UNIVERSITY OF CALIFORNIA

Los Angeles

Development on Ice:

Global Transportation Infrastructure and the Arctic Frontier

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Geography

by

Mia Moy Bennett

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ABSTRACT OF THE DISSERTATION

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Professor John A. Agnew, Co-Chair

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At the end of the nineteenth century, the seeming unavailability of "free" land elicited declarations of the closure of the frontier. But in the twenty-first century, it seems like more frontiers are opening than ever before. The Arctic is a prime example of this trend. With climate change melting away the Arctic ice cap, multinational corporations, national governments, and indigenous corporations all see opportunities for development. Even as the polar seas and the lands around them are rapidly and unpredictably changing, plans are underway to build new infrastructure like ports along Russia's northern coast and a highway to the Arctic Ocean in Canada. More than geophysical factors, however, are motivating this infrastructure push. Political, economic, and technological drivers are leading developmental interests to seek to shorten the distance between global markets by bridging the supposed "infrastructure gaps" that exist in not only the Arctic, but also places like Central Asia, Siberia, and beyond. Using a mix of qualitative methods and remote sensing, this dissertation analyzes the scalar politics of infrastructure development in two contemporary frontiers: the Arctic and Russian Far East. This research first aims to explain how contemporary frontiers are conjured as spaces in need of development and globally articulated infrastructure by focusing on the Arctic as a regional example (Ch. 1) and the Canadian Arctic as a national example (Ch. 2). I then use two case studies to illustrate how transportation infrastructure projects are spearheaded both from within and outside frontier spaces, drawing on the cases of the indigenous Inuvialuit people and their role in lobbying for and building Canada's first highway to the Arctic Ocean (Ch. 3) and the Singaporean government's foray into Arctic development initiatives (Ch. 4). Expanding beyond traditional methods in political geography, I review advances made in using multitemporal night light imagery to study socioeconomic dynamics (Ch. 5) and apply techniques from this field to study regional development in Russia and China (Ch. 6), two countries that experienced vastly different development trajectories following the collapse of communism. Coming full circle, I consider how post-Soviet Russia, suffering from a major infrastructural deficit that is illustrated both by fieldwork and remote sensing, may be a lucrative yet precarious investment site for China's Belt and Road Initiative (Ch. 7). A central conclusion of this research is that the development of frontiers is politically and economically conditioned, locally negotiated, and cyclical rather than linear.

The dissertation of Mia Moy Bennett is approved.

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CHAPTER 3:
From state-initiated to indigenous-driven infrastructure:
The Inuvialuit and Canada's first highway to the Arctic Ocean

CHAPTER 4:
Singapore: The “Global” City in a globalizing Arctic

CHAPTER 5:
Advances in using multi-temporal night-time lights satellite imagery to detect, estimate, and monitor socioeconomic dynamics

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Except for chapter 3, each chapter of this dissertation has either been published or is forthcoming in a peer-reviewed journal. Citations for chapters 1, 2, and 4-7, including all co-authors, are as follows: **Chapter 1.** Bennett, M.M. (2016). Discursive, material, vertical, and extensive dimensions of post-Cold War Arctic resource extraction. *Polar Geography* 39(4): 258-273, doi:10.1080/1088937X.2016.1234517. **Chapter 2.** Greaves, W., Riedlsperger, R., & Botella, A. (2016). Articulating the Arctic: Contrasting state and Inuit maps of the Canadian North. Polar Record, 52(6): 630-644. doi:10.1017/S0032247416000164. **Chapter 4.** Bennett, M. M. (Forthcoming.) Singapore: The "Global" city in a globalizing Arctic. *Journal of Borderlands Studies*. doi:10.1080/08865655.2017.1367708. **Chapter 5.** Bennett, M.M. & Smith, L.C. (2017). Advances in using multi-temporal night-time lights satellite imagery to detect, estimate, and monitor socioeconomic dynamics. *Remote Sensing of Environment*, 192: 176-197. doi:10.1016/j.rse.2017.01.005. **Chapter 6.** Bennett, M.M. & Smith, L.C. (2017). Using multitemporal nighttime lights data to compare regional development in Russia and China, 1992-2012. *International Journal of Remote Sensing*, *38*(21): 5962-5991. doi:10.1080/01431161.2017.1312035. **Chapter 7.** Bennett, M.M. (2016). The Silk Road goes north: Russia within China's One Belt, One Road initiative. *Area Development and Policy,* 1(3): 341-351. doi:10.1080/23792949.2016.1239508. Some stylistic changes have been made between the published versions of the articles and the dissertation chapters.

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BOOK CHAPTERS

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NON PEER-REVIEWED PUBLICATIONS

Lee, C.M., Shupe, M., Wilson, C., Sheffield Guy, L., Wiggins, H.V., **Bennett, M.M.,** Hoy, E., Kwok, R., Nguyen, A., Payer, D., Schuur, E., Starkweather, S., Stearns, L. (eds.), (2017). Arctic Observing Open Science Meeting Report. Arctic Research Consortium of the US (ARCUS), Fairbanks, Alaska. 2017. 6 pp.
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Introduction

Transportation frontiers as global infrastructure gaps

If the World Economic Forum is to be believed, the planet is suffering from a $1 trillion dollar global "infrastructure gap" (World Economic Forum, 2013). This deficit, the Davos-based organization argues, concerns the yearly difference between the global demand for infrastructure investment and the actual amount invested. In developing countries, growing populations, economies, and cities are generating new needs for everything from railroads to highways to electric grids, while in the developed world, ageing infrastructure like potholed roads and failing bridges requires costly maintenance while tighter environmental regulations mandate upgrades. Underlying this infrastructure gap at a global scale is the rewiring of international trade routes and supply chains, many of which increasingly center on Asia. If European cities like London, Paris, and Berlin were driving global growth in the twentieth century, in the twenty-first century, Asian cities like Hong Kong, Beijing, and Tokyo are (Beaverstock et al., 1999). From 1992 to 2009, the geographic center of Earth's emitted light – a reliable proxy for population, gross domestic product (GDP), and urbanization (Doll et al., 2006; Imhoff et al., 1997; Sutton et al., 2001) – shifted 1000 kilometers east, reflecting the growth of the Asian metropolises over the past two decades (Cauwels et al., 2014). To sustain this growth, World Bank officials, corporate officers, and Chinese foreign policy strategists alike advocate investments in land-based and maritime transportation corridors that link the East with all points west, north, and south. Yet these actors are careful to speak in terms of mutual benefits in an attempt to underscore how globally articulated infrastructure development will foster local development, too (eg Alves 2013). They also attempt to convince the inhabitants of less developed places, like remote frontiers, that they *need* development (Escobar, 1992).

As the geography of globalization shifts eastward, new frontiers are coming into Asia's orbit. Areas rich in resources and sparse in population and infrastructure like the Arctic, Siberia, and Central Asia are increasingly portrayed from Asian vantage points as lying at the heart of the global infrastructure gap. The rationale for the largest infrastructural undertaking in the world at the moment, Beijing's $1 trillion Belt and Road Initiative, offers, "On the basis of respecting each other's sovereignty and security concerns, countries along the Belt and Road should improve the connectivity of their infrastructure construction plans and technical standard systems, jointly push forward the construction of international trunk passageways, and form an infrastructure network connecting all subregions in Asia, and between Asia, Europe and Africa step by step" (National Development and Reform Commission, 2015). It is these places "in between" the world's major markets that constitute some of the most important contemporary frontiers for development. Whereas frontiers in the past were typically conceptualized as areas that had yet to be tamed and settled by Europeans, today, frontiers can be thought of as areas that have yet to be physically connected into global supply chains increasingly oriented towards Asia.

Frontiers have traditionally been defined as places with little or no human settlements, low population densities, and significant deposits of natural resources. The concept is perhaps most closely associated with American historian Frederick Jackson Turner (2010/1920) and his theory of the frontier. Long criticized by historians, anthropologists, and geographers but still taught to schoolchildren in the U.S., Turner's frontier theory describes Western expansion as a microcosm of civilization's evolution from "primitive savagery" to industrial cities, though the theory did not provide much in the way of an explanation of the mechanisms that drove this evolution (Cronon, 1987). Indeed, his frontier theory is aimed more at justifying America's westward expansion than explaining it. The twentieth-century historian Ray Allen Billington (1966), who similarly ascribed valor to America's westward expansion, defined a frontier as a place with a lack of settlement, sparse population, and abundant natural resources. Environmental economist Edward Barbier (2010) identifies frontiers by their high ratio of land and resources relative to labor and capital.

Frontiers' lack of physical assets generally make them peripheral to the global economy. Yet under the right circumstances, this detriment can make these liminal spaces useful to global capital as it seeks to find a new spatial fix for investment. Underscoring the link between economic growth in the urban core and frontier expansion, environmental historian William Cronon draws attention to "the expansion of a metropolitan economy into regions that had not previously been tightly bound to its markets, and the absorption of new peripheral areas into a capitalist orbit" (2009, p. xviii). Just as industry boosters in nineteenth-century Chicago turned the Great West into the metropolis' hinterland through the construction of railroads (Cronon, 2009) and the Brazilian government's Plan for National Integration in the 1960s sought to tame and settle the Amazon with a major road-building program (Hecht and Cockburn, 2010), in the twenty-first century, countries like China are attempting to foster new infrastructural connections across seemingly marginal and underinvested spaces in Eurasia and beyond (Ferdinand, 2016). Conveniently, these newly conjured frontiers are portrayed as shortcuts lying at the center of global markets rather than on their distant edges in order to make these spaces appear as logical next steps for investment in transportation infrastructure.

Over time, the concept of the frontier has expanded to encompass settlement frontiers, extractive frontiers, remote and environmentally hostile frontiers, the New World and Oceania, and the near planets (Kellerman, 2007). To this, I venture to add "transportation frontiers": places previously seen as idle but where there is now a perceived need, generally from the outside but increasingly adopted from within, for major transportation infrastructure projects. Save for anthropologist Kenneth Lewis' brief paragraph on transportation frontiers, in which he explains, "They represent the intrusive society's links between frontier regions or between such regions and the homeland," (1984, p. 268), little scholarly attention has been paid to them. Yet as calls to bridge the global infrastructure gap grow louder from countries like China and institutions like the United Nations and World Bank (Bughin et al., 2016), more research is required to theorize how transportation frontiers discursively and materially fit into the global infrastructure gap from local to global scales. Questions that are paramount to this line of research are: Who frames frontiers as spaces for infrastructure investment and why? What are the scalar politics of infrastructure in frontiers? What are the consequences of investing in globally articulated networks while locally or regionally articulated ones are ignored, or is there a way for an infrastructure project to simultaneously meet needs at multiple scales?

The emergence of the Arctic as a transportation frontier in the twenty-first century is a clear example of the power of both environmental imaginaries and actual changes to the physical environment in creating new demands for transportation infrastructure, and it is the example that this dissertation considers the most closely. In September 2007, Arctic sea ice plummeted to a record low (Perovich et al., 2008). As scientists reported the figures – close to 25% less sea ice than the previous record minimum reached in September 2005 (Stroeve et al., 2008) – government officials, corporate executives, and media outlets breathlessly revealed their excitement at the new opportunities afforded by climate change in the Arctic. Finally, they thought, that big, hulking obstacle that had supposedly prevented the Arctic's development for centuries, ice, would melt away. With sea ice set to disappear, shipping routes would open, oil and gas fields would become more accessible, and unexploited fisheries would be up for grabs (eg Borgerson, 2008). In 2016, a *Bloomberg* headline, paraphrasing the words of the chief financial officer of Guggenheim Partners, and investment firm with interests in the Arctic, trumpeted, “The world has discovered a $1 trillion ocean” (Roston, 2016). This valuation was based on the estimated amount of infrastructure that would have to be built in the Arctic to support the development of the region’s economy, largely in the areas of resource extraction and transportation rather than in public services.

Yet in the eyes of many sustainable development practitioners, academics, and organizations, building massive amounts of infrastructure in a place like the Arctic is folly for two reasons. The first is the so-called Arctic paradox, which posits that pursuing the very economic opportunities that geophysical shifts like melting ice are rendering easier may exacerbate climate change and hasten the Arctic’s environmental demise. The second reason is that many critics of industrial development tend to view global capital, which is behind many proposed megaprojects in the Arctic, as synonymous with unsustainable and unrelenting growth. In contrast, local initiatives, particularly if directed by indigenous populations, are viewed as preferable for achieving their goals. As Mark Roseland writes, “If sustainable development is ever going to be achieved, it needs to begin with citizens at the grassroots level, whereby local success can be translated into national achievements” (2012, xviii).

A preference for locally scaled policies and actions, one that is common among geographers and political ecologists, however, may be misguided (Brown and Purcell, 2005). This is the case for three interrelated reasons. First, extolling the values of the local and indigenous can underestimate how local economies can be disrupted and distorted by external forces (Selman, 1996). Second, and as a caveat to the first reason, scale and political-economic processes are often mistakenly conflated (Brown and Purcell, 2005). Political and economic processes are assumed to occur at national and global scales, whereas only cultural and ecological processes happen at the local scale. Yet, as this dissertation shows, political and economic processes can and do arise from the local scale, often in opposition to wider scale movements that seek to, for instance, conserve the environment. Third, local actors, even when indigenous, occasionally seek the right to development (Gibbs, 2005; Salomon and Sengupta, 2003), contradicting assumptions that locally-scaled solutions are inherently sustainable. On the one hand, proposals and financing for infrastructure in remote transportation frontiers can generally be traced to the hubs of global capital: cities like Toronto, Singapore, and Beijing. On the other hand, actors residing within these frontiers sometimes seek to use their position within spaces that shift from a peripheral to more central status within global geopolitical and economic networks to their advantage, as I explain with the case of the Inuvialuit in Canada's Northwest Territories (Ch. 3). Meanwhile, environmental campaigns attempt to keep development away from areas that have not been paved, dredged, or polluted – the places *inside* the infrastructure gap, so to speak. At a regional scale, this can be seen with Greenpeace's campaign to "Save the Arctic," for instance, whose platitudes, ironically, are in some ways less attuned to the interests of local indigenous peoples than the language of corporate social responsibility.

This dissertation seeks to explain three important frontier dynamics: first, the conjuring of contemporary frontiers as spaces in need of development and specifically, globally articulated infrastructure; second, the scalar politics that shape how, where, and why infrastructure projects on the frontier materialize; and third, the occasional reversal of development. Through a mixed-methods approach that focuses on two areas contemporarily viewed as frontiers – the Arctic and the Russian Far East – this dissertation concludes that the development of transportation frontiers is politically conditioned, locally negotiated, and often cyclical. Particularly now, as frontier development from the Arctic to the Amazon becomes less a case of nationally-scaled social and political projects and more a case of globally-scaled market-led economic endeavors (Hecht, 2005), remote regions may be running higher risks of eventual peripheralization even as they are becoming more physically connected to the global economic core. This is because development is not always linear, nor is it always moving forward. For instance, even as the Northwest Passage continues to be promoted as a future Asia-Europe shipping corridor, last year, the only deep-water port in the Canadian Arctic, the Port of Churchill, closed, while a Northwest Territories marine transportation company that supplied local communities went bankrupt in the absence of viable markets.

Remote regions like the Arctic and Siberia demonstrate how development, particularly when driven by external market factors, can happen in a sudden burst only to unexpectedly halt, leaving behind abandoned infrastructure and forcibly settled populations with little local economy to support them. As the collapse of the Soviet Union shows, levels of development can reverse, too, with socioeconomic outcomes in the Russian Federation severely declining in the 1990s, particularly in the remote reaches of the Russian Arctic and Far East. Under the imposition of market logic in the 1990s, the Kremlin came to see these regions as overpopulated and too expensive to support. Yet eastward shifts in global markets, changing geopolitical strategies in Moscow and Beijing, and strategic local leadership may make them once again the site of major infrastructural projects, though possibly thanks to Chinese rather than Russian investment. The ramifications of closing infrastructure gaps as part of foreign economic and political strategizing rather than as local or national policy, however, remain to be seen.

Throughout, this dissertation aims to paint a complex, multi-scaled picture of frontier development and demonstrate that it cannot be reduced to single factors like climate change or

Chinese demand. While macro-scale forces like alterations to the physical landscape or global economy are clearly important, micro-scale forces like local land tenure regimes and a community's receptiveness to development are also key. Furthermore, the local can articulate itself as global and vice versa, a substitutability which emerges in both discourse and practice. To cite one example, the President and CEO of the Ukpeaġvik Iñupiat Corporation, based in Utqiaġvik on Alaska's North Slope, offered, "As an Iñupiat village corporation, it is our responsibility to aggressively seek out new, healthy business opportunities that are not only profitable but meet an intrinsic need to enrich the lives of our shareholders, preserve our values, and leave a positive, lasting impact on the next generation of shareholders" (UIC, 2016). Following through on what are essentially efforts to "go global," the indigenous corporation acquired royalty interests in multinational Shell Oil Company's Chukchi Sea leases in late 2016. The empowerment of Arctic indigenous peoples and their corporations and the resulting pro-development stance of many indigenous elite in the North American Arctic demonstrates that closing the infrastructure gap and building out the frontier involves a tangled scalar politics that is more complicated than pitting local against global or indigenous against non-indigenous.

Lastly, this research makes a methodological contribution by illustrating how development cannot be understood solely through site-specific fieldwork or from the optic of outer space. When possible, these different vantage points, which provide insight into processes and dynamics at different scales, should be combined to build a holistic understanding of the drivers and impacts of the critical and material practices of frontier development. To that end, this dissertation is based on fieldwork carried out in Canada's Northwest Territories (June-July 2016 and March-April 2017), the Russian Far East (February-March 2016), Singapore (September 2016), and at eight different Arctic development conferences (2013-2016), along with applications of night-light imagery from 1992-2012 to study development over time in Russia and China. Although night light imagery has largely been used to study urban- or national-scale dynamics in places that are growing over time like China, this dissertation specifically uses the data to examine provincial- and regional-scale processes in places that have experienced periods of socioeconomic decline, namely post-Soviet Russia.

