on by Steinberg (1994) in the context of the *new industrial geography*, although it was not directly taken up. The concept's capacity for hinging spatial form with political-economic power was enough to give territoriality a fleeting role within the first generation of GPN research (e.g., Hess 2004). Yet it remained a marginal term within GPN 1.0, overshadowed by GPN 1.0's conceptual trinity of power, embeddedness, and value.

Coe and Yeung (2015) recently highlighted territoriality's analytical potential as part of a GPN 2.0. For them, territoriality comprises vertical and horizontal dimensions of production networks: the former refers to the *spatial scope* or geographic reach of different economic actors (on a scalar continuum from global to local) within a production network; and the latter refers to the *territorial interfaces* among value activities that have different spatial expressions (for example, some may be highly localized and others expressed as regional clusters). Schematic and provisional, we nonetheless find this framework a useful starting point as it recenters the question of

spatial configuration within GPN research. It has long been acknowledged within GPN research that GPNs are spatially fragmented and *discontinuously territorial*, but the problem of global shift—that is, how the territorial configuration of production networks evolves in relation to the generation and capture of value—has not been a core research focus in recent years. The analytical value of territoriality in this task, we suggest, is that it foregrounds the particularity of a network’s territorial configuration (why *this* spatial form, why *now*?) and links this form to strategic intent (for what *ends*, with what *effects*?). It is, then, more than a fancy synonym for describing a network’s complex spatial form as we retain the processual and evolutionary understanding associated with its initial application—that is, territoriality points to the practices undertaken by network actors to establish, maintain, and adapt a production network’s territorial form.

- 6 As we will show, the LNG production network is rapidly evolving: its organizational structures are diversifying and the *spatial rules* that have characterized LNG production and consumption for nearly fifty years are changing in ways that are economically and geopolitically significant (cf. Glassman 2011). Importantly, these organizational, territorial, and geopolitical dimensions are not captured by conventional analyses that understand the geographies of LNG through the lens of binational trade flows. Conventional analyses readily show LNG consumption to be growing, and the number of producing and consuming countries and firms to be increasing, but say very little about how the global shift under way in LNG (and gas markets more generally) arises from significant organizational changes in LNG production networks. The concept of territoriality provides a way to think about the evolving spatial configuration of LNG production networks, its relationship with the relative power of different network actors, and geographic and geopolitical consequences.

Materiality

A significant strand of recent work in economic geography has called for greater attention to the material transformations at the heart of GPNs and commodity chains. Building on calls to better understand the “influence materiality exerts on industrial organization” (Bridge 2008, 415; see also Boyd, Prudham, and Schurman 2001; Prudham 2005; Hudson 2008), this work explores the significance of materials, and biological, chemical, and mechanical processes, within GVCs. The central provocation of these accounts is that the heterogeneity of materials and the variability of biophysical processes enables and shapes a production network’s spatial and organizational form in ways that are economically significant, yet underappreciated. A logical starting point for investigating how materials matter has been *nature-facing* primary sectors, such as forestry, fisheries, mining, and agriculture, which are strongly characterized by seasonality, biological reproduction times, and geological and ecological variability. Ciccantell and Smith (2009) argued that material and locational attributes of the primary sector influence production networks in distinctive ways: they highlight, for example, how large and *lumpy* capital investments are frequently required to mobilize raw materials via ports and pipelines, and the dynamic interaction of scale economies in raw material production and transportation (see also Bunker and Ciccantell 2005). Gibson and Warren’s (2016) description of a “resource-sensitive global production networks” showed how shortages of traditional hardwoods (which have prized qualities of resonance, strength, and beauty) and environmental regulation influence the organization and spatiality of acoustic guitar manufacturing, leading to both fragmentation and concentration within the production chain. In a similar way, Crang et al.’s (2013) research on economies of waste highlighted the profound heterogeneity of materials encountered in waste flows and how the

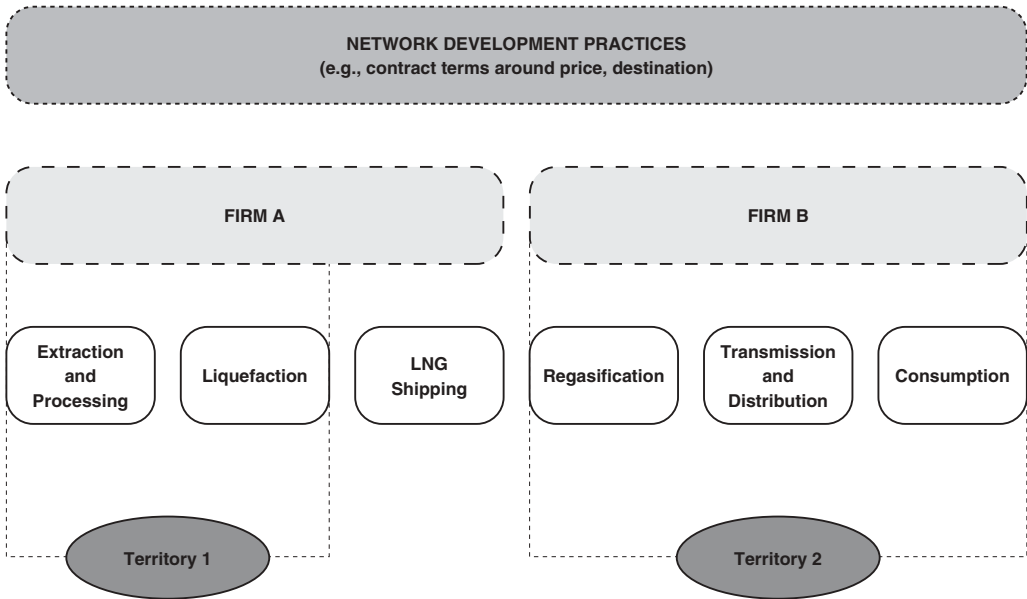


Figure 1. Conceptualizing the LNG production network.

corresponding need for fine-grained sorting gives intermediary brokers (rather than large lead firms) a key role within waste value chains because of their capacity for assessing material quality.

The primary insight of these different studies is to problematize accounts of production, exchange, and consumption by emphasizing how production networks are organized around moments of material transformation, in which the (biological, chemical, physical) qualities of materials shape strategies for value capture. To call attention to materiality in this context, then, is to emphasize the *political-economic possibilities* and limitations of material qualities, and their influence on the organizational and spatial structures of energy regimes (Birch and Calvert 2015). In the case of LNG, for example, production networks are structured around the flow of gas from the upstream wellhead to the downstream consumer as part of an overall value creation process.¹ At the core of the production network are material exchanges and transformations associated with extracting, processing, liquefying, shipping, regasifying, distributing, and consuming gas (Figure 1). Representing the production network as a series of physical input–output structures enables consideration of how infrastructural assets and the technological division of labor associated with long-distance gas supply are territorially embedded. Figure 1 illustrates how gas extraction and liquefaction stages, for example, are shaped by the developmental aspirations of the host state (Territory 1), for which gas extraction and LNG export are typically part of a strategy of resource-based development. Similarly, downstream

¹ The *difficulty* of natural gas (a mixture of different gases that contains impurities, is highly flammable and readily dissipates) is a staple feature of industrial accounts of the sector's evolution. Kaup's analysis (2008) of the Bolivian gas sector noted that because natural gas requires modes of extraction, separation, transport, and technological innovation that are capital intensive (and, accordingly, large scale), there are only limited opportunities for local firms and/or the domestic state to control technological innovations that enhance value capture (such as investment in gas-to-liquids technology to address local deficits in liquid fuels such as diesel).