Chapter 1, "Rethinking the frontier: discursive and material practices of Arctic development," proposes an integrated framework for rethinking resource development on the Arctic frontier that considerse its discursive, material, vertical, and extensive dimensions. Chapter 2, "Articulating the Arctic: contrasting state and Inuit maps of the Canadian North," compares four maps produced by the Canadian government and a leading Inuit organization in Canada in order to understand the different ways in which the Arctic was portrayed as a geographic, political, and social region under former Prime Minister Stephen Harper (2006-2015) and the effects these imaginings have had on northern policy and people. Chapter 3, "From state-initiated to indigenous-driven infrastructure: The Inuvialuit and Canada's first highway to the Arctic Ocean," examines how Inuvialuit elite in Canada's Northwest territories leveraged Canadian state interests in Northern nation-building through Arctic resource extraction to achieve a local road-building agenda. Chapter 4, "Singapore: the "Global" City in a globalizing Arctic," illustrates how the Arctic's globalization and Singapore's deterritorialization have together created an opportunity for the Singaporean government to "jump scale" in Arctic development initiatives, specifically by shedding light on its partnerships with indigenous peoples' organizations. Shifting gears, Chapter 5, "Advances in using multi-temporal night-time lights satellite imagery to detect, estimate, and monitor socioeconomic dynamics," reviews progress in using multitemporal night-light imagery from the Defense Meteorological Satellite Program Operational Linescan System (DMSP-OLS) and the Suomi National Polar-orbiting Visible Infrared Imager Radiometer Suite (VIIRS) to analyze urbanization, economic, and population dynamics across a range of geographic scales, drawing on specific examples from the Russian Arctic and Russian Far East, among others. Chapter 6, "Using multitemporal nighttime lights data to compare regional development in Russia and China, 1992-2012," analyzes how lights respond to socioeconomic decline by comparing Russia, which experienced severe economic turmoil following the Soviet Union's disintegration in 1991, with a booming China across its southeastern border. Coming full circle and returning to the political and economic framework of the earlier chapters, Chapter 7, "The Silk Road goes north: Russia within China's Belt and Road Initiative," considers how Russia's underfunded infrastructure and ample energy resources are turning the country into a logical yet precarious site for Chinese transportation initiatives and investment. The conclusion briefly remarks on future directions for studying infrastructure in frontier regions, specifically with attention to indigenous lands.

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Chapter 1

Rethinking the frontier: discursive and material practices of Arctic development

1.1 Abstract

This chapter proposes an integrated framework for rethinking the Arctic resource frontier that involves consideration of its discursive, material, vertical, and extensive dimensions. Such a model enables more rigorous analysis of the drivers of Arctic natural resource extraction in the post-Cold War era than contemporary pronouncements about the region as pristine, unexploited, and newly opened by climate change. Indeed, despite five centuries of extraction, state and corporate discourses position the Arctic as on the brink of unprecedented development. Yet in fact, the development of the Arctic resource frontier represents a place-based, cumulative process that builds on previous rounds of degradation, extraction, and export of commodities ranging from furs to oil. The post-Cold War Arctic resource frontier is a globally networked space of extraction that exemplifies three characteristics of resource frontiers worldwide: existing histories of environmental degradation that legitimize further extraction, vertical intensification fueled by technological and spatio-legal innovations, and a growing array of lateral, fixed connections like pipelines and roads with cities that are increasingly concentrating capital and commodities. I argue that the Arctic's concretizing links with the world's urban core are possibly peripheralizing the region within the global economy by creating a path dependency towards deepened resource extraction.

1.2 Introduction

By many accounts, a new frontier is opening in the Arctic due to the shrinking of the polar ice cap and the consequent unlocking of vast resource deposits. Among media outlets in recent years, a BBC article declared, “Climate is driving a ‘new era’ in the Arctic Ocean” (Shukman, 2015), while a Bloomberg article claimed, “Climate change is making the Arctic’s natural resources accessible for the first time” (Arnsdorf, 2014). In Foreign Affairs, analyst Borgerson (2008) contended, “Global warming has given birth to a new scramble for territory and resources among the five Arctic powers” (p. 63). Regardless of whether they assign responsibility to climate change, many actors perceive the emergence of a new frontier ripe with economic opportunities. Italian oil corporation Eni, which is establishing the world’s northernmost offshore oil field in Norway’s Barents Seas, refers to the Arctic as a “new frontier" (Eni, 2013), while the White House’s National Strategy for the Arctic Region calls it “one of our planet’s last great frontiers” (White House, 2013). The generally unreflexive use of the term ‘frontier’ in discourses about the Arctic hinders critical thinking about motivations for the concept’s deployment and masks the mechanisms by which the region is putatitively becoming increasingly central to global economic growth, particularly in the world’s urban core, for reasons beyond melting sea ice. Declarations of the Arctic as a new or last frontier also overlook lengthy histories of extraction and problematically imagine the region as an unknown space to be discovered.

While anthropogenic climate change is facilitating the opening of new Arctic shipping routes (Stephenson, Smith, Brigham, & Agnew, 2013), technological advances, depletion of easy-to-access resources in and outside the Arctic, and the growing urbanization and interconnectivity of the planet are arguably more important drivers of the intensification and expansion of Arctic extraction. Understandings of the current round of extraction, which represents the culmination of five centuries of northern resource development, would thus benefit from being traced along these lines rather than climate change determinism and oversimplified pronouncements about a new frontier. Far from being a peripheral region opening for the first time, the Arctic is a globally networked space of extraction that exemplifies three characteristics of resource frontiers worldwide: histories of environmental degradation, the vertical intensification of extraction fueled by techno-logical and spatio-legal innovations, and increasing lateral connections with the world's urban core. Consideration of these three dimensions enables the construction of a frame-work to guide research and policymaking on Arctic extraction that views the process as deeply historical, globally interconnected, and crucially motivated by socioeconomic dynamics rather than novel, isolated, and purely climate-driven.

This chapter is organized as follows. The second section briefly reviews the literature on resource frontiers and ties it into Arctic extraction. The third section explores the representational and material dimensions of the Arctic resource frontier: first, repeated dis-cursive framings of the Arctic as a region primed for extraction, and second, the historical, processual, and cumulative nature of the region as resource frontier. The fourth section considers the two spatial dimensions of the contemporary Arctic resource frontier, examining how the vertical intensification of extraction and global extension of urbanization distinguish current extraction from previous iterations. In short, this paper aims to offer a model of the macro-level drivers of contemporary Arctic extraction that considers its discursive, material, vertical, and extensive dimensions. This paper also attempts to revitalize critical thinking about frontiers in the face of frontier studies being declared stagnant (Imamura, 2015). The revitalization of the concept of the frontier – a maligned topic since Limerick (1988) and later Worster (1992) criticized Turner's (1920/2010) triumphalist vision of the American frontier – perhaps has its most promising framework in theorizations that consider it as both representation and reality across space and time.

1.3 Resource frontiers revisited

Since the sixteenth century and particularly since the Second Industrial Revolution at the end of the nineteenth century, the development of resource frontiers worldwide has hastened. This acceleration has been enabled by political, economic, and technological arrangements that have become increasingly complex in order to extract resources from more challenging and remote areas such as the Arctic, a region that can be categorized alongside extractive spaces like the Amazon, Western Australia, and Mongolia. While such areas have alternately been called extractive frontiers (Barsh, 1994; Bebbington & Bebbington, 2011; Priest, 2005), resource peripheries (Barton, Gwynne, & Murray, 2008; Hayter, Barnes, & Bradshaw, 2003; Potter, 2009), and extreme peripheries (Bunker, 1984), these concepts all emphasize the economic primacy of extraction and distinct linkages between these areas and the global economy, even though it is often recognized that frontiers are heterogeneous spaces (Barney, 2009; Ferguson, 2005). Bunker (1984) characterizes extreme peripheries as “regions whose economic ties to the world capitalist system are based almost exclusively on the exchange of extracted commodities” (p. 1020). Similarly, Friedmann (1996) conceptualizes resource frontiers as “formed when the primary reason for invading the thinly populated margins of the national territory is not to establish a more or less permanent rural settlement but to prospect for, extract, and export resources, such as minerals, timber, and hydroelectric power for the benefit of the industrial heartlands of the world.” (p. 2). As edges, peripheries, and liminal spaces, frontiers are typically defined in relation to somewhere else, usually a core, heartland, or metropole. Barney (2009) defines resources frontiers as relational spaces not fully incorporated into the networks of global production and consumption, while Cleary (1993) and Jepson (2006) see the frontier as a peripheral region absorbed into or incorporated by expanding capitalist economies.

External market demands have motivated Arctic extraction on land at least since the Siberian fur trade began in the sixteenth century and at sea since European whaling expeditions set off for Svalbard in the seventeenth century. One could argue that the Arctic resource frontier arose even earlier in the ninth and tenth centuries, when ivory was exported from Iceland and Greenland to continental Europe (Frei et al., 2015). Regardless of when the Arctic resource frontier opened, its linkages with the global economy have concretized since the end of the Cold War through the construction of long-distance fixed infrastructures like the Yamal-Europe pipeline (Saxinger, 2015) and the forthcoming extension of the Canadian highway system to Tuktoyaktuk, on the shores of the Arctic Ocean. Intricate global supply chains have also formed such as the shipment of nickel and copper concentrates onboard a Japanese-built icebreaker via the Northwest Passage to China from a Chinese-owned nickel mine in northern Quebec (Nunatsiaq News, 2014). Paradoxically, even as a resource frontier becomes more connected to the core, its reliance on extracting and exporting resources may cause its relative economic peripheralization. Such peripheralization through connection characterizes the development of places such as Siberia, termed "Russia's North Asian colony" (Forsyth, 1994), and Canada under the British. There, although the exploitation and export of primary products like fur and later timber promoted national development, it also caused Canada's ultimate peripheralization relative to the metropole, Britain (Innis, 1930/1999, 1933). Similar processes may be occurring within the Arctic on a global scale as the region's fossil fuels, minerals, and fish are exported to markets worldwide.

Realizing the contemporary importance of resource frontiers within world markets, Hayter et al. (2003) call for their relocation to the core of theorizing within economic geography. They argue, 'Resource peripheries are significant for understanding globalization as a contemporary stage in capitalist development' (p. 19), since natural resources are crucial for ensuring the future of global industrial capitalism. Yet Hayter et al. (2003) only mention in passing one of the key drivers of remote resource extraction: cities in the global core. Indeed, the term 'resource periphery' underplays the centrality and connections of resource frontiers to continued urban growth. While humans have settled in and altered sparsely uninhabited environments since time immemorial, the emergence of backward linkages between them and the metropolis and state is precisely what makes frontiers developments of the modern era (Richards, 2003). The 'expansion of a metropolitan economy into regions that had not previously been tightly bound to its markets, and the absorption of new peripheral areas into a capitalist orbit' (Cronon, 1991, p. xviii) underscore the inseparability of urbanization from frontier expansion. Whereas urbanization and the advance of industrial technology were accelerating globally during the Cold War, they exercised a diminished impact on Arctic extraction compared to the dominance of military and geostrategic imperatives. This is not to say that export-oriented resource extraction did not occur in the Cold War Arctic: even the USSR exported resources from its northern regions like diamonds from Yakutia and gas from Urengoy (Jensen, Shabad, & Wright, 1983). But overall, northern extraction was more limited in scope and scale. It is only since the Cold War ended that global markets have refocused on the Arctic's raw materials (Doel, Wråkberg, & Zeller, 2014), a shift accompanied by renewed imaginings of virgin frontiers.

1.4 Representations and materializations of the Arctic resource frontier: Repeated imaginings of unprecedented opportunity

The enclosure and operationalization of a resource frontier depends on two processes: the initial and ongoing representation of a region as frontier and its actual enclosure and exploitation. The frontier is accordingly both representational and material (Barney, 2009); a rhetorical device on the one hand and reality on the other. In both instantiations, frontiers undergo constant renewal, but whereas frontier discourse tends to manifest a collective amnesia of prior histories of extraction, processes of enclosure and exploitation build on each other over time. Cleary (1993) criticizes the concept of the frontier for being a linear theoretical device, but frontiers are perhaps better construed of as cyclical in their rhetorical deployment and cumulative in their materialization.

Arctic resource extraction can be assessed by first analyzing repeated conjurings of the region as a great expanse of unexploited land following the suggestion by Forrest (2011) to consider "invocations of the frontier" (p. 51). Outsiders have molded imaginings of the Arctic since at least the Medieval period, and narratives about the evil, unknown, and mystical character of the "idea of North" can even be traced back to the Romans (Davidson, 2005). More recently during the Cold War in the North American Arctic, "frontier-engineering" portrayed the region as a zone for military science (Farish, 2006). Today, Southern-based actors again invoke the mythology of an unknown, untrammeled terra nullius to generate excitement about the potential of northern extraction. In 2015, Icelandic President Ólafur Ragnar Grímsson offered at an Arctic forum in Singapore, "We are in fact talking about a big part of our planet which until 20 or so years ago was completely unknown." He subsequently remarked, "It is as if Africa suddenly appeared on our radar screen of cooperation" (Grímsson, 2015), drawing parallels with previous colonial land grabs. External populations see frontiers as "empty" (Kopytoff, 1987, p. 25) areas lying at "the mystical edge of the known world" (Friedmann, 1996, p. 10), which are open for settlement and exploitation. In that respect, the word "Arctic" represents a colonial term deployed by southern actors to describe a remote, resource-rich region onto which they can project aspirations of development (eg Bennett, Greaves, Riedlsperger, & Botella, 2016).

Corporations with a stake in Arctic resource extraction offer numerous examples of such representations. Norwegian-based certification body and classification society DNV GL calls the Arctic "the next risk frontier," elaborating, "The harsh and pristine Arctic environment is gradually opening up for business" (DNV GL, 2016). In 2013, a director of Shell gave a speech entitled "Conquering New Frontiers Together" at a Norwegian shipping conference in which he remarked, "We can't talk about new frontiers without mentioning the Arctic. According to the International Energy Agency, the Arctic could hold 14% of the oil and over 25% of the gas of the world's yet-to-be discovered resources" (Brown, 2013). When a place is conjured as uninhabited, untouched, and newly discovered (though also "yet-to-be discovered"), extraction appears more justifiable since its resources do not have to be "stolen" from anybody. Tsing (2005) contends,

> A distinctive feature of this frontier regionality is its magical vision; it asks participants to see a landscape that doesn't exist, at least not yet. It must continually erase old residents' rights to create its wild and empty spaces where discovering resources, not stealing them, is possible (p. 68).

A brochure published in 1995 to promote hydropower by the now-defunct Icelandic Energy Marketing Unit (IEMU) illustrates what Steinberg and Tasch (2015) perceive as a conflicted binary between wild nature and resource wealth in the Arctic. Directed at American and European investors, the brochure reads:

> Iceland is nature at its purest. The freshest air you will ever breath and the purest water in the world are goals worth striving to maintain … Power-intensive industries using these environmentally-friendly power resources for making manufactured products contribute towards protecting the global atmosphere and at the same time do wonders for their corporate image (IEMU, 1995).

This narrative omits nine centuries of human impact on Iceland's landscape, whose rocky, treeless terrain is a direct consequence of deforestation by farmers (Arnalds, 1987). This, perhaps, is why we should be especially attentive to conjurings of resource frontiers in sparsely inhabited regions like the Arctic, where the lack of dense populations may render such discourses more convincing.

The success of a frontier imaginary depends on how effectively it conveys an area's openness and emptiness. Paradoxically, actors interested in resource development often use the word "opening," with its positive connotations of development possibilities, to describe the beginning of extraction in an area even though this process could equally be called "enclosure." De Angelis (2004) refers to this practice as "enclosure discourses" that "wear the mantle of rationality, and project a vision of the future that makes sense to a multiplicity of concrete subjects" (p. 82). Watts (2009), drawing on Redclift (2006), argues that frontier processes "imply a sort of opening or opening up, but it is necessarily a sort of closure (fencing, displacement), a space of violent and lawless primitive accumulation" (p. 21). The repeated discursive creation of a resource frontier exemplifies the state's ongoing practice of "accumulation by dispossession" (Harvey, 2003), whereby land is commodified and privatized for capital gain.

Distinctly from previous eras, even if sovereign boundaries now enclose much of the Arctic, post-Cold War frontier discourses invoke the idea of the Arctic as being on the verge of limitless development for the first time even though previous iterations of extraction and enclosure have rendered the region legible for more complex and intensive extraction. Conveniently omitting this history, contemporary narratives instrumentalize the melting of sea ice to build a sense of discovery, glorifying and mythologizing resource extraction in the process. The chief investment officer of a leading firm interested in building out Arctic infrastructure purported, "This is the greatest (development) opportunity since the end of the Ice Age" (Medred, 2014). Indeed, the development of Arctic offshore oil thrives on the myth of a region suddenly open for oil and gas extraction even though Arctic wells have been drilled since the USSR began exploration at

Chibyuskoe in the Republic of Komi in 1930 (Kontorovich, 2015). Prior to current enrollments of climate change as reason for development, technology was provided as the cause of the Arctic's inevitable opening. At a symposium on marine transportation and High Arctic development held in Canada in 1979, one professor expressed, "We are now in a technological position to make the final breakthrough which will make the sailing of [the Northwest Passage] a normal day-to-day or week-to-week affair … The period of navigational exploration is over; that of development is upon us" (Dunbar, 1979, p. 4). The transition at some point over the past two to three decades from technological to climatic narratives of Arctic development requires further research. In either case, the Arctic has repeatedly been imagined as a place poised for an unprecedented resource bonanza despite a lengthy history of extraction, which has indelibly shaped the region for five centuries.

1.5 Accumulations of extraction and degradation

The cumulative tendencies of natural resource production and the accumulation of environmental degradation facilitate the scaling up of extraction, especially in the North. Thinking about resource frontiers like the Arctic may benefit from metaphorically borrowing physical scientists' term "Arctic amplification" (cf. Serreze & Barry, 2011), the process whereby positive feedback loops of warming at the poles cause changes in surface air and water temperature to be greater than in the rest of the world. The material enclosure and emptying of places like the Arctic has also amplified over time, particularly now as extraction penetrates downward and extends northward. The Arctic resource frontier can thus be viewed within a core-periphery model in which capitalist processes of surplus extraction deplete peripheral resource frontiers and enrich the core (Moore, 2000; Wallerstein, 1974), typically metropolitan areas. While geopolitical factors and state desires to support sovereignty claims are important motivations for resource extraction at particular locales within the Arctic such as Svalbard (Hacquebord & Avango, 2009), the region-wide intensification of extraction, particularly in the post-Cold War era, is perhaps better explained by macro-level drivers including technological advances and increasing global resource demands.

The Arctic's cumulative tendency towards the production of natural resources has resulted in its deepened peripheralization over time. In Canada, for instance, "energy has been directed toward the exploitation of staple products and the tendency has been cumulative" (Innis, 1999, p. 288). This cumulative tendency is closely tied to technological advances produced for extraction in challenging resource frontiers. Italian oil corporation Eni employed the world's largest heavy transport vessel to move the world's biggest floating production and storage offloading unit from a South Korean shipbuilding facility to its Goliat lease area, the world's northernmost offshore oil field, located in Norwegian waters. A company report expressed, "The Arctic represents for eni [sic], as for all other oil and gas companies, a significant technological and managerial challenge" (Eni, 2013). Underscoring the role of technology in opening new frontiers, Rex Tillerson, CEO of ExxonMobil, expressed, "Anytime you are dealing in these frontier areas where you are really driven by technology, these are very long time frames, multi-decade time frames" (Fahey, 2015). The phrase "last frontier" is therefore a misnomer for a place that is more of a "perpetual frontier." In the Gulf of Mexico, the oil industry's "seemingly limitless capabilities to find virgin sources in deeper waters and increase output from oil fields have made off-shore oil a perpetual extractive frontier" (Priest, 2005, p. 214). Similarly in the Arctic, as farsighted southern corporations, often with state support, develop technologies like ice-class tankers and jack-up rigs, it becomes harder for the people living within resource frontiers to pursue forms of economic development alternative to resource extraction. Meanwhile, both public and private southern actors' "policies of alienation and exploitation" (Petrov, 2010, p. 39) reinforce local boom-and-bust cycles inherent in extractive economies. Although downturns within these cycles may merely represent short-term variations to corporations with long-term plans, they can devastate resource-dependent communities. These pauses in extraction also only offer a momentary respite from a longer-term, region-wide trend of cumulative depletion.

Environmental degradation resulting from centuries of extraction has caused the Arctic resource frontier to intensify and expand. When extraction and export of Arctic commodities took off in the fifteenth century, it began at the biotic level. On land, Russians forced indigenous peoples in Siberia to capture fur-bearing animals. The rapid depletion of species like sable and fox pushed Russian traders east to Alaska, where they hunted sea otters (Gibson, 1969). Over the course of a centuries-long hunt, Dutch, Basque, and English whalers seeking Arctic resources for profit rather than subsistence decimated marine mammal stocks. In 1860 in Canada, Hudson Bay's whaling grounds were the last in the world opened to industrial whaling. Overhunting of bowhead whales there marked the "close of a century of worldwide exploration" (Vaughan, 1983/1984, p. 152). Once whales disappeared in lucrative quantities from the Arctic, it was not possible to look elsewhere for them in the region: they were simply gone. While the whaling industry, led by the Norwegians and their new technology, set its sights on Antarctic waters (Vaughan, 1983/1984), natural resource extraction continued in the Arctic by shifting into the substrate. Technological advances and changing global commodities markets, with petroleum oil replacing whale oil, also spurred this downward penetration. In future, processes of enclosure and extraction could move even deeper if ongoing expeditions by organizations like the U.S. Geological Survey Gas Hydrates Project manage to commodify methane hydrates locked into permafrost and continental shelves (Ruppel, Robertson, & Pierce, 2013).

In the Arctic and other resource frontiers, locales subject to heavy extraction are likely to remain sacrifice zones: industrial areas that are repeatedly degraded over time for economic or military gain (Colten, 2012). In the Soviet Union for instance, industrialization led to heavy pollution and industrial decimation across great swaths of the country. Soviet scientists referred to these as “unique geochemical regions,” but Josephson (2007, p. 295) more bluntly refers to them as “industrial deserts.” Cumulative degradation can legitimize the intensification of extraction, making the status of “sacrifice zone” seemingly ineluctable. The Norilsk nickel mine in northern Russia, home to one of the world’s largest nickel ore bodies (Humphreys, 2011), exemplifies how localized degradation can perpetuate extraction while revealing the flaws in conceptions about the Arctic’s uniform pristineness. Extractive activities began under a GULag initiated under Stalin in the 1930s. In the 1950s, a closed company town replaced the forced labor camp, which managed operations until privatization following the Soviet collapse. Norilsk is now one of the highest contributors to air pollution in all of Russia (Kotov & Nikitina, 1996). Emissions from sulfur dioxide, nitrogen oxide, and heavy metal have created a zone of damaged forest spreading over 200 kilometers out from the city (Zubareva, Skripalshchikova, Greshilova, & Kharuk, 2003). In 2000, NASA featured a satellite image taken over Norilsk on its website with the caption: “Heavy metal pollution near Norilsk is so severe that it is now economically feasible to mine the soil, which has been polluted so severely that it has economic grades of platinum and palladium”) (NASA, 2008). A new resource frontier has materialized on top of the soil thanks to previous extractive efforts, demonstrating the layered and intensifying nature of resource extraction in the Arctic.

The former Soviet Union is not alone in such examples: various closed mines in Greenland have reopened over the past decades, while the Canadian North has 160 abandoned mines, many located in aboriginal territories. Yet here, debates over reopening closed mines have occasionally been met with resistance by indigenous peoples bearing negative experiences of previous mining operations (Keeling & Sandlos, 2009). While it is commonly suggested that Southern industrial activities are responsible for Arctic climate change – and indeed, emissions outside of the Arctic, specifically from Asian nations, have caused the bulk of the region's warming – pound-per-pound, emissions within the Arctic generate the highest impact (Sand et al., 2016). Thus, the ability of localized anthropogenic environmental change to reproduce resource frontiers in already-degraded areas may contradict Frederick Jackson Turner's argument that the frontier constitutes a "process rather than a fixed geographical region" (as cited in Worster (1992, p. 22, emphasis in original)). Resource frontiers may actually be more likely to regenerate in the same place due to the accumulation of environmental degradation and the seeming legitimization this grants to industry to continue extraction in an area seen as forsaken.

Finally, illustrating how representations and materializations of frontiers reinforce one another, southern discourses often instrumentalize the effects of global climate change, itself an externality of industrial activities, to justify Arctic resource development. Instead of melting sea ice and thawing permafrost presenting a warning to shift away from heavy extraction, many corporations and states perceive an opportunity to extract even more resources. This perspective perpetuates the Arctic's status as a global commodity supplier. As the world's resource demands increase, various actors underscore the need, occasionally framed as urgent, for Arctic extraction. The coastal states of Russia, Norway, Canada, the United States, and Denmark/Greenland all have economic stakes in developing their offshore resources (Harsem, Eide, & Heen, 2011). A 2015 report from the National Petroleum Council (2015), a US federal advisory committee to the Secretary of Energy which is currently chaired by ExxonMobil's CEO, recommended, "To remain globally competitive and to be positioned to provide global leadership and influence in the Arctic, the United States should facilitate exploration in the offshore Alaskan Arctic now." Even the Arctic

Council, a body whose mandate primarily concerned environmental issues following its establishment in 1996, has developed an Agreement on Cooperation on Marine Oil Pollution, Preparedness, and Response in the Arctic. This signals the body's normative shift from environmental steward-ship towards nominally sustainable development and resource extraction. All this potential future extraction lies at the root of the so-called "Arctic paradox," which really is germane to all resource frontiers: as ongoing extraction exacerbates environmental degradation, it creates a path dependency towards future extraction, which can extend deeper into or on top of degraded soil and out into new areas.

1.6. The vertical and extensive dimensions of the Arctic resource frontier: Reaching new technological and spatio-legal depths

For the past two-hundred years, alongside older forms of "inventory science" (Sörlin, 2002, p. 91) like surveying, cartography, and natural history, resource extraction has relied on geology: the study of the Earth's structure and historical formation. Since minerals-based resource frontiers generally expand downward to continue production, they rely heavily on combining technology with geological knowledge of the planet's strata. The vertical expansion of the global resource frontier has its roots in the Industrial Revolution. In 1709, English industrialist Abraham Darby's discovery that coke could be made by heating coal permitted the vertical extension of Britain's resource frontier, from which above-ground layers of forest and soil had been stripped over prior centuries, into its coal seams (Jones, 2003). In the nineteenth century, a "mania for geological research" coincided with geology's "acquisitive territorial imperative" (Oldroyd, 1996, p. 134). Arctic exploration played an important role in the field's advancement: Van Campen (1877), referencing mineralogical specimens like cryolite specific to Greenland, expressed, "Arctic research, therefore, may in no slight degree extend our knowledge of the mineral riches of the earth" (p. 212). In 1898, coal prospecting began in Svalbard (Avango et al., 2011) and the Kiruna iron ore mine opened in northern Sweden, where nineteenth-century geology was colored by economic patriotism and nationalism (Sörlin, 2002). Soviet mines like Norilsk (nickel), Vorkuta (coal), and Mirny (diamonds) all got their start from the 1930s onward, when production of northern oil fields also began. In the post-war era, Canada opened its first Arctic mines beginning with nickel and copper production at Rankin Inlet. At present, the proliferation of bathymetric surveys and other geological studies of the Arctic (especially its continental shelves) such as the U.S. Geological Survey's Circum-Arctic Resource Appraisal in 2008 can be interpreted as the return of a type of mania for mapping in pursuit of territory and resources, now at subsea levels.

Aside from requiring novel forms of scientific knowledge and technology, the expansion of resource extraction into greater geological depths has required the legal definition of new vertical spaces like the continental shelf. The degree of knowledge required to intervene in society is "roughly commensurate with the depth of the intervention" (Scott, 1998, p. 183); the same can be said for interventions in geology. Oil fields on the continental shelves are estimated to have been deposited during the Cretaceous period (Dow, 1978), yet only since the 1958 signing of the Convention on the Continental Shelf (CCS) have these spaces been rendered legible for resource extraction. As Braun (2000) writes, "In order to optimize use of the nation's 'vertical' territory, property regimes needed to include the internal architecture of the earth" (p. 34). Particularly in vertical resource frontiers like the continental shelf with high risk and barriers to investment, companies seek an operating environment that is stable, regulated, and legible. For instance, Norway and Russia agreed to delimit a disputed zone in the Barents Sea after nearly four decades in part because of the possibility that once the area was legally defined, extraction would be able to proceed, though other reasons such as Russian foreign policy considerations were also key

(Moe, Fjærtoft, & Øverland, 2011). Extractive interests may flee if they do not find a regulatory environment conducive to vertical extraction: Shell, for instance, after failing to find oil in the Chukchi Sea off Alaska in 2015, blamed "the challenging and unpredictable federal regulatory environment in off-shore Alaska" (Royal Dutch Shell, 2015).

In the Arctic and around the world, one legal instrument above all has made the vertical resource frontier legible: the 1982 United Nations Convention on the Law of the Sea (UNCLOS). This treaty built on the aforementioned CCS and three other treaties signed in 1958 pertaining to international management of the high seas. UNCLOS and its associated Commission on the Limits of the Continental Shelf enable territorial legibility and sovereignty in the Arctic Ocean (Dodds, 2010). Yet equally important is their establishment of the regulatory framework necessary for resource extraction in the vertical space of the continental shelf, for the Arctic has "become 'open' to energy exploitation following deepwater technological advances and, importantly, associated spatial arrangements" (Powell, 2008, p. 829). Until the convention's signing in 1982, much of the offshore Arctic, particularly the seabed, constituted areas never before enclosed or subject to extraction. Operations in the new frontier of the continental shelves have necessitated novel political-economic arrangements between states and corporations to make areas like the seabed and water column legible for extractive interests, such as the establishment of exclusive economic zones (EEZs), where coastal states have "sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources" (UN General Assembly, 1982). Here and in several other instances, UNCLOS mentions resource utilization before conservation. The convention, particularly its definition of EEZs, can accordingly be seen as a spatio-legal arrangement that condones and legitimizes the pursuit of oil and gas deep into the continental shelf.

In tandem, technologies and governance of vertical frontiers pave the way for extraction at new depths to meet the changing demands of external consumers and corporations.

1.7 The city extends north

Although seemingly distant from the world's urban core, processes within the Arctic resource frontier are directly linked to the phenomenon of planetary urbanization. Developed to theorize the patterns, processes, and consequences of worldwide urban expansion (Brenner, 2013; Brenner & Schmid, 2015; Merrifield, 2013), this concept has numerous dimensions. Germane to this paper, one dimension purports that processes of urban agglomeration and concentration are contributing to the socio-spatial and socio-ecological reorganization of places outside the typically imagined bounds of the world's cities, for urbanization comprises both concentration and extension (Brenner, 2013). Swyngedouw (2006) explains, "The city's growth, and the process of nature's urbanization are closely associated with successive waves of ecological conquest and the extension of urban socio-ecological frontiers" (p. 36). The movement of more than half of the world's population into cities, which has led the United Nations to declare the advent of an urban age, is impinging upon Arctic extraction.

The growth of the urban population and the size and number of megacities, however, is only one expression of the world's socio-spatial restructuring (Brenner & Schmid, 2015). Of its five other forms, three directly affect the Arctic: massive infrastructural investments to connect cities, the transformation and extension of large-scale land-use systems devoted to resource and energy extraction, and the "operationalization of erstwhile 'wilderness' spaces, including the rainforests, deserts, alpine regions, polar zones, the oceans, and even the atmosphere itself, to serve the relentless growth imperatives of an accelerating, increasingly planetary formation of capitalist urbanization" (Brenner & Schmid, 2015, pp. 152–153). The operationalization of deeper, broader deeper swaths of the Arctic is more than a result of urban growth; in fact, it can be seen as part of the urban condition itself. From this perspective, the twenty-first-century city is not just a fixed point on a map, but rather a globe-spanning process that exhorts the transformation of nature in reaches as distant as the Arctic. While many Arctic residents support resource extraction, struggles over industrial projects like Iceland's Kárahnjúkar hydropower plant and aluminum smelter or Shell's offshore drilling in Alaska transcend efforts to conserve traditional Arctic ways of life and the environment. They manifest attempts to turn back the shadow that planetary urbanization casts upon resource frontiers, where pipelines, drilling rigs, and tailings are as much expressions of urbanization as skyscrapers and boulevards in London and Dubai.

Understanding relationships between the Arctic resource frontier and urban centers of capital like London and Singapore requires thinking across the space of the Earth. Already for centuries, non-Arctic metropolises have received commodities from northern resource frontiers: eleventh-century Novgorod served as a trading hub for furs, blubber, walrus ivory, and hides (Vaughan, 1982), coats made with fur from northern Canada were worn in nineteenth-century Beijing (Bockstoce, 2009), and today, the Druzhba pipeline delivers natural gas to Central European cities from Russia's Urengoy gas field in one week (Saxinger, 2015). One difference now is that whereas commodities were once exported via transient infrastructures, with mobile equipment like ships and sailboats adaptable to a landscape always in flux between frozen ice and liquid water in places like Canada (Piper, 2010), fixed infrastructures like highways, railways, and pipelines are proliferating even as northern landscapes become less predictable and stable due to thawing permafrost. Pretes (1988) argues that underdevelopment of the North – in order words, domination by external capitalist interests – might not have occurred without the strengthening of ties between the metropolis and peripheral satellite. As the construction of material, networked bonds between Arctic sites of extraction and depletion and urban areas of consumption and agglomeration fix and harden these ties, they may exacerbate the region's peripheralization through connection.

Notably, cities are more than just consuming resources like aluminum smelted in Iceland or oil dredged up from offshore Russia. Increasingly, city-centered capital is directing this extraction, which represents a change from Arctic development during World War II and the Cold War, when Arctic states were at the helm. To cite a few examples, Singapore, a global city par excellence (Olds & Yeung, 2004), has built ice-class tankers for Russian oil company Lukoil and an accommodation and construction support vessel for Eni's Goliat field. Barclays, headquartered in London – the world's financial capital – arranged a $400 million loan for the construction of Iceland's Kárahnjúkar hydro-power plant. And the Toronto Stock Exchange, which provides "the best access to capital in the world for junior explorers" (TMX Group, 2014), lists companies like True North Gems, which plans to mine ruby and sapphire in Greenland. To fully understand the post-Cold War Arctic resource frontier, we must trace back the commodity and financial circuits to the metropolises dictating the spatial restructuring of the Arctic. We must also examine how they interact with Arctic actors across scales, from indigenous and aboriginal corporations to multilateral organizations.

1.8 Conclusion

For five hundred years, capitalist-driven export-oriented resource development has extracted raw materials from the Arctic for consumption elsewhere. Invocations of the frontier that claim the region is newly open for development thanks to climate change fail to tell the full story. Centuries of depletion have transformed the Arctic into a resource frontier that is witnessing intensified and expanded extraction and more concrete connections to urban nodes of capital and consumption in the post-Cold War period. Thus, instead of attempting to understand the Arctic as a place that has suddenly become a "new frontier," a model that considers the representational, material, vertical, and extensive dimensions of Arctic resource extraction allows for greater engagement with the forces that are reshaping and restructuring the region from the inside out at multiple scales.

The expansion and intensification of resource frontiers has been realized through more intricate, scaled-up economic, political, and technological arrangements to extract resources from deeper and more remote peripheries. Together, these combine to induce environmental changes that facilitate further resource extraction. Given the interlocking forces of capital, the state, and technology atop environmentally degraded landscapes and seascapes, there may never be a last or final frontier. Instead, resource frontiers nearly appear "perpetual," deepening and expanding into areas presently detached from global markets whether they constitute the last unexploited forests, minerals in the deep sea bed, or asteroids in outer space. Places such as these are becoming increasingly operationalized and stitched into the fabric of planetary urbanization as cities around the world seek resources to continue their growth. Resource frontiers may suffer even more in an era of heightened urbanization, concentrated wealth, and global climate change, as wealthy urban enclaves fortify themselves while sparsely populated, resource-rich, environmentally denuded areas become forsaken sacrifice zones. This possible future demonstrates that while resource frontiers are becoming increasingly central to processes of planetary urbanization, they remain inescapably place-based and peripheral, too.