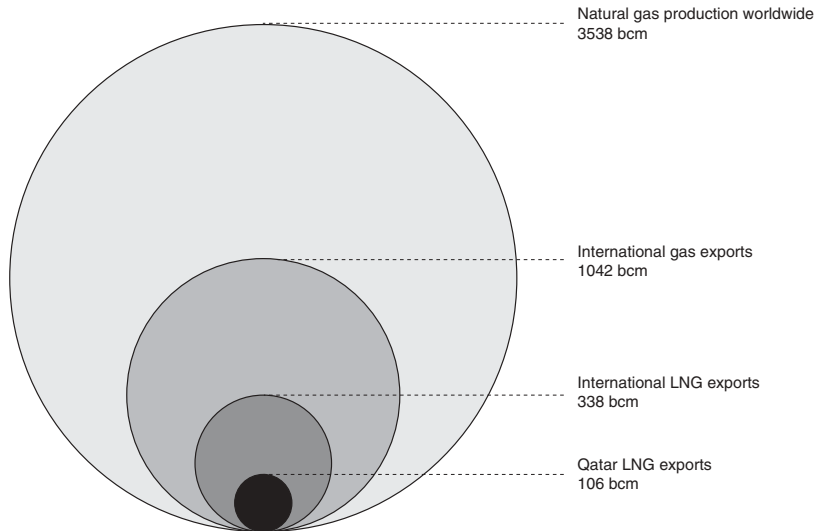
elements are strongly influenced by the differential ways in which gas is embedded in municipal and national energy markets (Territory 2), via electricity generation, for example. We are aware that others have found this stage-based model of production limiting because it may overlook differences among firms within individual stages as well as how some actors may be involved in several stages in different ways (Coe and Yeung 2015). However, a stage-based model of gas production based around key moments of material transformation is well suited to analysis of LNG production networks. Historically the LNG production chain has conformed to a simple organizational model in which upstream and downstream stages have been internalized within the organizational structures of two different firms (Firms A and B in Figure 1). By starting with a stage-based model, we are able to show how, following processes of vertical and horizontal integration by lead firms, the organizational structures of the production network no longer map straightforwardly onto an underlying technical division of labor between upstream extraction and processing and downstream distribution and consumption. Moreover, we are able to show how these organizational shifts are, simultaneously, introducing significant new territorial forms to LNG production networks.

8

Network Practices

GPN research has a comparatively granular approach to the organization of economic activity, focusing on the “intra-firm, inter-firm and extra-firm networks that characterize contemporary production systems” (Hess and Coe 2006, 1207). The capacities of GPN’s relational network perspective are well known for situating economic actors in social and institutional context, emphasizing the significance of their interaction, and understanding the contingency of economic processes (Bathelt and Glückler 2003). However, the organizational practices that link buyers and sellers, align their interests, and reproduce these relations over time and space—that is, which constitute relational networks as networks (as opposed to intrafirm hierarchies, for example)—require further elaboration. In the context of GPN research, for example, Murphy (2012) highlighted a need for greater attention to the ways in which network agents establish, maintain, and adapt network linkages. In his work on the international Bolivian wood products industry, Murphy identified a range of ways in which actors develop ties to international markets. He drew attention to the different strategies that Bolivian suppliers adopt in aligning their interests with international buyers and clients, highlighting the importance of these *network development practices* to enhancing relational proximity and creating network structures.

We take up Murphy’s call for greater attention to the socioeconomic process that hold production networks together and maintain spatially distributed elements as a functional whole. We agree that grounded “empirically informed exposition(s) of how different production network configurations develop through the actions of agents” can shed light on the processes behind emergent spatial forms (ibid., 210). Focusing on practices of interaction and coordination complements the processual and evolutionary understanding of territoriality, outlined above, in that it makes it possible to understand the production network as a set of competing agendas and asymmetric power relations through which the territorial configuration of a production network takes shape. Paying attention to devices through which practices are negotiated and prescribed, such as contract terms, enables an assessment of how spatial ties are created and modified over time. Accordingly, the concept of network development practices (Figure 1) provides a way to focus our analysis on key interactions between sellers and buyers that sustain



Source: data from BP, 2016

Figure 2. World production and exports of natural gas and LNG, 2015 (billion cubic meters).

the LNG production network, and that are important in understanding its changing organizational structures and geographic form.

Researching LNG: An Introduction to the Sector and Our Research Methods

In comparison to oil, natural gas consumption remains strikingly localized: nearly three quarters of the natural gas consumed worldwide (70.5 percent in 2015, see Figure 2) is consumed in the country where it was produced, in comparison to the 64.4 percent of global oil production that is exported (BP 2016). However, the proportion of natural gas traded internationally has been increasing every year. A growing proportion (32.4 percent in 2015) of the just over 1 trillion cubic meters of gas traded internationally each year does so as LNG (Figure 2). Unbound by the fixed infrastructure of pipelines, LNG introduces much greater geographic flexibility to international gas trade and offers, for the first time, the prospect of a global gas market analogous to that for oil. An increasing supply of flexible and relatively inexpensive LNG is anticipated to be one of the most significant developments in the global energy system in the remainder of this decade (IEA 2016).² The growth of international trade and cross-border investment in LNG is, then, part of a larger process of deepening globalization under way within international energy markets such that national systems of energy provision are increasingly porous (Bridge and Bradshaw 2015; Overland 2016).

At the core of the LNG production network is a process of capital-intensive material transformation that upgrades the value of gas per unit volume. Liquefaction is achieved by cooling natural gas to below its boiling point (-163°C), increasing its energy

² A recent analysis of global LNG markets by the Oxford Institute for Energy Studies talks of *the great reconfiguration* (Corbeau and Ledesma 2016).