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Chapter 2

Articulating the Arctic: contrasting state and Inuit maps of the Canadian North

2.1 Abstract

This chapter compares four maps produced by the Canadian government and Inuit Tapiriit Kanatami, the indigenous peoples' organization representing Inuit living in the four recognized Inuit regions (*Inuit Nunangat*) of Canada. Our analysis is based on publicly available maps, documents, and records and extends the rich existing literature examining the history of definitions of the Canadian north. Distinctly, our research aims to understand the different ways in which the Arctic has been articulated as a geographic, political, and social region during the Harper government (2006–2015) and the effects these articulations have had on northern policy and people. We find that the federal government maintained a flexible definition of the Canadian Arctic as a region when in pursuit of its own policy objectives. However, when it comes to incorporating areas outside the boundaries of Canada's three federal territories, particularly communities along their southern fringes, those boundaries are inflexible. The people who live in these areas, which the state considers to be outside the Canadian Arctic, are marginalized within Arctic public policy in terms of access to federal funds, determination of land use, and a sense of social belonging to the Canadian Arctic. Our goal in this chapter is to demonstrate that national-level disputes over what constitutes "the Arctic" can significantly impact the day-to-day lives of people who live within and just outside the region, however it is conceived.

2.2 Introduction

Maps are crucial instruments for defining a region and affecting popular perceptions and understandings of its geographic, social, and political shape. In the northern polar region, mapmaking processes have been especially important for articulating the extent of the Arctic. From the efforts of European explorers between the sixteenth and nineteenth centuries to find the northwest passage to modern-day bathymetric charting of the Arctic Ocean seafloor, mapping the Arctic remains an important pursuit for the eight countries with territorial claims north of the Arctic Circle, along with the many countries south of 66°33'N that possess northern interests.

A rich body of literature has deconstructed Canada's historical attempts to define its "North" or "Arctic" region (for example Grace, 2002; Wonders, 2003). In his essay, "The North in Canadian History," mid-century Manitoba politician William Morton (1960) declared that Canada was unlike the United States, for "what makes the difference is the North, the fact that Canada is a northern country, with a northern economy, a northern way of life, and a northern destiny" (1960, p. 26). The north is integral to Canada's identity and to its future, but defining what is included within it has long challenged the federation. Quebecois geographer Louis-Edmond Hamelin introduced the concept of "nordicity" to quantify a place's degree of northerness based on ten "polar values," variables ranging from latitude to degree of economy activity (Hamelin, 1979). Despite such attempts at quantification, Grace avers, "North is an idea as much as any physical region that can be mapped and measured for nordicity" (2002, p. xii). But in fact the north constitutes multiple ideas. As we attempt to show in this paper, different groups possess different conceptions of the region.

Since the 2000s, ideas about the Arctic have been shifting domestically and internationally, driven by the melting of polar ice and the global commodities boom, among other factors. Many Arctic countries' northern regions have moved closer to the center of their domestic and foreign policy strategies (Heininen, 2012), while areas just on their fringes have become marginalized as liminal spaces neither included within the newly (re)defined "Arctic" nor in the southern metropolitan heartland. In Canada, former Prime Minister Stephen Harper aggressively promoted Canadian sovereignty over its Arctic, the region's economic value, and the importance of the north to Canadian national identity (Dodds, 2011). Given these developments, it is worth reassessing how the Canadian north is articulated in the contemporary era. We argue that insufficient attention is paid to the ways in which the Arctic is defined domestically within each country, hampering understanding of how region-building processes have impact on communities and individuals as well as inter-state Arctic relations. This topic is also worthy of reflection because domestic perceptions also affect international definitions of the Arctic. For instance, pressure from indigenous groups forced the government of Canada to include Nunavik and Nunatsiavut (the Inuit homelands in northern Quebec and Newfoundland and Labrador, respectively) in regional maps for the Arctic Monitoring and Assessment Programme and the Arctic Human Development Report (Arctic Council, n.d.), even though Canada does not officially recognize either of these more extensive spatial definitions of the Canadian Arctic within its own northern policy. This discrepancy may speak to Canada's perception of itself as a leader when it comes to Arctic foreign policy, which contrasts with its status as a “laggard” in domestic Arctic policy (Keskitalo, 2004).

In contrast to much of the recent work that interrogates how the five littoral countries around the Arctic Ocean (Canada, Greenland (Denmark), Norway, Russia, the United States and arguably Iceland), delimit the international borders of their Arctic regions in relation to one another (Blunden, 2009; Dodds, 2010; Gerhardt et al., 2010), we elucidate the process through which the contemporary Canadian Arctic is defined through many and competing cartographic practices and by different organizations. We pay special attention to maps produced by representatives of Inuit in Canada who put forth a vision of an Inuit homeland, *Inuit Nunangat*, that differs significantly from the state-defined Canadian north. Though outside the scope of this paper, it is worth noting that competing definitions of the north affect more than just Inuit. Aboriginal peoples, some of whom live within the state-defined north and some beyond, experience these same divisions, too, as do non-aboriginal northerners.

Rather than considering state-centric geopolitics, our approach shifts questions about Arctic mapmaking and policy to the scale of the individuals inhabiting the Arctic. Here, decisions about how government defines the Arctic region have tangible impacts on people living both inside and outside the state-defined space. The mapmaking efforts and policies that materialize due to disparities between state and local inhabitants' definitions of the Arctic create bifurcated communities, with those living outside the state-defined Arctic, we argue, being marginalized due to their exclusion from federal programs, state subsidies for northern residents, and conceptual belonging as northerners.

We begin this paper by tracing the role of Inuit and western knowledge in mapping the Arctic. We then examine three case studies to question how the Arctic is defined and mapped within Canada. We review, in the following order: a state-oriented map produced by the federal government as part of its *Northern Strategy* (2009) policy document; a resource-oriented map produced by the federally-funded Geo-Mapping for Energy and Materials (GEM) program; and two recent indigenous-oriented maps produced by Inuit Tapiriit Kanatami (ITK), the national organization representing Inuit in Canada. Drawing on Rundstrom (1990), for these three case studies we perform an institutional analysis to help explain how the values associated with different institutions are presented in maps. Our approach is novel in that we attempt to show that while the process of making an individual map is a finite process, articulating a region is an iterative process that occurs partly through a "cartographic conversation" in which maps enter the public sphere, and the world views that inform them are taken up, consciously or not, in the creation of other maps.

In the discussion, we elaborate on how the differences in cartographic articulations of the Canadian Arctic between state and indigenous maps have substantive implications for policy, particularly in terms of land use and access to certain Arctic-specific federal funds. In this section, we also investigate how the four maps "speak" to each other in order to highlight differences in state- versus indigenous-led mapmaking efforts. First, we show how ITK has adopted western cartographic thinking and conceptions of space and territory, and second, we explore how what is left out is just as revealing of a mapmaker's agenda as what is displayed, be it communities, environments such as sea ice, or other countries. We thus illustrate that the definition of the Arctic as a region is predicated on deliberate erasures and omissions. To conclude, we reflect upon how the *Northern Strategy*, GEM, and ITK maps demonstrate that articulating the extent of the Canadian Arctic remains a continuing and contested process.

2.3 Inuit and Western mapping in the Canadian Arctic

Cartographic mapping is a vital part of constructing the Arctic region. This is especially the case because, as the *Arctic Human Development Report* notes, "there is nothing intuitively obvious about the idea of treating the Arctic as a distinct region…It is possible to resort to the use of biophysical criteria to determine the extent of the Arctic as a region…[but] this approach has little to recommend it in cultural, economic, or political terms, [and] it also fails to produce a clear cut result" (Young and Einarsson 2004, pp. 17–18). Mapping, as many acknowledge, is thus clearly subjective (Harley, 1988; 1989; Monmonier, 1991; Edney, 1993; Crampton, 2011). Maps are cartographic artifacts that represent specific worldviews and spatial ontologies (Mundy, 2000). Rundstrom (1990, p. 155) claims that, when put to paper, maps resulting from different interests and ways of thinking "reflect and reinforce the world view or spatial thought of a culture." Certainly, when a single spatial ontology takes hold within the public domain as the accepted definition of a region, this can extinguish other spatial images. However culture's representations of space can coincide and influence each other too.

Since the first contact between Inuit and European explorers in the Canadian Arctic, indigenous modes of spatial thought have rarely developed in isolation from western ways of thinking about visualizing space. Still, while the mapmaking processes of Arctic indigenous peoples have been explored, especially within Canada (for example, Spink and Moodie, 1972; Rundstrom, 1990; Okladnikova, 1998; Aporta, 2009; Tobias, 2009), they have rarely been put into contrast with maps made by states and other organizations, which are usually considered independently. Though Inuit conceptions of geography were historically distinct from European spatial ontologies (Aporta, 2009), modern Inuit maps such as those discussed below indicate apparent shifts in Inuit spatial thought, dividing *Inuit Nunangat* using settler-colonial Canadian boundaries rather than relying on traditional Inuit ways of seeing the north.

Whereas today's ITK maps adopt western mapmaking practices, the flow of cartographic knowledge was previously reversed, with Inuit often assisting European explorers in their navigational endeavors. Rundstrom (1990, p. 159) explains how the accuracy of Inuit maps constantly "astonished" British and Danish mariners, geologists, and explorers. Indigenous knowledge, though often provided voluntarily, was later used to support the expansion of western imperial and colonial interests, enabling dispossession of traditional Inuit territories by the Canadian state. In the post-World War II period, indigenous lands in Alaska and Canada were accurately mapped, often by military bodies, in order for the state to secure land tenure and establish control over access to natural resources (Chapin et al., 2005).

By the 1980s and 1990s, the Canadian state's military interests in the Arctic were secure (though reduced compared to their Cold War's height), but perhaps as important was the material and cartographic reorganization of the region according to Western concepts of permanent settlement, and private property. Price and Cooper (2007, p. 116) argue that “maps have power because there is a tendency by map readers to equate territorial representation with ownership.” Mapping is a practice that, especially when carried out by the state, supports its structuring of a physical space (Sikor and Lund, 2009). Consequently, the dominance of Western cartographic practices in delineating and visualizing the Canadian Arctic as a region based on features such as straight baselines, continental shelves, and the 60th parallel rather than a networked and interconnected area based on indigenous use means that map readers may first think of the Canadian Arctic as the state's northern frontier rather than as an Inuit homeland. Whereas Aporta (2009) has shown that the Inuit in Nunavut conceive of their northern homeland as a network of trails connecting communities, fishing lakes, and hunting grounds, Canadian state-produced maps tend to emphasize the region's physical geography and natural resources while showing only a handful of isolated settlements. Such people-less portrayals convey a decidedly different narrative for ongoing or potential land use in the region and conceivably make it easier to build public support for industrial activities like hydrocarbon extraction and trans-Arctic shipping.

While state-of-the-art mapping practices dominate current cartographic practices in the Arctic, new representations of Inuit ways of seeing space have entered the public debate. One example is the Igliniit project, which merges Inuit traditional knowledge with new technology to track Inuit travel routes across sea ice (Gearheard et al., 2011). A second is the interactive online atlas of Pan-Inuit Trails (Aporta et al., 2014), which visualizes Inuit mobility and occupancy in the Canadian Arctic. Such projects could be considered forms of “counter-mapping,” a term used for the practice of mapping against dominant power structures (Peluso, 1995). Poole (1995) advocates the potential of counter-mapping to enable greater protection of indigenous land rights and management of resources, among other things. In this context, Inuit creation of their own maps of the Arctic, or the simple attachment of Inuktitut place names to locations they know and inhabit, allows them to assert claims over the region as they perceive politically, geographically, and socially appropriate. As remarked in a document by Qikiqtani Inuit Association (2012, p. 14) on Inuit participation in managing Lancaster Sound: "Maps are one of the most important tools to collect *Inuit Qaujimajatuqangit* [Inuit knowledge] and make it available for direct and sustained participation of Inuit in the integrated planning of the Lancaster Sound [National Marine Conservation Area]."

In reflecting power relationships and constructing boundaries, maps define territory with critical implications for identity and difference (Wastl-Walter and Staeheli, 2004). This is not to say that southern scientists and policymakers never work with indigenous peoples or engage with indigenous knowledge, but rather to point out that their epistemologies often triumph when it comes to presenting a region cartographically. The cartographies of maps issued by national governments and scientific agencies can have implications beyond just defining where the Arctic is; indeed, they affect the investments and subsidies that support northern communities and can even unite or divide entire groups of people, depending on where boundary lines are drawn. Far from the unified, pristine expanse that it may appear as when seen from outside, the Canadian north, in particular, is continually driven by conflicts at the national level over where to draw the domestic border between north and south.

2.4 Reading between the maps

2.4.1 Case study 1: A government's view of the North

At least since the 1950s, the Government of Canada has attempted to integrate its northern regions into the nation and encourage the idea of a "Northern homeland" (Tester and Kulchyski, 1994). Paradoxically, however, the federal government routinely defines the North as a region apart from the rest of Canada. In step with increased global interest in the Arctic and the release of policy documents in other northern states regarding their Arctic regions (Heininen, 2012), the federal government published its own Arctic policy in 2009, entitled Canada's *Northern Strategy* (Canada, 2009). Since its purpose was to provide an overarching framework for all areas of federal Arctic policy, the *Northern Strategy's* depiction of the Arctic may be interpreted as authoritative – though not the sole representation of how the decade-long Harper government conceived of the region with a spatial definition that has generated definite consequences for the people living within and outside its bounds.

The government of Canada inconsistently defines the territorial extent of its Arctic region; over time and across departments, documents, and maps, the geographic and social boundaries of Canada's Arctic fluctuate. The principal map provided in the *Northern Strategy* (Figure 2-1) identifies "Canada's north" as congruent with the three federal territories of Yukon, Northwest Territories, and Nunavut, even though seven communities located in the northern regions of three different provinces are listed on the map and in the index of "populated places." This may represent a pragmatic effort to include communities that would typically be defined as socially and ecologically "Arctic" while avoiding the inclusion of land area under provincial jurisdiction. Yet, at the same time, it puts these populations into a state of "peripheral Arcticness," with little legal or political clarity regarding their potential northern status, as they remain officially outside the three territories that constitute the state's view of the north's extent. Maps, documents, and websites related to the *Northern Strategy* repeatedly emphasize the three territories in depictions of “the Arctic” or “the north.” Similarly, the government's list of achievements under the *Northern Strategy* highlights numerous federal-territorial programs and agreements while omitting any programming or policy achievements outside the territories (Canada, 2011). In sum, while there are inconsistencies in the government's own definition, the federal government principally defines the Arctic in terms of the three territories.

The lines delineating the international limits of the Canadian Arctic are also drawn on a political, rather than legal or geographical, basis. In Canadian legal terms, “international boundary” refers to national borders as determined by the International Boundary Commission, but in the *Northern Strategy* map, the term also refers to the Exclusive Economic Zone (EEZ) and prospective limits of the extended continental shelf. Extending all the way to the North Pole, the area on the map enclosed by “international boundaries” is actually larger than the present EEZ afforded to Canada under international law. It mirrors the “sector” of the Arctic from 60°W to 141°W, first proposed as Canadian in 1907, claimed by Canada in 1925, formalized by the Imperial Privy Council in 1927, and abandoned by Prime Minister Harper in 2006. Since the sector principle was never recognized under international law, the map enshrines as cartographic fact a political claim of dubious legal standing (Byers, 2009, p. 43–44). The map also divides the waters contained within Canada's supposed “sector” of the Arctic Ocean between Nunavut and the Northwest Territories, but not between Yukon and the Northwest Territories. Thus, not only does the map lay claim to waters not officially recognized as Canadian, it also arbitrarily apportions these between only two of its three territories, despite the fact that blue marine areas in the north fall under federal, not territorial, jurisdiction (Becklumb, 2013).

Similarly, the western maritime boundary in the Beaufort Sea is drawn as a prolongation of the terrestrial border between Alaska and Yukon, reflecting the government's position in the continuing boundary dispute with the United States. In the east, however, Canada is *not* represented as having an “international boundary” but rather a “dividing line” with what the map labels *Kalaallit Nunaat* (instead of the more conventional “Greenland”). This line is drawn all the way to the North Pole, representing the boundary established between the two countries in 1973 “on the basis of the equidistance principle from straight baselines created along the coastlines of Greenland and of Canada” (Office of the Geographer, 1976, p. 5). However, the “dividing line” changes into an “international boundary” north of Greenland as it passes through the Lincoln Sea, suggesting that the Canadian government views this potentially resource-rich marine area as its sovereign territory. This is even more puzzling given that the only disputed land territory in the entire circumpolar region is Hans Island, located in the middle of the Nares Strait between Canada's Ellesmere Island and Greenland. Thus, the *Northern Strategy* map clearly stakes Canadian claims to contested Arctic territory in some areas while demonstrating a surprisingly vague commitment on the subjects of international separation between Canada and Greenland and sovereignty over Hans Island, which is also not listed in the index of Arctic locations.

While principles such as straight baselines, sectoral lines, equidistance, and political boundaries between territories and provinces inform delimitation of the western Canadian Arctic and Arctic Archipelago, in the eastern Arctic the *Northern Strategy* map illustrates that geography, particularly water, is a significant determinant of boundaries. In addition to the provincial status of Quebec and Labrador, in the eyes of government cartographers their separation from Nunavut by Hudson Strait (*Nuvummiut Tariunga*) justifies their exclusion from the Arctic. This division speaks to categorical differences between the Government of Canada and Inuit in their conception of terrain. Whereas western understandings tend to view water as a material that divides, for Inuit who have long navigated the many waterways in their environment (Arima, 1994), limiting the Arctic's southern extent to the Hudson Strait is counterintuitive. Müller-Wille (1989, p. 20) finds that “Inuit consider this area - coast and offshore - as one within the bounds of Nunavik as represented by their contiguous Inuit place name system.”

The *Northern Strategy* map clearly demonstrates the dominance of settler geographies over those of indigenous peoples. While Canada's Arctic sovereignty rests in part on Inuit use and occupancy (Canada, 2009), the *Northern Strategy* map minimally reflects Inuit spatial ontologies. Indeed, the map represents a bifurcated landscape of water and land contrary to the Inuit view of their relationship as an integrated whole (Aporta, 2009). In this respect, the map (re)inscribes the Arctic in terms of southern Canadian values and interests and from the perspective of Canadian sovereignty. Curiously, the omission of Inuit perspectives serves to undermine Inuit sovereignty as a self-determining indigenous people while also potentially weakening Canada's own Arctic sovereignty claims. The federal government has used the prior occupation of Inuit to support its Arctic sovereignty claims since at least 1985, when Secretary of State for External Affairs Joe Clark told the House of Commons: “Canada’s sovereignty in the Arctic is indivisible. It embraces land, sea and ice…From time immemorial Canada's Inuit people have used and occupied the ice as they have used and occupied the land” (quoted in Byers, 2009, p. 53). Some analysts have wondered why the federal government has not explicitly marshaled Inuit sovereignty to support its own assertion of Canadian sovereignty with respect to the northwest passage (Fenge, 2008; 2013; Mifflin, 2008; Byers, 2009). Instead, the *Northern Strategy* map omits Canadian Inuit polities entirely, denying them recognition as constituent political units of the Canadian north. However, the use of a “dividing line” rather than an “international boundary” to separate Nunavut and Greenland, as well as use of the Inuit term *Kalaallit Nunaat*, seem to imply the possibility of some alternative political relationship. Perhaps inadvertently, the map suggests some possible form of "Inuit Union" (Ejesiak, 2013), given that the boundary between Inuit in Canada and Greenland is not depicted as a political border separating sovereign states.

This reflects a further inconsistency in the *Northern Strategy* map's elucidation of the transnational boundaries between Inuit inhabiting Canada, Greenland, and the United States (as well as Russia, which is not shown on this map). Inuit in Nunavut and Greenland are shown as separated by a vaguely defined "dividing line," but the 141°W border that separates the Inuvialuit and Inupiat communities living in Yukon and Alaska, respectively, is clearly depicted as an international boundary separating Canadian sovereign territory from the United States. Overall, the map portrays certain geopolitical boundaries as more significant than others and certain intra-Inuit relations as more meaningful, while selectively employing contested legal concepts, political claims, and indigenous sovereignty in ways that are both confused and, quite possibly, counter-productive to the execution of Canada's Arctic policy objectives.

2.4.2 Case study 2: Geo-mapping for energy and minerals, but not people

The second case study analyses a map produced by Natural Resources Canada's (NRCan) Geo-mapping for energy and minerals (GEM) program. Established in 2008, GEM is described by the *Northern Strategy* as "a significant new geo-mapping effort…that will combine the latest technology and geoscientific analysis methods to build our understanding of the geology of Canada's north, including in the Canadian Arctic Archipelago" (Canada, 2009, p. 16). GEM was a cornerstone of the Conservative government's economic vision for the Canadian north, which prioritizes non-renewable natural resource extraction, private sector involvement in northern governance, and commercialization of Arctic science and research (Aglukkaq, 2012). While the program reflects top-down, government-initiated science, it also has an Advisory Group of Northerners that includes “representatives from territorial governments, the private sector and aboriginal socio-economic development organizations” (NRCan, 2015). The first phase of GEM lasted from 2008–2013, and the program was renewed until 2020 with a further CAD$100 million. GEM can be seen as a realization of NRCan's (2015) stated commitment to “helping unlock the full mineral and energy potential of the North and to promoting responsible land development in the region.”

Before it becomes possible to develop Arctic resources, the federal government must first determine the boundaries of the region to be explored. GEM, which has so far created over 700 maps, builds on a long history of mapmaking for identifying and securing natural resource deposits (Vandergeest and Peluso, 1995; Vandergeest, 1996), especially in Canada (Chapin et al., 2005). When Prime Minister Harper announced GEM prior to his annual northern visit in 2008, he drew parallels with the cartographic efforts of Arctic explorers in previous centuries:

> The geo-mapping project is part of a larger plan to map and chart Canada's North, to continue the bold tradition of exploration that has defined our history, and to strengthen our understanding and our sovereignty over a region that will define our future. As I've said before, use it or lose it is the first principle of Arctic sovereignty. To develop the North, we must know the North. To protect the North, we must control the North. To accomplish all our goals for the North, we must be in the North (Prime Minister of Canada, 2008).

Harper's comments divulge his view that it is not enough for a state to merely claim land, especially in areas with abundant natural resources. Instead, it must transform the land from uncharted terrain into mapped and known territory to render it legible for state interests. Under the “use it or lose it” sovereignty doctrine of the Harper government, Canada has been preoccupied with the notion that the state must outwardly demonstrate ownership over its Arctic territory through “control, surveillance, and regulation vis-à-vis markets, populations, and external agencies" (Ong, 2000, p. 56). Control, surveillance, and regulation, however, cannot take place without knowing where resources of interest are located, which is where the scientific and industrial knowledge produced through mapping activities like GEM become relevant.

Due to the importance of GEM in realizing the natural resource potential of the Canadian Arctic, which constitutes a large part of the *Northern Strategy's* economic and social development pillar, in this case study we focus on an overview map included in a 2012 NRCan report that depicts GEM's area of interest (Figure 2-2). Though also commissioned by the Conservative government, the map depicts the Canadian north in a markedly different fashion than the one produced for the *Northern Strategy*. Three of the GEM map's features are particularly notable: its project zones, categorization of areas into essentially known and unknown, and diamond corridors.

First, while the colored area in the GEM map matches the terrestrial Arctic region as defined in the *Northern Strategy*, the "project zones" for resource exploration extend far beyond the three territories' southern borders. The project zones are all ovals of various sizes without reference to geographical or even political features, as if a government cartographer's hand were drawing at whim over a map of northern Canada. One project zone includes an area approaching Prince George, British Columbia, while another includes areas in the provinces of Quebec and Newfoundland and Labrador, and the Inuit region of Nunatsiavut. Other project zones are depicted entirely within the provinces of Saskatchewan and Manitoba, with no overlap at all with the territories. The inclusion of significant provincial areas illustrates a fundamental distinction between the GEM and *Northern Strategy* maps regarding the areas considered within the scope of "the north." The federal government's boundaries of the Arctic appear flexible when a looser definition supports its resource development plans, but less so when it entails including communities in the provincial north. Notably, however, the resource-rich Beaufort Sea, one of the most accessible areas in the Canadian Arctic, is omitted as a project zone even though other marine resource areas are included. This selective representation of resource areas may be due, in part, to NRCan's wish to avoid raising the question of disputed boundaries with the United States. In that sense, then, the map is not even comprehensive with respect to potential areas for resource extraction, emphasizing that a large part of the stories maps tell is revealed by their exclusions, whether people, areas, or resources.

A second notable feature of the GEM map is its division of land into two categories: areas with “Sufficient knowledge to identify potential for resources (pre GEM)” and areas without. The report in which the GEM map is included describes public geoscience knowledge and geological knowledge as the information necessary to support stable long-term resource development and for “investment and development decisions by the private sector and Northerners in general” in such sectors (NRCan, 2012). Agrawal (2002) finds that indigenous spatial ontologies are often appropriated by more powerful actors for the purposes of identifying resources, a distraction which undermines their ability to upset existing power relations. But no indigenous spatial ontologies seem to inform the GEM map. The geoscience and geological knowledge required involve data from state-of-the-art scientific methods and high-tech infrastructure, while the resources in question are limited to non-renewable commodities such as fossil fuels and minerals. Both the knowledge GEM needs and the export-oriented resources it uncovers are of a qualitatively different nature than indigenous knowledge and resources, which generally encompass the biotic resources necessary for subsistence (Wenzel, 2009). Together, these differences in valuation of natural resources, and by extension the different locations in which they may be found, speak to the role of historically and geographically contingent social appraisals in turning nature into resources (Castree, 1997). In the NRCan map, no maritime areas fall within the category of "Sufficient knowledge to identify potential for resources (pre GEM)" even though places including Lancaster Sound, the northern part of Hudson Bay, and the eastern Beaufort Sea are deemed "Project zones." This omission underscores the Canadian government's tendencies to bifurcate water and sea areas and to depict greater confidence in its knowledge of land rather than water, which continues to complicate Western conceptions of territory. Areas for which there is sufficient knowledge, a category that visually encompasses about a quarter of the three territories, are often shaped like quadrants, suggesting the state surveyor's hand at work dividing space according to geometric principles rather than indigenous familiarity with land, sea, and ice.

Diamonds are the only natural resource specifically identified on the GEM map and are illustrated by the third feature of interest: the dashed-line "diamond corridors." Minerals like gold, nickel, and uranium have attracted miners to the Canadian north since at least the late nineteenth century, but the diamond boom only began in earnest in the Northwest Territories in the 1990s following the discovery of diamonds at Lac de Gras, within the westernmost "diamond corridor" on the map. The encircled diamond corridor has resulted in a literal diamond highway. This is where the world's longest heavy-haul ice road lies, supporting the area's diamond mining and exploration activities. The NWT's transformation into one of the world's major diamond producers has had significant impact on the territory's people and environment, generating not only unprecedented revenues but also negative effects ranging from mental health problems to environmental degradation (Gibson and Klinck, 2005). Many of these issues could play out again in the map's two proposed diamond corridors in Nunavut.

Also not represented in the map are most communities, living resources, and ice. Instead, only the three territorial capitals are featured, along with Resolute, an Inuit hamlet that has been a central focus of Harper's policies towards Arctic sovereignty. There, the Department of National Defence (DND) and NRCan are constructing a joint facility that will incorporate a new Canadian Armed Forces Training Centre, a project that requires the expansion of the existing facility housing NRCan's Polar Continental Shelf Program. DND asserts that "as activity in Canada's Arctic accelerates, the military will play an increasingly vital role in demonstrating a visible Canadian presence in this potentially resource-rich region" (National Defence and the Canadian Armed Forces, 2013). Ostensibly, the GEM map is intended to display potential zones of natural resource extraction. It also reveals the interdependence of science, resource extraction, sovereignty, and the military in the Canadian Arctic, which often occurs at the exclusion of northern communities.

2.4.3 Case study 3: **Inuit Nunangat***: the Arctic as homeland to Canadian Inuit*

The third case study examines two maps produced by ITK. Founded in 1971, ITK "represents and promotes interests of Inuit on a wide variety of environmental, social, cultural, and political issues and challenges facing Inuit on the national level" (ITK, n.d.). In 2005, ITK produced a map titled Kanatami Inuit Nunalingit [Inuit communities of Canada] (Figure 2-3) portraying the 53 Inuit communities located across northern Canada (ITK, 2005). In addition to including individual communities, the map visualises Inuit Nunangat as comprising the four federally recognized Inuit regions: the Inuvialuit Settlement Region, Nunavut, Nunavik, and Nunatsiavut. The map's foundation thus rests on human geography and Inuit land claim agreements. Map features are presented primarily in Inuktitut (both syllabics and Roman orthography), with English and French translations taking a secondary role. ITK published a second map, Sikunga Ausuittuq Ammalu Inuit[Polar ice and Inuit] (Figure 2-4), to complement "Inuit communities of Canada" (ITK, 2008b). While it provides names and descriptive passages for each of the four Inuit regions in English and Inuktitut, the map's principal feature is its distinction between “land fast ice,” “marginal ice,” and “polynyas,” all rendered in shades of icy blue and white. In contrast to the Northern Strategy map, which depicts Greenland as Kalaallit Nunaat, the ITK maps do not allude to Inuit in Greenland, Russia, Alaska, or those living elsewhere within Canada but outside Inuit Nunangat. Somewhat surprisingly, these maps thus depict Inuit in northern Canada in isolation from the transnational Inuit community and omit significant numbers of Inuit who no longer reside in the north. This omission could be interpreted as the adoption of state-centric spatial ontologies by ITK that, rather than imagine the Inuit homeland as a transnational networked area of communities spanning the Arctic and sub-Arctic, conceive of it as predicated on sovereign space bounded within the international state system. Conversely, however, Sikunga Ausuittuq Ammalu Inuit [Polar ice and Inuit] exclusively depicts sea ice and does not visualize comparable terrestrial features such as land ice, ice roads, or permafrost. On the one hand, this emphasis underscores the centrality of sea ice to Inuit identity and ways of life (Bravo, 2009). On the other, this reproduction of a land/water binary also reflects Inuit adoption of western orderings of geographic space.

The ITK maps in Figures 3 and 4 address two crucial omissions in the federal government's Northern Strategy. First, the “Inuit communities of Canada” map (Figure 2-3) depicts all four recognized Inuit land claim areas in Canada, including Nunavik in northern Quebec and Nunatsiavut in northern Labrador, which are both excluded from the Northern Strategy map. This reflects the Inuit notion of themselves as a people separated by artificial jurisdictional boundaries within Canada as well as by international boundaries between Canada, Greenland, the United States, and Russia. In parliamentary testimonies, Inuit witnesses decried the division of Inuit Nunangat and the exclusion of Inuit located within the provincial north from Canada's

Arctic policy. Testimonial criticisms included explicit requests or references to past requests for the Government of Canada to reconsider its exclusion of certain Inuit on the basis of living within provinces rather than territories. For example, an executive with Makivik Corporation, which administers the Inuit land claim agreement in Nunavik, testified to the House of Commons Standing Committee on National Defence:

> We are not second-class Inuit. Nunavik's exclusion from the Northern Strategy is based on artificial boundaries, not geographical or social ones. We are Inuit, just like our cousins in Nunavut, and we want the Canadian government to recognise this simple reality…We request that the Canadian government clearly acknowledge that the Northern Strategy applies to Nunavik to the same extent as to other regions in Canada's Arctic…Make it a Northern Strategy for the northern population and the geography – the people and the land. Don't exclude us just because we happen to be in the province of Quebec (Standing Committee on National Defence 2009: 7).

Despite the clear, repeated, and insistent objections of the peoples in question, the federal government has maintained its policy of defining the Arctic in a way that divides and effectively excludes some indigenous peoples. In effect, the government's definition of the Canadian Arctic through the Northern Strategy acts to silence some indigenous voices through the imposition of settler-colonial boundaries.

Second, the "Inuit communities of Canada" map, particularly with its surrounding graphics and background, alludes to how Inuit Nunangat comprises land, water, and ice, as all three are integral to Inuit culture and ways of life (ITK, 2008a). Sea ice is often not considered in western-oriented, political maps of the Arctic, in part because its dynamic, seasonal nature makes it difficult to include in maps based on a spatial ontology of fixed and unchanging land, such as the Northern Strategy's. In contrast to such a static view of Earth's surface, the Inuit Circumpolar Council (ICC) (2008, p. 2) notes that "when defining our 'land,' Inuit do not distinguish between the ground upon which our communities are built and the sea ice upon which we travel, hunt, and build igloos as temporary camps. Land is anywhere our feet, dog teams, or snowmobiles can take us." For Inuit, "land" and "territory" are mobile rather than fixed concepts, and consequently, the Arctic conceivably extends to wherever they travel.

Translating these concepts into maps can be challenging. However, attempting to do so, and therefore appropriately conveying the scope of Inuit Nunangat, is crucial for sociocultural and political reasons, including Inuit representation to the federal government in Ottawa and allowing Inuit to maintain or re-establish alternative economic foundations on which to secure their livelihoods. It was in order to convey these important messages that ITK published Sikunga Ausuittuq Ammalu Inuit [Polar ice and Inuit] (Figure 2-4), which even more explicitly reminds us that sea- and ice-scapes are vital components of Inuit conceptions of, and well-being in, the Arctic (ITK, 2008b). But, as is now well known, climate change poses exceptional threats to the character and extent of sea ice in the Arctic, which has considerable implications for Inuit and non-Inuit use of the sea and land, including subsistence, resource extraction, and shipping (ACIA, 2004).

In addressing the omissions outlined above, ITK's maps contrast with the Northern Strategy and GEM maps by making Inuit in the Canadian north visible and recognizable. ITK's maps are not primarily cartographic renditions of the geographical extent of the Arctic in Canada, but rather visualizations of the Inuit homeland. The maps focus on human beings and their livelihoods, highlighting a key divergence in conceptions of the Arctic as indigenous homeland versus resource frontier. The message reiterated by ITK (2008a) echoes discussions from decades past: "The Arctic is not an empty, remote space waiting passively for Southern-led resource exploitation to occur; instead, it is filled with people who possess autonomy and lead distinct ways of life."

The ITK maps reflect major institutional shifts resulting both from and in increased political decision-making abilities for Inuit in Canada, but can only be effective if bodies other than Inuit themselves accept them. To address this concern, ITK also published a document in 2008 titled An integrated Arctic-Northern strategy. ITK submitted the document to the federal government during the drafting of the Northern Strategy to ensure Inuit were involved in the formation of government policy. Significantly, it includes a call for "getting the geography right" with the objective of "[d]ispelling confusion and defining a workable Canadian stage for Arctic-Northern policy" (ITK, 2008a). In the eyes of ITK, a workable stage for policy in the region is one that encompasses two precise geographic components: "an Arctic component, which can be said to be the same geographic area as Inuit Nunaat, the land and marine areas that make up the modern Inuit land claims agreements that stretch from the Beaufort Sea region to Labrador; and a north component, which can be said to be composed of the three territories" (ITK 2008a, p. 11). ITK proposed the unique term "Arctic-North" as a comprehensive label for the region in question that would bridge the gap between Inuit and government understandings of what constitutes the Arctic. An additional important component of the Integrated Arctic-Northern strategy concerns questions of land use and management. As Inuit regions strive to facilitate vibrant, self-sufficient northern communities able to practice their culture and traditions (for example, Nunatsiavut Government, 2012), the ability to inform land use decisions is as crucial as questions over the geographic extent of the Arctic.

2.5 Maps matter: effects of colonial cartography in Northern Canada

Our comparison of maps produced by the federal government for the *Northern Strategy* and the GEM program with two maps produced by ITK helps elucidate differences in how western and Inuit spatial ontologies articulate the Canadian Arctic. Whereas the priority of the *Northern Strategy* map is to delineate land extent, the GEM map focuses on demarcating land for the specific purpose of promoting resource extraction. The ITK maps serve as counter-narratives to the federal government's dominant paradigms of sovereignty and resource development. Yet the government's western way of defining the region with spatio-political boundaries based primarily on land rather than water or ice is clearly dominant. This dominance affects two key activities: delimiting an Arctic “in-group,” which has access to federal funds earmarked for the Canadian Arctic, and determining land use.

2.5.1 An Arctic in-group and a subaltern sub-Arctic

The federal government's definition of the Arctic excludes provincial Arctic and sub-Arctic regions from the Canadian north, separating the territories’ inhabitants from people short distances away, who might be considered near neighbors living in ecologically and socially similar circumstances. According to Coates and Poelzer (2014, p. 4), “The oddity of a massive federal presence in the territorial North and minimal on-the-ground activities just a few miles to the south is one of the most surprising and little discussed realities of Canadian political life.” Fundamentally, the federal government's emphasis on the three territories can be distilled into the production of social meaning, largely symbolic, for the area north of 60°N (which forms the southern boundary between the territories and the western provinces); and to the federal government's preference for avoiding negotiations with provinces over areas under their jurisdiction located north of 60° (as in Quebec), or in the sub-Arctic latitudes between 55° and 59° (all other provinces except for the Maritimes). The separation of the territories from the provincial north is a determining feature of the Canadian Arctic because these areas are solely distinguishable on this constructed, political basis. As the ITK maps show to the contrary, there is no meaningful distinction to be drawn between the spaces located immediately to the north or south of 60°N besides their political differentiation as reproduced through government policy.