density six-hundred-fold (to about 65 percent that of crude oil), and substantially improving the economics of gas transportation beyond the limits of the pipeline network (i.e., by road tanker or by ship). Liquefaction is an example of a broad suite of technological interventions that seek to overcome diseconomies of space (Bunker and Ciccantell 2005), effectively creating a commodity by transforming materials from one physical state to another. Its effect is to mobilize and globalize natural gas in unprecedented ways. Ocean-borne LNG enables gas producers to monetize historically *stranded* gas reserves and access large markets *beyond the pipeline*; it creates opportunities for arbitrage between regional markets, and enables utilities and other gas users to diversify sources of supply. By mobilizing gas beyond the continental limits of pipelines, the growth of LNG trade is disrupting established practices among buyers and sellers along the gas supply chain and driving new patterns of uneven development at the regional and global scale.³ Although LNG's growing significance can be interpreted as the inexorable evolution of a commodity market (Pirrong 2014), such accounts leave much unexplained. Where, when, and how (in a contractual sense) LNG moves worldwide depends on how a diverse group of economic agents—including international oil companies, state-owned oil and gas producers, sovereign governments, municipal utilities, shipping companies, and gas traders—are sustained in relation with one another. Understanding the structures and practices that create and maintain GPNs for LNG is essential, therefore, if we are to assess how LNG will reshape existing geographies of gas and its implications for energy security, low carbon energy transition, and other areas of policy concern. For gas importing states, for example, LNG can provide a way to offset physical and price risks associated with pipeline gas and other fuels: in a European context, the possibility of LNG imports from North America is seen as a means of reducing reliance on Russian pipeline gas imports and adding greater competition (Bordoff and Houser 2014; Coote 2016; European Commission 2016). The case of LNG, then, readily captures how GPNs are influenced by geopolitical considerations (cf. Glassman 2011).

To date, analysis of the geopolitical economy of LNG has been limited. There is good quality trade literature (e.g., GIIGNL 2015; International Gas Union [IGU] 2015) and several high-quality assessments conducted by consultancies, international agencies, and independent research centers (Jensen 2004; Pöyry 2010; Standard Chartered 2011; Stern 2012; IEA 2014; Rogers 2015; Corbeau and Ledesma 2016). However, such work tends to either focus on trade flows between states (reflecting a methodological nationalism common to work on international commodity trade) or provides empirically rich assessments of key trends that eschew conceptualization or theoretical development. At the same time, industry research tends to be uncritical in the sense that it seeks to *talk up* the future prospects for the industry, and often specific regions and projects, to reassure current and potential investors in the supply chain. Within economic geography, there is growing interest in understanding the geographic political economies of natural gas (e.g., Steen and Underthun 2011; Zalik 2011; Fry 2013; Andrews and McCarthy 2014; Bouzarovski, Bradshaw, and Wochnik 2015; Bradshaw, Dutton, and Bridge 2015). To date, however, there has been no systematic effort to analyze the structures and dynamics of the LNG sector and their territorial

³ Although we focus here on the growth of the international seaborne LNG trade, small-scale liquefaction is also increasingly associated with an inland truck-based retail trade in some gas markets where distribution pipelines are weakly developed (e.g., in China). This LNG retail trade—supplying industrial users that are *off grid* and the trucking industry—is frequently promoted by the LNG industry as a potential growth market. The French-based multinational ENGIE (formerly GDF-Suez), for example, estimates it could account for about 20 percent of the overall LNG market in 2030.

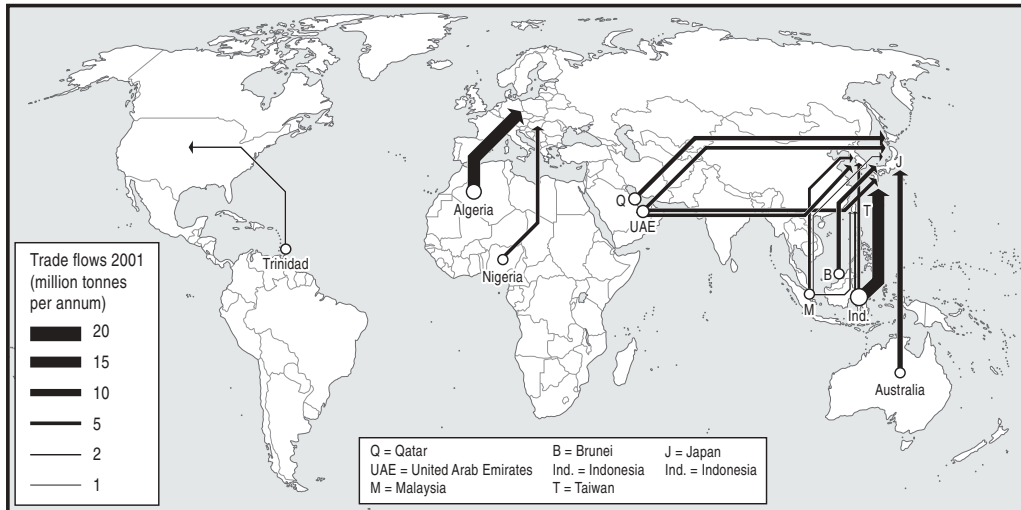
consequences. Studies that have applied GPN to the natural gas sector have used it to describe existing networks within a region rather than analyze their dynamic evolution: Leung (2014) adopted the framework to evaluate the role of gas in China's energy transition and characterize its organizational forms, and Stephenson and Agnew (2016) deployed a GPN framework to describe hydrocarbon production in the Russian Arctic.

The analysis in this article is informed by a two-year period of research focused on understanding the changing position of the United Kingdom within global gas markets associated with declining domestic gas production (from the North Sea) and growing dependency on imported gas since 2004. The LNG component of this research examined the organizational structures through which LNG arrives in the United Kingdom, the impact that significant changes in international gas markets had on LNG flows, and the role of organizational structures and coordination strategies in modifying these impacts in terms of the volume and timing of LNG imports.⁴ The project brought together economic geographers, other social scientists, and energy analysts with specialist gas industry expertise. It involved desk-based research using secondary sources (including annual corporate and sector overviews); sustained interactions with industry specialists and senior level corporate representatives (via bespoke research meetings, participation in international industry conferences, and the integration of gas analysts as project partners); site visits to Qatar Petroleum's facilities at Ras Laffan and the UK's LNG import terminals; and interviews (in the United Kingdom, United States, and Qatar) with firms active in the United Kingdom and other gas markets. In structure and purpose, both research meetings and interviews adhered to a model of *close dialog* with industry practitioners as a means of deriving knowledge and "mak(ing) sense of economic diversity in relation to broader ... processes of economic change" (Clark 1998, 74). Interviews followed an open-ended and semistructured approach, and were designed to develop an understanding of industry structures and observed practices associated with investment in the LNG production network. Since gas contracts are proprietary and their terms are rarely disclosed as a matter of public record, corporate interviews and frequent discussions with industry specialists were an essential element of the research, and enabled understanding to be built up through conversational exchange and iteration as well as via more formal modes like triangulation. These methods underpin the article's analysis of the interconnected agents, processes, and structures through which LNG is produced and distributed.

From LNG Trade to Production Networks

In this section we briefly review the evolution of the global LNG sector and highlight significant changes in its territorial form since 2000. We then explain in the following section how cross-border investment in network infrastructure and changing contract terms are enabling a global market for LNG to emerge. Early commercial uses of liquefaction were in local gas markets as a way to store gas in order to meet peaks in demand—a process known as peak shaving. The application of LNG to address spatial (rather than temporal) discontinuities in supply developed initially in the 1950s, although large-scale commercial shipments of LNG began with the commissioning of exports from Algeria to the United Kingdom and France in 1964. The early Mediterranean/Atlantic focus of LNG trade was supplemented in the 1970s by deliveries from Alaska, Brunei, Indonesia, and Abu Dhabi

⁴ The funded research consisted of three linked elements, and focused on (1) the implications of the boom in US shale gas production, (2) European pipeline networks, and (3) LNG. The project team included specialist partners in the Gas Programme at the Oxford Institute for Energy Studies (<https://www.oxfordenergy.org>).