The imposition of settler-colonial definitions of the Arctic and its inhabitants silences indigenous conceptions of the Arctic. In response, the ITK maps represent efforts at counter-mapping, even if they adopt many principles of western spatial knowledge and cartography. For example, the ITK maps sanction Canada's provincial, territorial, and international borders. They delineate a specific territory for Inuit that fits neatly within the political divisions of contemporary Canada and do not include Inuit living in southern cities or outside of Canada. The federal government's imposition of arbitrary boundaries over the areas it understands as the Canadian Arctic significantly curtails the capacity of some indigenous peoples to articulate their interests within the framework of Canada's federal Arctic policy, let alone within their own frameworks. The effects of this colonial demarcation are twofold: first, it reproduces political and policy distinctions between the territorial and provincial Arctic regions, most notably in Quebec (which has territory north of 60°N); second, it divides Inuit into different groups despite their leaders' insistence that Inuit are a single, unified people.

In a basic sense, returning to our initial point regarding the subjectivity of defining the Arctic as a region, the Arctic is predominantly a colonial construction. It is only in reference to southern metropoles and centers of government, capital, and population that a single "Arctic" exists, and the historical division of circumpolar territory into exclusive national regions is an entirely colonial process. Ejesiak is blunt in his assessment that "the international borders that separate the Inuit were imposed by the conquerors without any input from them" (2013, p. 68). Broadhead similarly observes the colonial nature of the Arctic, including the widespread substitution of Anglophone place names:

> The concept of the Canadian Arctic is a colonial construction, about which Canadians are neither taught nor curious. A cursory look at a map of the region demonstrates the colonial nature of the state's sovereignty claims…The names covering the area are thoroughly English…the Queen Elizabeth Islands, the Victoria and Albert Mountains, or…the British Empire Range at the tip of Ellesmere Island (Broadhead, 2010, p. 922).

The continuing reproduction of a federally defined and colonial Canadian Arctic is particularly problematic because it highlights both the current disposition of the Canadian state towards ignoring the taxonomic preferences of people who actually live in the north, particularly indigenous peoples, and the continual structural power the colonial state exercises over indigenous epistemologies and identities.

The inclusion of the territories and exclusion of the provincial north in the *Northern Strategy* also has significant ramifications for the allocation of federal programming funds and the inclusion of various groups in partnerships and consultations with the federal government. In its achievements under the *Northern Strategy*, the federal government lists billions' of dollars worth of funds spent on social and economic development and infrastructure (Canada, 2011, pp. 3–6). All these funds were exclusively allocated for the territories. Residents of the provincial north, a majority of whom are indigenous, were excluded from accessing them. It would seem justifiable, then, to claim the sub-Arctic is a "sub-altern" region in the eyes of the federal government, subaltern being defined as a population considered to be outside the existing power structure within either colonial or post-colonial societies (Spivak, 1988; Escobar, 2001).

If areas comprising the provincial north were included in federal Arctic policy, it would significantly increase the number of political bodies affected by, and thus legitimately able to speak to, Arctic policy. As Coates and Poelzer (2014, p. 2) note, "The vast sub-Arctic expanse [of the provincial north] has close to 1.5 million residents, holds enormous resource potential in oil and gas, forestry, mining, and hydro-electric development, is home to dozens of culturally-distinct First

Nations, Métis, and Inuit groups, and is facing enormous pressures for change." In addition to other possible reasons, including the provincial north in the Canadian definition of the Arctic would increase the number of bodies able to make claims against the Canadian state. Thus, the current federal framework serves to exclude millions of people, including significant numbers of indigenous peoples, from contributing to or benefiting from Canadian Arctic policy.

2.5.2 Defining land use

Similar to the *Northern Strategy* map, as a cartographic artifact of the federal government, the GEM map illustrates the predominance of southern interests and perspectives in articulating the Arctic's extent and land use. Although GEM professes to collaborate with indigenous organizations and emphasizes its desire to improve opportunities for northern employment, its activities can be considered another step in the process of colonizing the North, replacing indigenous ways of conceiving space as networked, fluid, and multipurpose with the delineation of land into quadrants, zones, and blocks designed to facilitate export-oriented resource extraction. While communities in the provincial North are ineligible for certain federal grants due to their location outside the borders of the Canadian Arctic as defined in the *Northern Strategy*, paradoxically, certain GEM project zones extend into the provinces in which federal money can be used to support resource exploration. GEM has already supported actual exploration in areas outside the territorial Arctic, such as investigating hydrocarbon potential in the Hudson Bay and Foxe Basins in Manitoba (Nicolas and Lavoie, 2009). GEM intends to share the knowledge it develops with "industry investors, land-use planners, government and community agencies" in order to inform natural resource development, mostly in the form of hydrocarbons and minerals, in the Canadian north (NRCan, 2015). The explanation accompanying the map states that "in large areas of the North, insufficient public geoscience information exists to attract and guide effective private sector investment in exploration" (NRCan, 2012). In other words, public funding earmarked for an ostensibly Arctic program is also being used to support private sector resource development outside areas the *Northern Strategy* considers to be Arctic while communities in many of these same project zones struggle to gain access to federal Arctic funds.

With its "project zones," "areas of sufficient knowledge to identify potential for resources," and "diamond corridors," the GEM map exemplifies the Conservative government's pursuit of an Arctic strategy in which the Arctic is conceived as a resource periphery whose commodities will enrich the industrial world, in line with core-periphery models of international political economy (Bone, 2009; McCannon, 2012). When compared, the GEM and ITK maps reiterate many of the longstanding tensions plaguing Arctic development and well-being, including differing perceptions of the Arctic as a sparsely inhabited extractive frontier of the Canadian south as opposed to a vibrant homeland for indigenous peoples.

The implications of maps like GEM's that inscribe certain areas for export-oriented, resource-intensive land use rather than traditional occupancy and subsistence lifestyles are far-reaching. As Tester and Kulchyski (1994) point out, extractive industries historically served as critical agents in the struggle to incorporate Inuit into the dominant Canadian society. Not only was the Arctic to be "modernized," its inhabitants were subject to significant socio-cultural interventions as well. These were partly the result of (colonial) allegations that indigenous groups in North America were not "using" the land appropriately; in other words, subsistence hunting and gathering were not considered viable alternatives to ideas of western economic development (Keeling and Sandlos, 2009; King, 2012).

Yet Inuit rights-holders have countered the government's ability to claim any area that is mapped as ripe for extraction, and even to produce maps in the first place. For instance, certain Inuit associations have opposed some of GEM's activities on the basis of their mapping technologies. Most notably, in August 2010 the Qikiqtani Inuit Association won an injunction against the government from the Nunavut Court of Justice to halt seismic testing in Lancaster Sound. John Cheechoo, director of ITK's Environment and Wildlife section, testified before the House of Commons Standing Committee on Natural Resources that the court had forcefully upheld the idea that "no approach to resource exploration development in the Arctic will be successful unless Inuit are full partners and draw direct and substantial benefits" (ITK, 2011). Illustrating the federal government's surprise, and its disconnection from indigenous communities, in its 2012 Evaluation Report NRCan (2012) called the Lancaster Sound injunction "the single largest unanticipated negative outcome of the Program." Conversely, in August 2015 an appellate court rejected efforts by the community of Clyde River to stop seismic testing off the east coast of Baffin Island, ruling that the federal regulator had sufficiently fulfilled its constitutional duty to consult local Inuit *(*Nunatsiaq News 2015). As a result of such conflicting outcomes, it is difficult to predict the efficacy of Inuit legal efforts to obstruct unwanted extractive activities in their territory.

Certainly, it would be misleading to label all Inuit as opposed to resource extraction (ICC, 2011; Nuttall, 2013). As northern residents become more integrated into resource extraction processes, the core-periphery economic model fails to adequately consider how locals, communities, or even entire regions interact and are embedded within land use and industrial development decisions. What is important, therefore, especially in the context of sustainable development and well-being, is to ensure that Inuit have voices and, more importantly, decision-making abilities to articulate and determine their own futures, and the spatial vocabularies and maps to represent their homeland as they see fit.

2.6 Conclusion

Each of the four maps discussed in this paper offers insight into how different political bodies construct the Canadian Arctic as a geographic, political, and social region for distinct political purposes. The *Northern Strategy* map exemplifies how the federal government applies particular parameters to define the geographic extent of the Arctic. While these parameters are not entirely consistent, even within the *Northern Strategy* itself, they are based on settler-colonial geographies that render the Canadian Arctic generally equivalent to the three territories, with selective exceptions made to include provincial areas. By eschewing most of the provincial north, this rendering is sensitive to the constitutional jurisdictions of the federal and provincial governments and mainly delimits the Canadian Arctic to territory under federal authority. In so doing, it demonstrates limited consideration of indigenous political claims, particularly those of the Inuit. By excluding two of the four recognized Inuit areas in Canada, the *Northern Strategy* map privileges settler boundaries at the expense of indigenous geographies, though it remains ambiguous with respect to the transnational ties that bind Inuit in Canada with their kin in Greenland and the United States.

The GEM map highlights forms of land use, particularly natural resource exploitation, that the federal government deems worthy of pursuit. It also demonstrates that, in the context of resource development, the federal government adheres to a more geographically flexible Arctic region than suggested by the *Northern Strategy*. The GEM map encompasses significant provincial territory and extends an understanding of the Canadian Arctic far south of 60°N. It also reduces northern Canada into two types of space: land sufficiently and insufficiently known to enable non-renewable natural resource extraction. GEM thereby reproduces longstanding conceptions of the Arctic as a resource storehouse whose value lies in providing commodities for southern-based producers and markets. This depiction erases forms of land use alternative to non-renewable resource extraction, including local and indigenous uses and the biotic resources on which they rely. The GEM map thus illustrates that the federal government flexibly interprets the boundaries of Arctic Canada in order to facilitate capital accumulation and resource extraction. Such activities, moreover, are premised not just on realizing rents from northern resources for the state and private sector actors, but on denying the possibility for other forms of economic or subsistence activities or even the possibility of *not* extracting natural resources.

Finally, the ITK maps provide a cartographic counter-narrative to those produced by the federal government. In contrast to both the *Northern Strategy* and GEM, ITK identifies an Arctic region defined by Inuit use and occupancy and interrelationships between land, water, and sea ice. The maps delineate the Inuit homeland without consideration of territorial or provincial boundaries, for all four regions of *Inuit Nunangaat* are included without distinction. The partial exception is Nunavut, which is represented in its entirety, and therefore is the only region whose political boundaries are delineated by both the ITK and Canadian state maps. However, it appears that ITK's cartographies are also shaped and constrained by settler-colonial influences. *Inuit Nunangat* is depicted in isolation from the broader, transnational Inuit homeland of *Inuit Nunaat*, suggesting that Inuit in Canada have come to see themselves as significantly detached from Inuit living elsewhere in the circumpolar Arctic. In this respect, the ITK map is actually *less* inclusive than its *Northern Strategy* counterpart, as it is entirely restricted to Canadian sovereign territory without allusion to Inuit political or cultural continuity across national borders.

Overall, we conclude that these maps convey different narratives of the Canadian Arctic while also contributing to the region's (re)production as a defined political space. As with any cartographic visualizations, these maps result in exclusions and omissions, though not necessarily in the ways one would expect. As the official, state-sanctioned representation of the Canadian Arctic for the federal government, the *Northern Strategy* map reflects the dominant representation of the north as a political region. It is an influential depiction of the Canadian Arctic that has significant social consequences for those peoples and communities included and excluded by its boundaries. The GEM and ITK maps demonstrate, however, that even dominant official representations of political space are subject to interpretation and contestation by the governments that produced them and by the actors who seek to rewrite the dominant depiction. Mapping space is a fundamentally political enterprise, and these maps suggest that in the Canadian Arctic, mapping remains incomplete and contested.

2.7 Figures

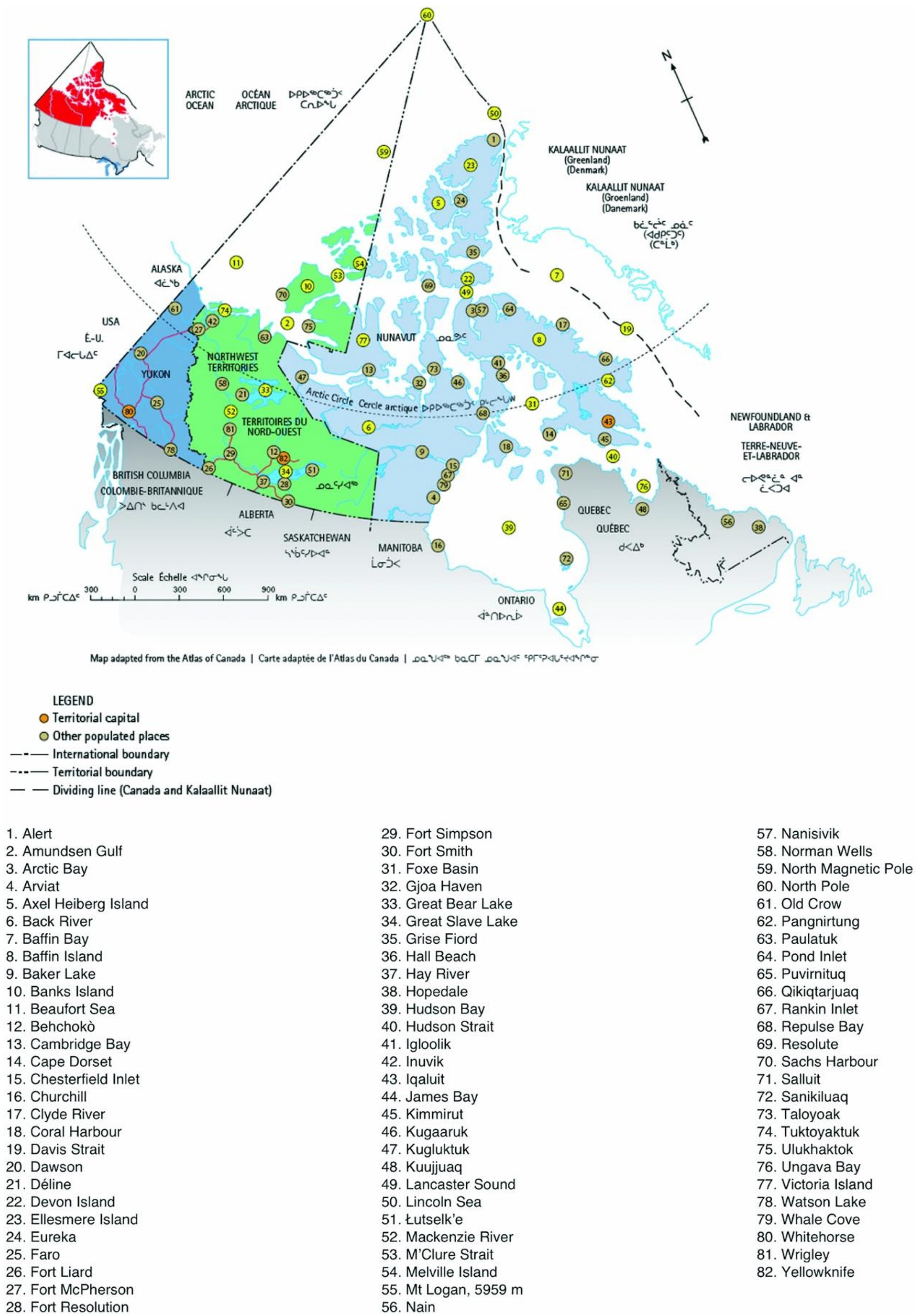

Figure 2-1. Map of Canada's North. Source: *Canada's Northern Strategy* (2009).

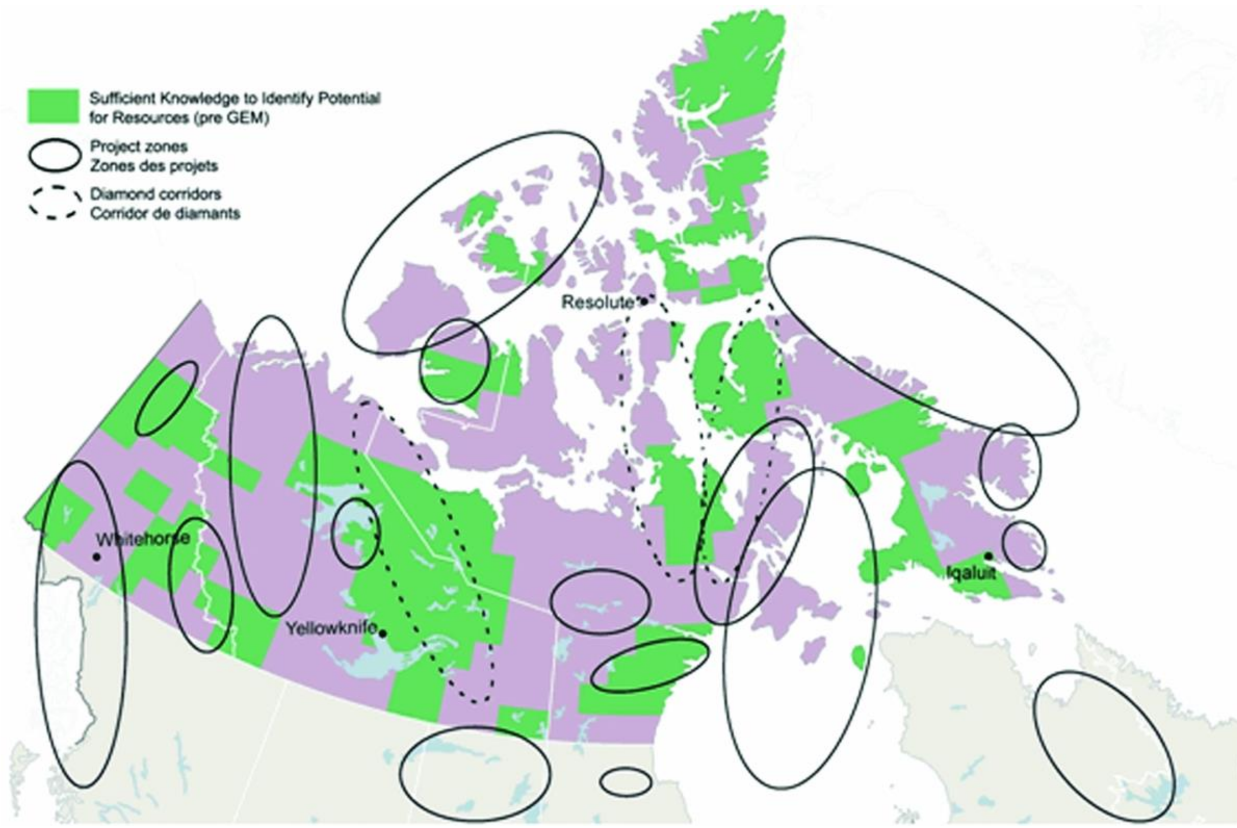

Figure 2-2. *GEM Project Areas*. Source: GEM Coordination Office, via NRCan (2012).

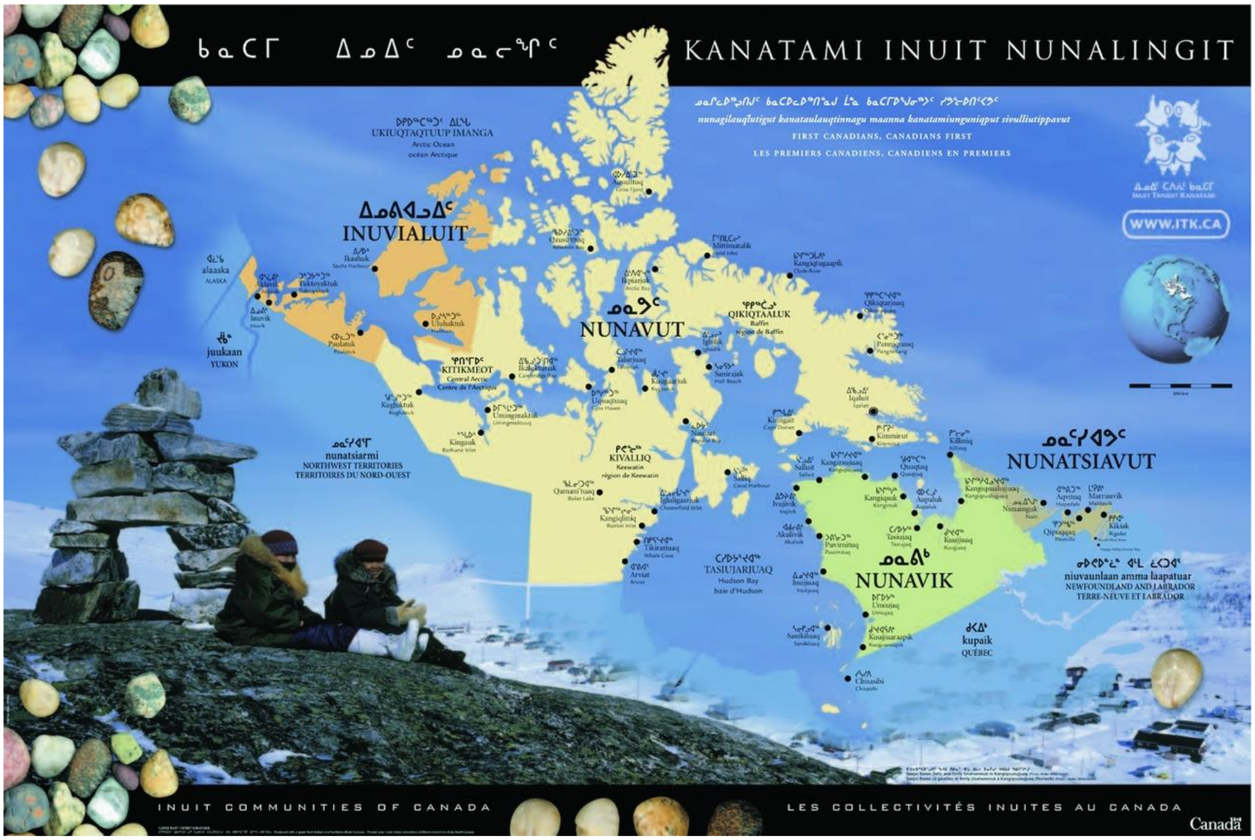

Figure 2-3. *Kanatami Inuit Nunalingit* (Inuit Communities of Canada). Source: Inuit Tapiriit Kanatami (2005).

Figure 2-4. *Sikunga Ausuittuq Ammalu Inuit* (Polar Ice and Inuit). Source: Inuit Tapiriit Kanatami (2008).

2.8 Note on figures

The *Northern Strategy* map (Figure 2-1) is reprinted with permission from Aboriginal Affairs and Northern Development Canada, while both ITK maps (Figures 2-3 and 2-4) are reprinted with permission from Inuit Tapiriit Kanatami. Permission to republish the GEM map (Figure 2-2) was requested from Natural Resources Canada but not granted. Upon consultation with the editors of *Polar Record*, however, the authors decided that since the map is freely accessible within the public domain, it qualifies for publication under fair use principles.

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Chapter 3

From state-initiated to indigenous-driven infrastructure: The Inuvialuit and Canada's first highway to the Arctic Ocean

3.1 Abstract

Nearly sixty years after Canadian Prime Minister Diefenbaker announced his vision for opening Canada's North via the development of a network of so-called "roads to resources," an important part of his plan is being realized. The Governments of Canada and the Northwest Territories are spending CAN $300 million to fund the construction of a 137-kilometer all-weather road across the indigenous Inuvialuit Settlement Region that will link the settlements of Inuvik (pop. 3,140) and Tuktoyaktuk (pop. 898) on the Arctic Ocean. During fieldwork in summer 2016, many individuals in Tuktoyaktuk explained that the road, which will be North America's first public highway to the Arctic Ocean, is being built in order to enhance access to offshore oil and gas resources and strengthen Canada's Arctic sovereignty. Such narratives invite assumptions that the highway exemplifies the state's ceaseless spread across the landscape in search of capital accumulation. However, closer examination reveals that many benefits from the highway project are accruing locally rather than nationally. Two Inuvialuit-owned corporations won the contract to build the highway, and representatives of both had expressed a need for a type of "make-work project" due to persistent regional economic malaise. This chapter argues that local stakeholders who sought a highway strategically leveraged state interests in Northern nation-building through Arctic resource extraction under former Prime Minister Harper to achieve their road-building agenda. The highway should thus perhaps be viewed as an example of indigenous actors marshaling state interests for their own goals rather than a state incursion onto native territory.

“Unless we use the Eskimos, we can never develop the Northland.”
– Arctic anthropologist Diamond Jenness (1923, in Stuhl, 2016)

3.2 Introduction

In 1958, Canadian Prime Minister John Diefenbaker announced his vision for opening Canada’s North via the development of a network of so-called “roads to resources.” Nearly sixty years later, an important part of his plan is finally being realized. The Governments of Canada and the Northwest Territories are spending CAN $300 million to fund the construction of a 137-kilometer public, all-weather road across the indigenous Inuvialuit Settlement Region that will link the inland town of Inuvik (pop. 3,140) with the coastal hamlet of Tuktoyaktuk (pop. 898), on the edge of the Beaufort Sea in the Arctic Ocean (Figure 3-1). The two-lane gravel roadway, officially called the Inuvik-Tuktoyaktuk Highway (ITH), will extend the Dempster Highway, which was initiated under Diefenbaker and currently terminates in Inuvik. The ITH will also replace an ice road built every winter between the two communities, allowing year-round access across the tundra rather than seasonal access via the frozen Mackenzie River (Figure 3-2).

Although the ITH is a small road project in a remote corner of the world, it exemplifies global trends in road-building and indigenous rights. By 2050, it is estimated that the world’s combined road and rail network will be 60% larger than in 2010, with 90% of these roads being built in developing countries (Dulac, 2013). Studies of the social and environmental impacts of the expansion of the global road network largely focus on the Amazon and find that more roads will lead to more deforestation, forest fires, and habitat fragmentation, along with peasant displacement, and natural resource exploitation (Nepstad et al., 2001; Perz et al., 2008; Southworth et al., 2011; Barber et al., 2014). All of these consequences from road-building would, on the face of it, negatively impact indigenous peoples. And yet, the ITH is being built on indigenous-owned lands in a highly developed country. Globally, indigenous peoples enjoy formal legal ownership over an estimated 10% of land worldwide, with Canada accounting for a fifth of all those lands (Rights and Resources Initiative, 2015). An estimated 44% of Canadian land is designated for or owned by indigenous peoples and local communities, one of the highest proportions in the world (Rights and Resources Initiative, 2015). More conservatively, the Canadian government states that 600,000 square kilometers, or six percent of Canada's landmass, are outright owned by Aboriginal peoples (Indigenous and Northern Affairs Canada, 2015). Notwithstanding the traumatic history of colonization, exploitation, and dispossession of Aboriginal, First Nations, and Inuit peoples by the Canadian government that reverberates into the present, the construction of the ITH illustrates how indigenous development can proceed in the context of relatively strong government recognition for indigenous land tenure and with what effects.

Many studies of development on lands occupied or held by indigenous peoples consider their resistance to new infrastructure and megaprojects like dams, mines, highways, and railroads (Fisher, 1994; Gedicks, 2001; Bargh, 2007a; Spronk & Webber, 2007; Gordon & Webber, 2008; Orta-Martínez & Finer, 2010). A focus on the negative effects of industrial development on indigenous peoples, often perceived to be victims in the process, is also prevalent (Davis, 1977; Whiteman, 2004; Bodley, 2008). Fewer studies examine indigenous support for industrial development, specifically roads. Representing a notable exception, Anderson's (1989) study of Aboriginal support for the Daintree-Bloomfield Road in Queensland, Australia, shows how Aboriginal views "surprised and shocked many conservationists, and was at considerable odds with their notions of Aborigines and Aboriginal culture" (p. 214).

This chapter contributes to the emerging literature on indigenous capitalism, entrepreneurialism, and neoliberalism (Harmon, 2010; Bunten, 2011; Ganapathy, 2011; Voss, 2013; Reid, 2015). These practices have also been theorized as "tribal capitalism" by Elizabeth

Rata, who has closely studied how various settlement claims between Maori and the New Zealand state have led capitalist relations to replace communal ones (Rata, 2000; Rata & Openshaw, 2007; Rata, 2012, 2014). This body of literature notably differs from work on pro-indigenous development and ethno-development, which examines how multilateral agencies and NGOs have promoted a new paradigm since the 1990s that supports culturally appropriate economic activities (Radcliffe et al., 2004; Andolina et al., 2009). Under this model, indigenous peoples are still perceived and framed as objects of intervention. However, I pay specific attention to how indigenous peoples can be *agents* of intervention whose activities serve to expand capitalist practices from the bottom-up. I also follow Abu Lughod's suggestion to avoid "the tendency to romanticize resistance" (1990, p. 42) by tracing relations of power among historically marginalized peoples, particularly as they become enmeshed with the state and capital. Considering the ITH, which two indigenous-owned construction companies are building with the support and involvement of the Inuvialuit Regional Corporation, provides insight into the intertwining of indigenous and state power while also drawing attention to the tensions that result both within and between actors and scales.

The ITH makes for an apt case study to investigate the political, economic, and environmental contexts in which an indigenous-led development intervention arose. As legal recognition of indigenous land rights expands in the Americas, Asia, and Australia, (O'Faircheallaigh, 2013), findings from this case study in the Canadian Arctic can be extrapolated to other parts of the world. Over the past few centuries, indigenous peoples in Canada's Northwest Territories have experienced many trends characteristic of indigenous experiences globally. To varying degrees, exploitation and marginalization of indigenous peoples has accompanied the northward penetration of resource extraction, from the fur trade in the 1700s to the diamond mining boom of the 1990s. In the past three hundred years, the region's resource-reliant, boom-and-bust economy has sent benefits flowing out to the state and southern corporations like Hudson's Bay Company and De Beers while locals are left to pick up the pieces. The rusting, abandoned oil rig that has been floating off Tuktoyaktuk since the oil industry went belly-up in the 1980s emblematizes this depletion and degradation. Yet, as Clegg (1989) argues, power is "episodic, facilitative and dispositional" (p. 239). Hegemonic power does not necessarily last forever, for the circuits of power can change.

In the northern Northwest Territories, indigenous empowerment can be traced to the signing of the Western Arctic Claim – Inuvialuit Final Agreement in 1984. This was the first comprehensive land claim agreement signed north of the 60th parallel, the line separating the Canadian territories from the provinces. In 2014, the final major step in the Northwest Territories' devolution process occurred, with the territory taking over land and resources responsibilities from the federal government. Funds totaling up to CAN $3 million are also transferred annually to five aboriginal parties in the NWT, helping to avoid the problem of "ungovernability" (Hale, 2011) or "autonomy without resources" (Stahler-Sholk, 2007, p. 57) – government without funding to accomplish newly delegated responsibilities. The IRC, supporter of the ITH, is the largest beneficiary of these payments (Northwest Territories Lands and Resources, 2013), demonstrating its ambivalent position as an empowered indigenous actor, yet one that continues to rely partly on the state to accumulate capital.

While most research that considers the roads-development nexus on indigenous lands examines why states build roads (Fairhead, 1992; Wilson, 2004; Demenge, 2015, Murton, 2017), I ask a different question: why, in the Inuvialuit Settlement Region, are two indigenous-owned companies building a road? How is it that an "off-road" rural settlement, to use Porter's (2002) term, lying on the edge of the Arctic will soon be connected into the Canadian national highway system? To understand this process of indigenous road-building, I conducted 22 semi-structured interviews and had informal conversations with many more residents in Inuvik and Tuktoyaktuk during two trips to the region in June-July 2016 and March-April 2017. Residents in Inuvik were more willing to be recorded than in Tuktoyaktuk, so nearly all of the interviews in Tuktoyaktuk were transcribed by hand. To protect informants' identities in such small communities, interviews were conducted under the condition of anonymity; interviewees' affiliations and residences are listed in Appendix 1. Many of the interviewees were employees of the Inuvialuit Regional Corporation or municipal government, providing insight into perspectives from the seats of indigenous power. A minority of informants, generally hunters and trappers and people who identified as white living in Inuvik and Tuktoyaktuk, voiced opposition to the road. While their views are addressed at the end of section 3.5.2, herein, focus is concentrated on explaining how indigenous and local authorities mobilized national goals and leveraged opportunities afforded by land claims treaties and devolution to accumulate state capital. Results from this fieldwork-based approach are used to challenge narratives that new roads are overwhelmingly detrimental for indigenous peoples and that indigenous interests are synonymous with local-scale interests and with environmental conservation. The fuzzy reality, as the ITH shows, is somewhere in between. Certain scholars and practitioners view industrial economies as anathema to indigenous well-being and the so-called "bush economy" – the reliance of people in northern communities on resource gathering and harvesting for their livelihoods (Robinson & Ghostkeeper, 1987). Yet members of some indigenous groups, including Canada's First Nations, "believe that they can achieve their development objectives through participation in the global capitalist economy" (Anderson, 1997, p. 1484).

Findings from this research indicate that indigenous agency and power can be used to support and advance capitalist and developmentalist aims, with the state condoning and funding, rather than imposing, industrial projects. The theoretical implications of this are that while some development practitioners and researchers have advocated for greater indigenous rights as a means of enabling small-scale, environmentally sustainable economies (Clarkson et al., 1992; Loomis, 2000; Zeppel, 2006), indigenous agency can also generate short-term, large-scale industrial development whose long-term consequences for local economic viability are unclear. Whether indigenous-led industrial development helps indigenous communities to accumulate capital and economic control or instead perpetuates social and economic marginalization and underdevelopment is yet to be determined.

3.3 The Inuvialuit Settlement Region: Invasion, accommodation, and accumulation

The Inuvialuit have inhabited the Mackenzie Delta area in western Canada since time immemorial, according to their oral histories (Kolausok 2005), and for at least 600-700 years according to archaeological records (Alunik et al. 2003). Closely related to other Inuit peoples residing from the Bering Strait to Greenland (Morrison, 1997), today, their population numbers slightly over 3,000 people. The Inuvialuit largely reside within six communities across the Inuvialuit Settlement Region (ISR), making them one of the most concentrated indigenous populations in the Arctic (Lyons, 2010). Other indigenous groups living near the Inuvialuit include the Gwich'in, a First Nation people to the south seen to be their traditional enemy, and the Iñupiat, who traditionally reside across the border to the west in Alaska (Lyons, 2010). Inuvik is the largest population center in the ISR, with 3,140 people, approximately 50% of whom are indigenous, while Tuktoyaktuk has 898 residents, 90% of whom are indigenous and mostly Inuvialuit.

In the ISR, the bush economy remains strong even as the environment experiences some of the most rapid climate change in the Arctic. Traditionally, the Inuvialuit have subsisted on "country food" – marine and terrestrial resources like beluga whale, whitefish, caribou, muskrat, geese, and berries. In 2013, 66% of Tuktoyaktuk residents reported hunting or fishing, with a similar percentage consuming country food for more than half of their subsistence (Statistics Northwest Territories, 2016a). These figures are significantly higher than in Inuvik. Living partly off the land remains vital for many in Tuktoyaktuk in part due to high unemployment rates and low salaries. In Tuktoyaktuk, the average personal income is $37,517, compared to $56,312 in Inuvik (Statistics Northwest Territories, 2016a, 2016b). Despite per capita GDP in the NWT being the highest in all of Canada thanks to its diamond mining industry and low population, the average personal income in Tuktoyaktuk is much lower than that of even the poorest province, Newfoundland. Furthermore, in Tuktoyaktuk, the employment rate among Aboriginal peoples in 2014 was only 35.8% compared to 89.9% for non-Aboriginal people, indicating a deep economic divide that runs along racial lines (Statistics Northwest Territories, 2016a).