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Figure 3. Worldwide LNG Trade, 2001.

Source: authors, based on data from BP Statistical Review of World Energy 2002.

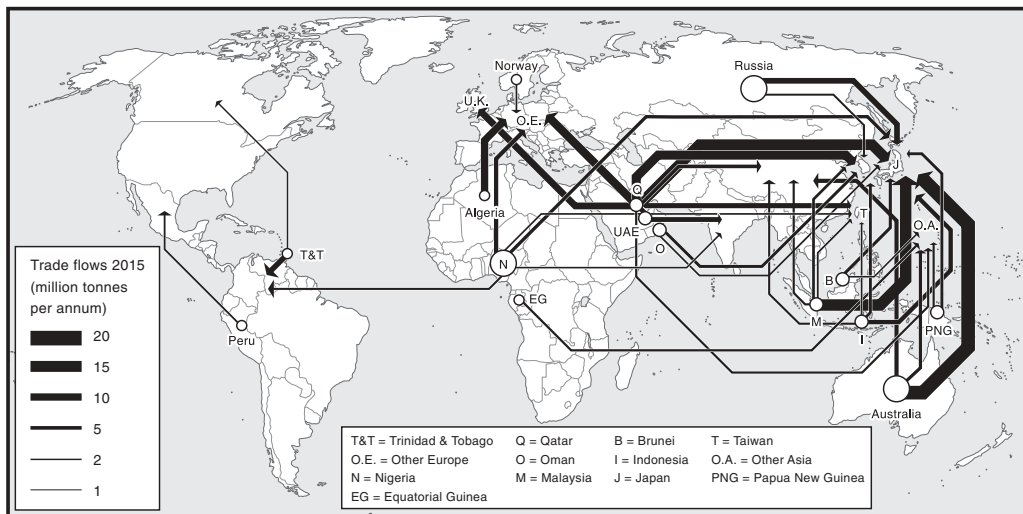


Figure 4. Worldwide LNG Trade, 2015.

Source: authors, based on data from International Gas Union.

(and later, Malaysia and Australia) into the Japanese market. From the mid-1970s onward, Japan and the intra-Pacific Basin trade came to dominate LNG flows (over 70 percent in the early 1980s), and most new export capacity developed in this period was associated with Japan's diversification away from oil (Vivoda 2014). The complexity of the global LNG trade slowly increased with the emergence of Korea (1986) and then Taiwan (1990) as significant LNG importers toward the end of the 1980s, and the entry of Trinidad and Tobago and Qatar as LNG exporters in the late 1990s. Although the scale of LNG flows was significant for the countries involved, the industry as a whole had a small number of players and was regarded as a high-cost, niche sector reserved primarily for countries with limited

access to pipeline gas. Historically, then, LNG has been a point-to-point trade from “dedicated reserves to dedicated markets” so that the *global* LNG sector has consisted of regionally discrete and largely independent projects (Tusiani and Shearer 2006, 67).

Since 2000, the scale and significance of LNG has grown markedly, and we briefly outline here how LNG trade has increased in complexity and geographic scope (Figures 3 and 4). The volume of LNG trade has more than doubled—from around 100 million metric tonnes per annum (MMTPA) in 2002 to over 248 MMTPA in 2015—growing at average of 6 percent per annum between 2000 and 2014 (IGU 2016). Global growth in liquefaction capacity has been led by Qatar, which experienced an 80 percent increase between 2006 and 2011 (Flower 2011). Qatar now accounts for a third of all LNG exports, eclipsing the role of historic exporters (such as Algeria, Indonesia, and Malaysia) in scale and reach through exports into both Atlantic and Pacific basins. However, Australia is expected to surpass Qatar as the world’s largest LNG exporter in 2018, following major capacity expansion (an additional sixty-five million tons—equivalent to 25 percent of current trade—are planned to come on stream in the next few years) (Ledesma, Palmer, and Henderson 2014; Ripple 2014). A similar build-up of export capacity is occurring in the United States, which became an LNG exporter in early 2016 (IGU 2016).⁵ Other new exporters have also entered the LNG market since 2000—Russia, Yemen, Angola, Peru, Norway, Equatorial Guinea, Papua New Guinea—raising the number of exporting countries to seventeen. At the same time, the number of LNG importing countries doubled to thirty (including new flows to Latin America [Brazil, Argentina, Chile] and the Middle East [Oman]). New regasification capacity has run ahead of liquefaction and now stands at around three times the volume of annual trade. Figures 3 and 4 summarize the growing extent and intensity of LNG trade between 2002 and 2015, which has eroded, although not replaced, the long-standing regional structure of LNG trade. Overall, LNG trade is anticipated to increase more rapidly than pipeline gas in the remainder of the decade, although the situation in the early 2020s is uncertain, since the current low oil price and the changing nature of LNG trade itself are deferring investment in new gasification capacity (IEA 2015).

The expanding network of LNG infrastructure provides foundations for a more globally integrated market in natural gas to emerge, similar to that for oil. Growth in regasification capacity, for example, has enabled a significant spot market to develop, along with a growing proportion of short-term (four years or less) agreements for the sale and purchase of gas: together these now represent 29 percent of global LNG trade (71.9 MMTPA) compared to less than 5 percent of the LNG market by volume in 2000 (IGU 2016). However, a series of shocks have disrupted a general trajectory of increasing gas market integration via LNG (Bradshaw, Dutton, and Bridge 2015). Three shocks, in particular, have exacerbated the geographic unevenness of gas market globalization, and LNG flows and pricing terms continue to be strongly regionalized. At the same time, these shocks have also contributed to new patterns of LNG trading, the emergence of production networks that adopt nontraditional organizational forms, and a diversification of contracts to include more flexible terms.

The loss of the United States as a potential LNG market constitutes the first shock. Much of the new LNG export capacity put in place in the early 2000s was underpinned

⁵ The *entry* of the United States into the ranks of LNG exporters (as it is popularly described) in January 2016, with the first shipments from Cheniere’s Sabine Pass terminal on the Gulf Coast, refers only to the lower-forty-eight states, since the United States has exported LNG from Alaska to Japan since 1969 via the Kenai LNG plant on the Cook Inlet. As of January 2016, sixty-two million tons of new capacity is planned in the United States.

by anticipated gas sales in the United States. However, US shale gas production since 2008 has driven down natural gas prices in North America, undermining the case for large-scale LNG imports. In the short term, the reassertion of North America as a largely self-contained *gas island* resulted in a surplus of LNG in the Atlantic basin, with much of this gas finding its way into Europe (and Spain and the United Kingdom, in particular), where it served to undermine the traditional long-term pricing system that had evolved around pipeline gas. In the longer term, the availability of domestic shale gas has encouraged the development of LNG export projects in both the United States and Canada (Boersma 2015). As we explain below, the significance of these export projects goes beyond the volumes of gas involved, since the terms under which gas is sold from these projects effectively internationalizes the US domestic gas price (Henry Hub⁶) as a global benchmark.

14 The Tohoku earthquake and resulting tsunami in Japan in March 2011 constitutes a second shock, since it overwhelmed the Fukushima-Daichi nuclear power plant and led to the shutdown of Japan's nuclear electricity-generating capacity. The effect was to substantially increase the demand for gas in power generation, driving up the price for gas in the Japanese market and compounding a regional price divergence begun with the decline of the US gas price as a result of the *shale gale*. At its peak, the spot price in Japan was around \$19 per million BTU, approximately double the price in European markets and over four times that in the United States. The effect was to reassert the dominance of Japan in LNG markets, draw spot cargoes toward Asian markets, and drive LNG importers in Japan (and elsewhere in Asia) to seek alternative and more sustainable pricing structures.

A third shock has been the fall in the price of oil since mid-2014. The drop in oil price has consequences for LNG for two reasons: most LNG projects are undertaken by oil and gas firms that have slashed expenditures on new project development; and most gas sold in Asian markets (and around 40 percent of gas sales in European markets) is indexed to the price of oil (rather than being based on gas-on-gas competition). Traditionally LNG projects have utilized oil-indexed pricing as a way to cover the relatively high costs of building liquefaction facilities. From a developer's perspective, the fall in the price of oil since 2014 "undermine(s) the rationale for relying on this pricing basis as the 'gold standard' for underpinning the economics of high cost-base LNG projects" (Rogers 2015, 47). Ironically, the previous period of high oil prices had led LNG importers—particularly in Japan—to question the logic of oil indexation and to explore alternative benchmarks for pricing gas, such as the US Henry Hub.

LNG Production Networks: Erosion of the Traditional Floating Pipeline Model

Increases in LNG production and slowing demand growth have resulted in a period of significant oversupply, creating opportunities for new actors and a diversification in the organizational and territorial forms of LNG's production network. LNG's traditional organizational model integrated core upstream phases of gas production, liquefaction, and shipping within the structure of a single entity (Kay and Roberts 2012). In early LNG projects (such as those of Pertamina in Indonesia or Sonatrach in Algeria) resource production, liquefaction, and shipping were vertically integrated within the

⁶ Henry Hub is a key trading point for natural gas in the United States. Occupying a central node in the gas transmission system, and located near Erath in Louisiana, Henry Hub has been the delivery point for the NYMEX gas futures contract since 1990.

structure of the national oil company. The production and export of LNG effectively extended the developmental state's role in securing value from sovereign resources. In parallel, downstream stages of regasification, transmission, and gas consumption were also often integrated within a single organizational structure: in Korea, for example, this has taken the form of a national monopoly buyer, KOGAS (until recently the world's largest LNG buyer); in Japan it has been municipal or regional gas and electric utility companies (such as Tokyo Electric Power Company, Chubu Electric Power Company, and Shizuoka Gas Co).

Since the capital costs of liquefaction are very high (and represent about 50 percent of total chain costs), and LNG plants have limited operational flexibility with regard to output volumes, commercial production of LNG is dependent on securing downstream markets able to absorb supply (Pöyry 2010).⁷ LNG production networks have therefore tended to assume a *project* character: the capital-intensive liquefaction stage is developed in association with both upstream (extractive) infrastructure and downstream import terminals, and underwritten by the value of long-term contracts (twenty-five years) committing buyers to take specified volumes of gas. Such long-term contracts have been essential to securing project finance to cover the cost of building the LNG plant and associated infrastructure as “without a meaningful commitment of a buyer (or buyers) to purchase the requisite volumes of LNG at an acceptable price and for the intended project duration, there would be no project” (Kay and Roberts 2012, 20; see also Douglass 2012). LNG projects, then, have traditionally brought together two territorial entities—a national seller and a national or regional buyer—via long-term, *take-or-pay* sale and purchase agreements. In these projects, integrated oil companies (IOCs) provide access to technology, often via a third-party engineering company (such as the German company Linde in the case of the cryogenic elements of the LNG plant), and project management and gas marketing experience. In regard to pricing, the balance of power between buyers and sellers in the traditional model rested largely with LNG producers, with buyers willing to pay a premium to secure supplies. This model was a direct product of the dominance of Japanese buyers in the expansion of the LNG sector where there was no pipeline alternative. Contracts allocated volume risk to buyers and price risk to suppliers, acting as “linchpins” linking the different elements of the LNG chain (Farmer and Sullivan 2012, 29).⁸

This organizational model has characterized LNG since its establishment in the 1960s. It has given the industry its distinctive structure of “a series of virtually self-contained projects made up of interlinking chains of large-scale facilities, requiring huge capital investments, bound together by long-term contracts, and subject to intensive oversight by host governments and international organizations at every stage of the process” (Tusiani and Shearer 2006, 4). The combination of integrated organizational structures, limited infrastructure, and contract terms binding a high proportion of production to particular buyers meant LNG production networks functioned, in effect, as a *floating pipeline* ferrying gas from a discrete

⁷ Capital costs have risen sharply in the last decade: in 2013 they stood at around \$1,200 per tonne LNG per year, implying a large liquefaction train (around 8 MMTA) may cost in the range of \$8–9 billion (Songhurst 2014). Pöyry (2010) indicated capital expenditure for an 8 MMTA liquefaction plant at \$6–10 billion, with this component significantly larger than shipping (\$1–2.5 billion) or regasification (\$1–1.5 billion).

⁸ In the dominant Asian market, for example, contracts price LNG against the so-called Japanese Crude Cocktail (or more properly the Japanese Custom Cleared Crude Oil Price, a weighted average price for crude imports to Japan) and the inclusion of a pricing cap—the so-called s-curve—protects buyers and sellers against large price swings (Farmer and Sullivan 2012).

16

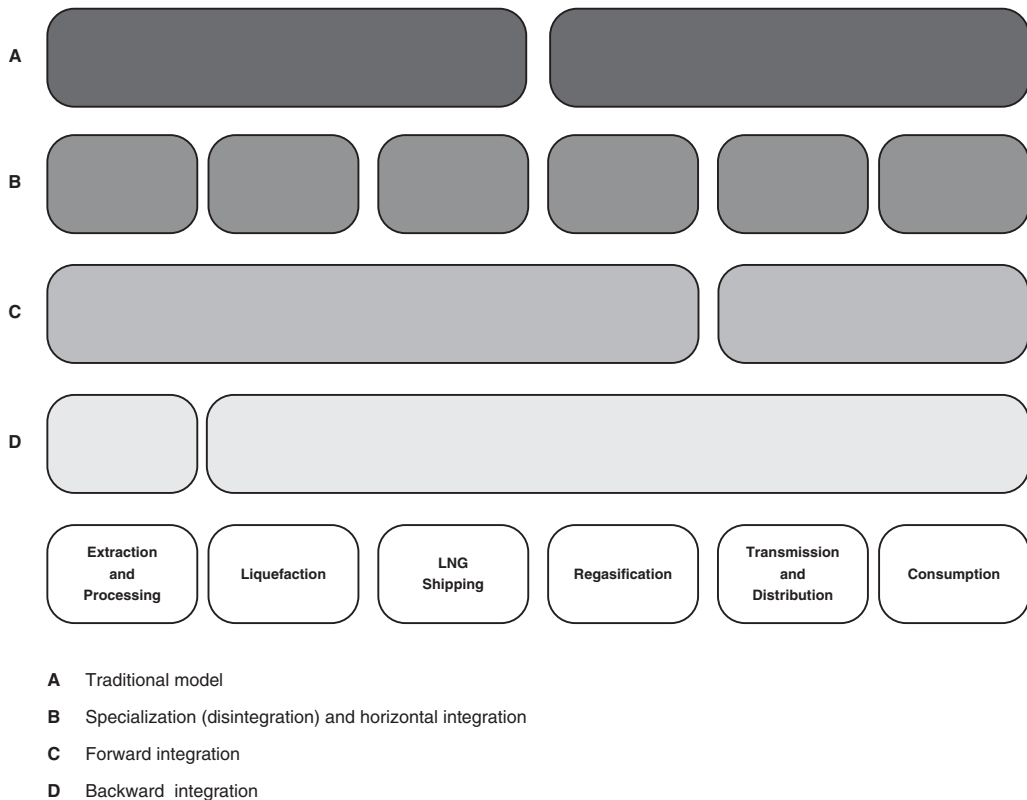


Figure 5. Organizational trends in the LNG production network.

source of supply to a discrete market (Tusiani and Shearer 2006): in other words, the potential spatial flexibility afforded by oceangoing gas trade was, in practice, highly constrained.

Diversification of Production Network Structures

The traditional model (A in Figure 5) has been eroded over time and is on the cusp of significant change. In this section, we identify three significant organizational trends (B, C, and D in Figure 5) in the contemporary global LNG sector and consider their implications. First, a *process of vertical disintegration and specialization* (B) has increased the number of actors in LNG production networks. In the critical area of shipping, for example, independent LNG shipping fleets—that is, not owned, managed, or operated by upstream gas producers (e.g., Mitsui O.S.K. Lines, Teekay, Golar, Dynagas, and Höegh)—increasingly supplement the large fleets constructed and financed as part of major LNG projects and managed by LNG producers (e.g., Qatar Gas, Shell, BP). Independent carriers conclude long-term shipping and service agreements (time charter contracts) with LNG producers for the transport of their gas. They facilitate the growing market for short-term and spot gas sales, and are central to the growing geographic flexibility of LNG trade.

The process of specialization and vertical disintegration in LNG extends beyond shipping to liquefaction and regasification, with the emergence of business models in which these facilities are operated on either a *merchant* or *tolling* basis (Miles 2013). In liquefaction, for example, merchant and tolling models separate the ownership of the

liquefaction facility from the ownership of upstream gas supply: in the merchant model, the owner of the LNG plant purchases gas and sells the resulting LNG; in the tolling model, the owner of the LNG plant does not take ownership of the gas but is paid a fee for the option to access physical processing capacity. The nascent US LNG export market is emerging around a tolling model with owners of gas paying a service fee for access to liquefaction capacity.⁹ Tolling models are emerging at the regasification end of the LNG production network, with regasification and storage capacity constructed by companies that are neither LNG producers nor downstream gas consumers and operated on a fee-for-service basis.¹⁰ The growth of infrastructure and the emergence of big price differentials in regional markets have also created conditions for the entry of third parties. New network participants include banks (Merrill Lynch, Barclays Capital, Société Générale, and JP Morgan) and commodity trading houses (Vitol, Trafigura, and Gunvor) that operating outside of long-term contracts, seek to capture value from the spatial flexibility that LNG affords, moving gas to markets with temporary shortages (ICIS 2010). Overall, the fragmentation described above has increased the number and diversity of actors in the LNG production network, enhancing its organizational and territorial flexibility relative to the traditional model.

Second, the traditional binational character of LNG projects *has been eroded in a significant way by cross-border investments along the production network*. This reflects, in part, the liberalization of national policies governing energy investment enabling nondomestic companies to take an equity stake and assume operational control of key assets such as liquefaction and regasification plants and the infrastructures of gas consumption (utilities, power generation). Transnational investments in the liquefaction phase of the LNG production network are dominated by joint-venture arrangements between national oil companies and the IOCs—notably Shell, BP, Total, Exxon Mobil, Chevron, and ENI. A number of state oil and gas firms, such as Malaysia's Petronas and PetroChina (both partners in proposed LNG export plants in British Columbia, for example), are also active as transnational investors in upstream LNG. The growing significance of cross-border investment also reflects a process of forward and backward integration (C and D, respectively, in Figure 5) occurring along the LNG production network, since downstream firms invest in assets upstream (and vice versa) in order to share risk and capture value. Examples include gas trading and marketing firms taking equity positions in new LNG plants (e.g., Japan-based Mitsubishi and Mitsui in Sakhalin Energy or similarly Mitsubishi's participation as an upstream investor in LNG projects around the world), and participation by utilities (e.g., Tokyo Gas, Osaka Gas, Engie, Gas Natural Fenosa) in shipping and/or

⁹ This model is being adopted, for example, at Cheniere Energy's terminal at Sabine Pass in Louisiana and is also the framework for a number of the country's other proposed export plants (Persilly 2013). The tolling model for liquefaction is enabled by the liquidity of the US gas market and the density of gas supply infrastructure. It also reflects the way proposed US LNG export facilities are essentially a strategic response to changed market conditions not by upstream resource holders but by companies owning land and facilities originally intended as LNG import terminals, and that have access to venture capital seeking relatively short-term returns.

¹⁰ The Grain import terminal in the United Kingdom, for example, is run by the national transmission system operator (National Grid) on a commercial tolling basis: National Grid neither imports LNG into Grain nor sells gas from it on its own account, but it sells capacity rights to a range of upstream LNG producers and downstream utilities. A similar model is associated with the rapid growth of floating storage and regasification units (FSRU). Moored offshore, these units allow municipal, regional, or national gas networks to expand and diversify gas imports by tapping into global LNG. Specialist companies (e.g., Høegh LNG, Excelebrate Energy) build and operate the FSRU and market regasification capacity to those owning LNG or seeking to import gas.

liquefaction stages via equity holdings such as the stake of South Korea's KOGAS in the Prelude (10 percent) and Gladstone (15 percent) LNG projects in Australia (Tusiani and Shearer 2006). This pattern of transnational coventuring in LNG projects is largely obscured by conventional *national* analyses of upstream assets: for example, over 90 percent of LNG imports to the United Kingdom come from Qatar, but the LNG project from which the bulk of these imports are sourced (Qatargas II) is a coventure of Total, Exxon Mobil, and Qatar Petroleum. The process of forward integration involves owners of resource and liquefaction assets acquiring market access by taking equity positions in, or concluding capacity agreements with, owners of regasification terminals.¹¹

18 Third, the discrete, point-to-point character of current LNG trade is also being reworked through a process of horizontal integration, since upstream and downstream companies take positions across multiple LNG projects. At the upstream end, IOCs, like Shell and BP, have well-established LNG trading arms (e.g., Shell Eastern Trading, BP Singapore) that source supply from the various projects in which they are partners. These arrangements are reflected in the emergence of an *aggregator* business model in which suppliers use portfolio flexibility to source gas from anywhere rather than from a single captive project. The BG Group (now part of Shell) adopted the aggregator model, building downstream market positions in the United Kingdom, United States, and Singapore, and a portfolio of flexible LNG volumes that could be sourced from north Africa, west Africa, and the Caribbean. By not being tied to a single project, the portfolio reduces supply risks for LNG buyers—especially when contracting to new liquefaction projects that are frequently delayed, and enables suppliers to optimize across a suite of assets. The portfolio organizational form is the clearest expression of an alternative to the floating pipeline model, which has characterized the historic evolution of LNG.

Changing Network Practices

The volume, timing, and destination of LNG flows are governed by the contracts concluded between buyers and sellers of LNG. Contracts are a critical “network development practice” in the sense implied by Murphy (2012, 211): that is, they are “mutually coherent, recognizable, and legitimated practices (through which) business-people develop relational proximity with each other” (ibid.). It is through contracts that the relational proximity that defines the LNG production network is achieved, with power relations between buyers and sellers shaping contract terms. The diversification of organizational forms and the growing complexity of LNG production networks described above are changing long-established contract practices with significant implications for the geographies of LNG trade. In general terms, these changes reflect a shift in market power within LNG production networks toward buyers associated with growing depth and liquidity of LNG markets: however, as we illustrate below, this is geographically very uneven. Contract terms are becoming more variegated over time as new practices around destination flexibility, volume flexibility, and price emerge (Table 1). Taken together, these nontraditional network development practices are

¹¹ A similar process of overseas downstream investment to secure market access characterized LNG import terminal construction in the United States in the 1990s and early 2000s. Prior to the growth of domestic shale gas production: Qatar Petroleum, Exxon Mobil, and Conoco Phillips, for example, constructed Golden Pass, one of the world's largest LNG import terminals, at Sabine Pass, Texas (Golden Pass has subsequently sought to redevelop the facilities as an LNG export terminal on a merchant model [Miles 2013]).

Table I*Changing Network Practices: Comparison of Traditional and Emergent Contract Characteristics*

Traditional Contract Characteristics	Emergent Contract Characteristics
Long-term, take-or-pay obligations	Shorter-term, options on delivery
Limited off-take flexibility	Flexibility in off-take volumes
No destination flexibility	Flexibility in delivery points
Oil-indexation of prices (outside United States/United Kingdom)	Pressure on oil indexation, hub benchmarking
Limited options for review/reopening	Contract reopening

Source: Based on Tusiani and Shearer (2006), supplemented with other sources.

causing LNG production networks to function less like floating pipelines, contributing to a more geographically integrated and liquid market. We focus here on two: destination flexibility and pricing.

Destination Flexibility

A growing number of LNG contracts allow for flexibility in cargo destination. In the historic mode, buyers were prohibited, by the terms of the contract, from landing a cargo at any other import terminal than that named in the contract (i.e., the buyer's facilities). This primarily reflected the interests of sellers who, whether for pricing, marketing, or financial reasons (e.g., export credit agency support for LNG plant construction was conditional on a proportion of cargoes being landed in a domestic market) wanted to restrict the ability of buyers to sell the cargo in a different market (Ashurst 2009). However, buyers are increasingly negotiating into contracts the right to divert cargoes, enabling them to trade LNG more widely. This process is more advanced in the Atlantic market, particularly in relation to contracts concluded for LNG export from the United States, but the process is also growing in significance in the Pacific basin. It is also associated with a greater use of free on board (FOB) terms in sale and purchase agreements, which give the buyer responsibility for delivery and destination. The traditional model, which still dominates sales in Asian and most European markets, specified delivery ex-ship (DES) and made the seller responsible for delivery (typically to a specified point). Although it is possible to write destination flexibility into DES contracts, the buyer is still beholden to the seller for delivery, and so diversion requires the seller's agreement. The growing use of FOB terms places destination within the buyer's control, affording flexibility in where the cargo is traded and enabling buyers to seek out arbitrage opportunities (Kay and Roberts 2012). National and international policy commitments to liberalize energy markets have also taken aim at destination clauses: the G7 has committed to "promote flexible gas markets" via relaxation of destination clauses, and under EU competition law, sale and purchase agreements involving the European Union cannot contain destination restrictions (Platts 2014; see also Weem n.d.; Farmer and Sullivan 2012). The effect of growing destination flexibility in the contract terms that structure LNG production networks is that a growing proportion of LNG is tradeable, since it is no longer bound to a particular destination.

Pricing Innovation

The territorially embedded character of LNG markets—derivative of regional energy histories and the availability of alternative sources (such as pipeline gas)—has given rise to regionally distinctive pricing regimes. The LNG sold in Asia, and in continental Europe (apart from the Netherlands and Belgium), has traditionally been priced against crude oil. In the United States and the United Kingdom, however, gas prices are disclosed through the market and reflect an energy infrastructure that enables gas-on-

gas competition: LNG pricing in the United States references the physical gas trading point of Henry Hub in Louisiana; in the United Kingdom, prices reference the national balancing point, a virtual location in the national transmission system. These different pricing regimes mean that two broad patterns of LNG production networks have emerged, differentiated by the markets into which LNG is sold: one linked to oil indexation and representing the bulk of LNG trade and a cornerstone of the *traditional model* described above; the other—an *emergent model*—linked to hub pricing in relatively liquid markets. In the latter case, the LNG importer has to accept the prevailing domestic market price, and the United Kingdom, for example, tends to be the market of last resort.

20 Since 2008 prices between the Henry Hub and Asia (JCC) have sharply diverged, driven initially by growing domestic US production of shale gas (Bradshaw, Dutton, and Bridge 2015) and compounded by the shutdown of the nuclear power fleet in Japan and South Korea (which created an additional demand for gas). The scale and persistence of this price difference (which was as much as \$15 per MMBTU) has encouraged innovation in LNG pricing. On the one hand, it spurred gas importers in Asia to review prevailing pricing structures, develop alliances that increase their market power, and seek greater transparency around price in the Asian markets (e.g., the Japan OTC Exchange, and Platts Japan-Korea Marker Price). In 2015, for example, Chubu Electric and Tokyo Electric Power Company, two of the largest buyers in Japan, created a downstream LNG purchasing alliance with a combined annual volume of around 35–40 MMTA. On the other hand, buyers like Chubu Electric sought to offload the volume risk associated with the traditional model, pursuing greater destination flexibility, negotiating FOB contract terms, and by entering into joint procurement with overseas buyers. More generally, the growing depth of the LNG market has encouraged buyers to seek mid- to short-term contracts once long-term contracts come up for renewal and to turn for an increasing proportion of their demand to the spot market. Most recently, and most significantly, the Japanese government has used its presidency of the G7 to put forward a strategy to promote the development of a flexible and liquid LNG market to establish an LNG trading hub in Asia (Ministry of Economy, Trade, and Industry [METI] 2016). Unsurprisingly, traditional suppliers have sought to defend oil indexation, and there is now the potential for significant commercial conflict over pricing between producers and purchasers in Asian markets (Stern 2016), exacerbating the uncertainty facing those seeking to invest in new liquefaction capacity in the early 2020s.

Innovations in pricing are significant because they exemplify a process of experimentation currently under way in LNG production networks as suppliers and buyers seek to reallocate risk. They are also a product of a shift in the power balance in favor of LNG purchasers. Experimentation, in the form of emergent network practices—such as destination flexibility and pricing discussed here—is eroding the regionalized character of LNG production networks. The appearance of Henry Hub pricing in LNG contracts for sale in Japan (which has been dominated by oil indexation) indicates how LNG is respatializing gas markets: the reference to Henry Hub carries material and infrastructural conditions that are characteristic of one highly regionalized market (the United States) into another (Japan). Although this trend has been slowed by the impact of falling oil prices, it shows how production networks and network development practices, rather than simply physical commodity trade, are driving gas market integration.

Conclusion

A global gas market is emerging enabled by major investments in the infrastructures for producing, shipping, and consuming LNG. Although claims for a global gas market are premature, the LNG sector is at a pivotal moment in its evolution. Most analyses of this sector—and of international energy markets more generally—focus on international trade flows in energy commodities, rather than on the cross-border production networks through which this trade is organized. In this article we have adopted a GPN approach focused on the actors and relational practices that influence where, when, and how gas moves beyond the limits of continental pipelines. This approach has enabled us to show how a dominant *traditional* model is being rapidly reworked in the context of growing LNG supply, identifying a process of organizational and territorial experimentation as buyers, suppliers, and other actors have sought new ways to reallocate risk and capture value. Although an LNG production network has been around for over fifty years, we have shown how it is only recently that organizational structures and network development practices have emerged that depart from the floating pipeline model and enable LNG's *potential* geographic flexibility to be realized.

To account for the processes shaping the globalization of gas markets, our analysis has mobilized three conceptual elements: territoriality, materiality, and network practices. The LNG production network is an exemplar par excellence of how the materiality of commodities is integral (rather than incidental) to the geographies of their circulation, presenting barriers to and opportunities for the rescaling of markets. We have approached LNG as a particular techno-material configuration of natural gas that enables it to be moved and sold beyond the traditional limits of pipeline. Material transformation (from gas to liquid, from liquid to gas) and material stabilization (e.g., maintaining gas as a liquid for transport and storage) create opportunities for value capture, although the technical challenges and large capital costs involved restrict these opportunities to particular actors. A techno-material perspective, focused on how the material properties of natural gas enable and constrain the pursuit of value, therefore, sheds light on the expansion of international markets for natural gas and the organization of LNG production networks. In its own, however, it is unable to account for significant recent changes in the organization and territorial configuration of the LNG production network. A key material aspect of LNG (the creation of discrete, oceanborne cargoes) has always given it a much higher degree of potential spatial flexibility than pipeline gas, but in practice this potential has been highly constrained and the LNG production network has operated as a set of largely separate floating pipelines. The concept of territoriality provides a way to understand how and why LNG's long-established territorial form is now changing. In turning to territoriality we have endeavored to retain something of the processual and explanatory (rather than spatially descriptive) meaning associated with its early application to geographic political economy. As a top-level concept, the value of territoriality is that it simultaneously leans forward to highlight a significant *global shift* under way in the geographies of the LNG production network and backward to the strategies and practices of network actors through which these spatial configurations are made. Our account of territoriality in the LNG production network is empirically grounded in the multiple activities of buyers, sellers, and other actors. The concept of network development practices provides a finer-grained analytical tool for sorting through these detailed activities, identifying key practices that hold the production network together and that have a key influence on its emergent territorial form.

The article has provided the first systematic analysis within economic geography of the globalization of the LNG sector and its influence on global gas markets. It makes two significant contributions. First, adopting a GPN approach and foregrounding the question of territoriality discloses significant changes in organizational structures and network territorial forms that a focus on energy technologies, resources, or patterns of gas trade is unable to

reveal. The new organizational structures and network practices emerging in the LNG production network are integral to the ways in which gas is becoming globalized, and they have significant geoeconomic and geopolitical implications. Contract flexibility and the growth of tradeable LNG create new uncertainties that are strategically significant for gas exporters and importers, and for future investment in network infrastructure. Increased flexibility around contracts and pricing may promote an increasingly globalized market, but it is unclear whether the associated lack of surety (in terms of future income streams) can finance the next generation of LNG projects: accordingly, there is potential for supply shortages in the 2020s if demand growth picks up as expected. Moreover, the erosion of the traditional model is geographically uneven. Importers in Japan and South Korea have evolved *dedicated* supply structures for which they pay a premium, whereas in Europe—and increasingly in China—LNG competes against domestic sources and pipeline gas. There is a growing commitment in Europe to marshal the flexibility of LNG to counter dependence on Russian pipeline gas imports, but LNG flows into Europe wax and wane depending on the relative price of alternative gas sources, providing limited supply security. From an LNG importing country policy perspective, there is a balance to be struck between achieving physical gas security through network practices that *lock in* dedicated supply (the Asian model) compared to a market-based form of security where the critical determinant is the price necessary to secure LNG imports (as in the United Kingdom). In sum, our analysis of the LNG production network demonstrates the potential of GPN for contributing new insights into the emergence, organization, and scaling of contemporary energy markets, and their economic and political implications.

Second, we have shown how an emergent territorial form (a *global* gas market) is enabled and shaped by the actors and relations internal to a production network. Our analysis identifies how actors in the LNG sector, and the organizational structures and network practices through which they are functionally integrated, have a central role in the emergence of a global market for gas. The practices of buyers and sellers in the LNG production network—to align interests, allocate risk, and capture value—make the market and shape its emergent territorial form (cf. Hamilton, Petrovic, and Senauer 2011). Their combined effects are changing the way gas is bought and sold and, at the same time, creating new geographies of gas that encompass international trade, cross-border investment, and price formation. A global gas market, in short, is neither self-organizing nor an ineluctable force, but rather an emergent property of the LNG production network. The article has responded to calls for more *process-sensitive* accounts of GPNs by focusing on the relationship between organizational structures, network practices, and territorial form. In doing so, we hope to have realized more fully GPN's potential for analyzing network territoriality by recognizing how network territoriality is constitutive of markets, rather than merely responsive to them.

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