The economic marginalization of the Inuvialuit can be traced to the start of sustained contact between the Inuvialuit and Europeans, Canadians, and Americans in 1890, when American commercial whalers began to base themselves at Herschel Island in the Beaufort Sea. Some Inuvialuit profited from trapping and selling furs to the whalers, and a lucrative, entrepreneurial trade developed. One New England whaling captain remarked, "There had always been some trading, but I think the trading developed to a new high level at about this time, owing to increased knowledge among the whalers, and likewise among the natives" (Bodfish, 1936, in Usher, 1971, p. 174). The industry wreaked havoc on the local whale and terrestrial caribou populations, which the Inuvialuit depended on for subsistence (Lyons, 2010). European epidemics caused the

Inuvialuit population to drop, too, with Iñupiat from Alaska consequently moving in. As the indigenous population grew more accustomed to a market economy and permanent settlement, Inuvialuit, Iñupiat, and Gwich'in began moving to the burgeoning town of Aklavik in the early twentieth century. Meanwhile, the Hudson's Bay Company established a fur trading post in Tuktoyaktuk in the 1930s.

By the middle of the twentieth century, the Canadian government came to see the development of the North and its people as a national responsibility (Farish & Lackenbauer, 2009). Ottawa decided to pursue an interventionist strategy of treating the Inuit as "Canadians on territory claimed as Canada" rather than leaving them alone (Ironside, 2000, p. 106), though Pickles (1998) argues that the government did not genuinely perceive them as Canadians and treated the Inuit with a paternalizing attitude. Indeed, policies of cultural assimilation carried out by the government, church, and residential schools caused intergenerational trauma that persists into the present (Andrachuk & Smit, 2012). The Inuvialuit also had to contend with a shrinking land base. Whereas agricultural expansion had displaced indigenous peoples in southern Canada, industrial expansion began to displace their northern counterparts in the mid-twentieth century (Berger, 1977).

At the start of the Cold War in the 1950s, Ottawa sought to establish an administrative center in the western Arctic that would house the largest military installation in northern Canada. Since Aklavik was prone to flooding, Ottawa chose a site with high banks and ample gravel for its planned settlement. To the consternation of many locals who saw the new center as an imposition on the land, the government gave it an Inuvialuit name: Inuvik – literally, "the place of man." The town's construction created numerous casual and permanent jobs, introducing the wage economy to the region (Hargrave, 2003 [1971]). As part of its Cold War militarization efforts, the government's construction of a Distant Early Warning radar station in Tuktoyaktuk in the 1950s to guard against possible Soviet attacks created jobs for Inuvialuit, too.

In the late 1970s and early 1980s, high oil prices and Canadian government subsidies for exploration created an oil boom off Tuktoyaktuk in the Mackenzie Delta-Beaufort Sea, which employed many Inuvialuit. At the same time, it exacerbated a range of social problems introduced initially by the rapid spread of the industrial system such as alcoholism, crime, violence, and welfare dependence (Berger, 1977). Once oil prices returned to their normal levels, the boom waned and most of the icebreakers, supply ships, and drilling platforms were redeployed or decommissioned (Voutier et al., 2008), with one drill rig left to float just a few hundred feet offshore in a bay, where it still idles.

In the 1970s and 1980s, as government officials dreamed big about northern development fueled by oil and gas extraction, Ottawa proposed the construction of the 1,220-kilometer Mackenzie Valley Pipeline. An inquiry led by Justice Thomas Berger traveled to 35 communities in the Western Arctic and Mackenzie Valley. Berger concluded that many indigenous peoples were opposed to the pipeline and that it would have irreversibly damaging effects, particularly socially. Recommended a ten-year moratorium on pipeline construction, the justice damningly avowed, "We must recognize now that if we remain indifferent to their opposition, that indifference will bring yet more severe deformation of the native economy, serious social disarray, and a cluster of pathologies that will, taken together, constitute the final assault on the original peoples of the North" (1977, p. 116).

Berger's report sparked a new era of relations between Northern indigenous peoples and the Canadian government (Anderson et al., 2006). Indigenous peoples sought to build their economic development capacity by regaining control of traditional lands (Anderson, 1997). In the

1960s, the Canadian government gave away permits for exploration without consulting the Inuvialuit, as it saw their land as Crown Land. As oil and gas exploration took off in the 1970s in the Mackenzie Delta, the Inuvialuit attempted to settle their land claims with the Canadian government in order to obtain control over resource development (Belanger, 2008). In 1984, the Inuvialuit Final Agreements were reached. These allowed the Inuvialuit to retain title to 91,000 km^2 of land and receive $45 million paid over 13 years, plus another $10 million for developing industries and businesses. Four corporations were formed: the Inuvialuit Regional Corporation, which initially received the lands and funds, the Inuvialuit Land Corporation, to own and manage the lands, the Inuvialuit Development Corporation, to engage in business activities, and the Inuvialuit Investment Corporation, to invest in portfolio securities. Notably, the agreement states that Canada and the Inuvialuit both agree to support "(a) full Inuvialuit participation in the northern Canadian economy; and (b) Inuvialuit integration into Canadian society through development of an adequate level of economic self-reliance and a solid economic base" (Indian and Northern Affairs Canada, 1984, p. 67). Integration is therefore no longer premised on cultural assimilation, but rather economic assimilation that is carried out, paradoxically, through Inuvialuit economic independence and self-sufficiency.

The Canadian federal government's promotion of economic independence among the Inuvialuit differs starkly from the paternalistic, protective attitude that prevailed from the 1930s-1970s. Yet government schemes to foster self-regulating indigenous subjects by linking ideas of freedom to economic independence still represent a form of government intervention (Lawrence, 2005). A report from the Auditor General (Office of the Auditor General, 2003) noted, "The major responsibility for their economic development rests with First Nations" (p. 20). Similarly championing market values, the Department of Indian Affairs and Northern Development's

Aboriginal Economic Development Division, formed in 1999, strongly supported "building a vibrant and diverse Aboriginal business sector through the establishment of sustainable First Nation and Inuit businesses where opportunities exist in major regional resource development activities" (Indian and Northern Affairs Canada, 1984). The corporate leadership of the Inuvialuit has accumulated the benefits of the government's support for entrepreneurialism. Of the more than $40 million distributed to indigenous development in the NWT from 2000-2004, the Inuvialuit received $12 million, with three-quarters of that going to oil and gas-related ventures. The total amount of funding they received is over five times higher than the Tli'Cho despite the two indigenous peoples having similar populations. The Inuvialuit corporations' past success in receiving government funding can be partly attributed to their strong support for industry, whether it is road building or fossil fuels. The IRC, for instance, is a staunch supporter of Arctic oil, critiquing the five-year moratorium placed on the industry's development by Prime Minister Justin Trudeau (Inuvialuit Regional Corporation, 2017). One non-indigenous resident of Inuvik argued, "There's no difference between the Inuvialuit and Exxon. Their bottom line is their profit. A corporation is a corporation is a corporation" (personal communication, June 29, 2016).

In the quarter-century since land claims, Inuvialuit leadership has arguably adopted the tenets of market rationality, neoliberalism, and industrial development. At the same time, communities in the ISR have recently hit hard by market woes and recession. As the prospects for oil and gas dimmed after a mini-boom in the early 2000s, economic opportunities for the Inuvialuit did, too, especially outside of the government center of Inuvik. In Tuktoyaktuk, hotels, shops, and other services like barbershops, bakeries, and take-aways all shuttered, leaving abandoned buildings in their wake. Against this backdrop of economic desperation, a highway may seem like the last thing Tuktoyaktuk would need. But to many Inuvialuit corporate elite and locals alike, it was exactly what the town and Western Arctic region needed to get back on its feet – a “make-work” project, in the words of a representative from one of the two contractors building the highway (Interview 5). As market forces were not working positively in the ISR at the beginning of the 21st century, the Inuvialuit would instead create narratives and undertake lobbying efforts to spur the government to fund their own intervention in the land, one that would take up 80 years' worth of the amount of gravel Tuktoyaktuk uses annually: a highway to the Arctic.

3.4 Theoretical framework: Indigenous peoples, infrastructure, and roads

Adopted in 2007, the United Nations Declaration on the Rights of Indigenous Peoples affirms that the General Assembly is “convinced that control by indigenous peoples over developments affecting them and their lands, territories and resources will enable them to maintain and strengthen their institutions, cultures and traditions […]” (United Nations General Assembly, 2011). Numerous studies find a relationship between indigenous rights and indigenous well-being (Selverston-Scher, 2001; Colloredo-Mansfeld, 2009), although Cooke et al. (2007) worryingly find less consistent progress despite increasing rights.

Yet what if control over lands, territories, and resources also promoted industrial capitalist development and the creation of an indigenous elite? This is a question that merits serious consideration rather than romanticization, for land claims and the “trajectory of indigeneity,” to use the words of anthropologist Jonathan Friedman (1999, p. 13), do not guarantee the preservation of social relations, cultural practices, and the environment. While Rata's (2014) theory of tribal capitalism aptly shows how institutional changes can reconfigure indigenous relations and practices, little attention has been paid to the territorial dynamics that condition development possibilities in indigenous lands. This is important to understand because, as Castree (2004) notes, at its root, the indigenous movement concerns control over place. While it is often assumed that the global indigenous movement "must confront a tension between local needs and extra-local wants," (Castree, 2004, p. 137), in certain cases, these needs and wants are mutually supportive. Below, I theorize how local and extra-local development imperatives in the same place can come to be reconciled through the lens of a political economy of roads.

In the geographically expansive settler-colonial societies of the Canada, the U.S., and Australia, the state sought to clear lands of indigenous peoples to gain a monopoly on territorial control. The process of westward expansion in Canada was less violent than in the U.S., where the Indian Removal Act of 1830 authorized the president to negotiate with Native tribes to remove them from their land to territory west of the Mississippi. In part, this was due to fewer demands north of the border for agricultural land. Yet the Canadian state still sought Native expulsion and termination - and ultimately, a monopoly on territorial control.

The modern state did not just control territory seized from indigenous peoples with force, but also through the project of development, which became increasingly rationalized and technocratic in the postwar period. An important strategy of the state's exercise of territorial control involved the production and maintenance of transportation and communications infrastructures like roads, railroads, and canals (Mann, 1984). As the state's territorial reach expanded, it sought to enhance its coercive capacity, too. To reach sparsely populated remote frontiers, the modern state built road and rail systems – the "hardwiring" that made distant provinces legible to central authorities (Scott, 1998, p. 73). In places like the Arctic and the Amazon, Canada's "Roads to Resources" program in the 1960s and a spate of Brazilian road-building in the 1970s epitomized state visions of nation-building and modernization through the construction of new thoroughfares.

It may appear that roads are a product of outmoded state visions of top-down, centrally-oriented development – a form of "twentieth century political economy," according to anthropologists Dimitris Dalakoglou and Penny Harvey. Yet, they argue, roads are also "the paradigmatic material infrastructure of the twenty-first century" (2012, p. 459), and their construction "involves financial, regulatory and technical relations that often fold international, national and local regimes into a single and specific location." In this sense, roads embody new relations between the state and the places it seeks to connect not primarily to the political center, but rather to markets, especially global ones. Contemporary road projects in the Amazon, for instance, aim to open up access to resources for export in order to stimulate regional development (Perz et al., 2008).

Roads are also important for understanding development processes because their construction does not neatly fit into an orthodox theory of top-down modernization, a radical theory of dependency and accumulation by dispossession, or even newer theories of post-development or alternative development. As I will show with the case of the ITH, indigenous interests managed to capture state capital by strategically linking the road's construction to governmental goals of shrinking distance, enhancing sovereignty, and expanding political and economic development. Drawing on Bebbington (2000) and Rata (2014), rather than seeing development as immanent and imposed from above with local and indigenous actors as powerless to modify it, I see development as intentional, with local and global processes mutually constitutive.

The origins of Inuvialuit pursuit of local accumulation through road construction can be traced to the state's recognition of their land claim, agreed in 1984. In early 1970s Canada, Aboriginal political activism, increasing public awareness of Aboriginal issues, and a series of court rulings that affirmed the case for Aboriginal title to land led to the comprehensive land claims agreements with Aboriginal peoples whose title had not been extinguished by treaty or superseded by law (Usher, 2003; Henderson, 2007; Saku, 2008). This largely applied to Aboriginal peoples living in the country's far north and west; treaties had been signed with Aboriginal peoples living closer to the upper Great Lakes watershed, the political and economic center of early Canada, beginning in the 1860s. The northward expansion of industry such as with hydropower in Quebec's James Bay, a gas pipeline in the Mackenzie Valley Delta, and oil and gas in the Beaufort Sea sparked indigenous organization and attempts to settle land claims to obtain control over natural resources on their lands (Saku, 2008). The same was true across the border in Alaska, where the discovery of oil at Prudhoe Bay in 1968 prompted swift resolution of land claims under the 1971 Alaska Native Claims Settlement Act (ANCSA) (Smiddy, 2005).

As the tide of indigenous activism was growing, in the neoliberal era, states began shifting from a territorial to an entrepreneurial logic, preferring spatially differentiated zones of governance over territorial encompassment (Hale, 2011). In this account, the modern state is content to divest itself of responsibility over areas deemed irrelevant to the global economy. Many of these so-called "empty spaces" are the areas to which indigenous and black people are granted autonomy (Hale, 2011), from the formerly remote, arid plains of Oklahoma to the barren Arctic tundra. In Canada, the Nunavut Land Claims Agreement, "by far the largest of the land claims settlements in the modern land claims era" (Berger, 2006, p. 8), comprises one-fifth of Canada. This may seem like a vast amount of land, but Nunavut is the only province or territory with no road connections to the rest of Canada. The transfer of these remote lands may thus have been relatively easy for the state to justify. Devolution also permits the state to transfer state responsibilities to indigenous communities as part of a broader neoliberal strategy (Lawrence and Gibson, 2007; MacDonald, 2011; Howlett et al., 2011). The argument could also be made that the state is willing to agree to land claims over "empty spaces" for a slightly different reason than Hale (2011) suggests: instead, to encourage private and indigenous enterprises to take on the risks of development in frontiers that it would like to see economically integrated but not necessarily at its own expense, such as the Arctic.

Beginning in 1975, the Canadian state settled numerous land claims with indigenous peoples in the country's northern territories. Of the 21 comprehensive land claims agreed between 1975 and 2005, 18 were in the Canadian Arctic (the territories north of the 60^{th} parallel), northern Quebec, or northern Labrador. Substantive differences distinguished these comprehensive land claims from treaties settled in the nineteenth century. Although the government pursued a tried-and-true "land-for-money" strategy (Whyte, 1982), larger Aboriginal land ownership was granted. The Inuvialuit Settlement Region, for instance, comprises 30% of the original land base (Usher, 2003). Importantly, lands were transferred to specially established Aboriginal corporations like the Inuvialuit Land Administration, a division of the Inuvialuit Regional Corporation, which manages Inuvialuit lands. The Canadian land claims were inspired by ANCSA (Barsh, 1984), which established 13 regional Aboriginal corporations to manage lands and capital transferred from the government. The Canadian government also made one-time capital transfer payments to Aboriginal corporations while establishing programs such as resource revenue sharing and guarantees of fair access to government contracting, procurement, and other economic programs (Usher, 2003). Similar moves to commodify and corporatize the settlements process took place around the same time in New Zealand, where the state used treaty settlements "as a conduit for neoliberal policies and practices" (Bargh, 2007b, p. 41).

A strategy of land and capital transfers and corporatization pursued by states aiming to resolve indigenous claims may have the effect of reorienting indigenous aims towards economic development rather than cultural preservation. Altamirano-Jimenez (2004) argues that land claim treaties separate territory from indigenous culture, turning indigenous citizenship into market citizenship. As a result of these treaties, Nasdady (2003) finds a bureaucratized indigenous society in which people are sitting in offices rather than being out on the land. This cultural shift as a result of land claims treaties is partly why some view them as perniciously reproducing policies of colonization and assimilation (Nasdady, 2003; Altamirano-Jiménez, 2004; Coulthard, 2007), even though some also note the treaties' practical benefits for indigenous peoples (Chaffee, 2008). Henderson (2007) specifically finds that in Nunavut, while residents initially saw devolution as a means of reviving Inuit cultural practices, contemporary concerns focus more on reviving the economy. An entire banking industry has arisen in Canada to support the indigenous economy, complete with marketing campaigns and testimonials from indigenous entrepreneurs who advertise, "If you're Aboriginal, the entrepreneur is there inside you…We are creating jobs for people. We are taking care of ourselves. So it's time to be proud of First Nations in Canada" (BDC, 2017). In a potentially fraught proposition, key stakeholders, including the Standing Senate Committee on Aboriginal Peoples, have drawn attention to what they see as one of the biggest obstacle to securing loans and fostering economic development: using Aboriginal on-reserve land as collateral, which is prevented by Section 89 of the Indian Act, passed in 1876 (Conference Board of Canada, 2017). Over time, if the state convinces enough indigenous peoples that their real fight is one for economic development than political and cultural recognition on their own terms, Escobar's (1995) description of the Aboriginal struggle as "above all a struggle over symbols and meanings, a cultural struggle" (p. 248) may become hollowed out.

State efforts to spur indigenous self-sufficiency focus on remote areas rather than cities, where indigenous peoples are forgotten and excluded from its model of indigenous development (Altamirano-Jiménez, 2004). This is in part because remote areas may be rich in resources, which require infrastructure to access them – two characteristics that may persuade their indigenous peoples of their ability to participate in development once their land claims are settled. Compared to agricultural expansion, resource extraction like mining or logging may more insidiously threaten indigenous lands and cultures because since such acts do not result in a loss of territory, they may be viewed as "economic opportunity rather than invasion" (Schwartzman & Zimmerman, 2005, p. 723). Thus, particularly in Arctic indigenous lands, where pressure has come from 20th and 21st-century resource extraction as opposed to 19th-century agricultural expansion, the resolution of land claims could potentially hasten the development of resources and associated infrastructure.

While the state might have once seen devolution as a means of divesting itself from responsibility over unimportant lands and populations, changes at the global scale can cause territory once seen as idle, marginal, and left to the devices of indigenous corporations to become nationally relevant again. This occurred in Canada in the early 2000s, where increasing recognition of climate change and the global commodities boom enhanced the perceived geostrategic and geoeconomic importance of the country's Arctic periphery. As global speculation about the Arctic frontier grew, so too did Ottawa's concern with exercising sovereignty, in no small part through developing the North (Dodds, 2011). Canadian Prime Minister Stephen Harper famously uttered, "Use it or lose it." Yet now, rather than the Canadian state seeking to impose a high-modernist vision from above, it instead seeks to stimulate projects that it sees as entrepreneurial. When the state feels a need to develop lands now held by indigenous corporations, this creates opportunities for indigenous accumulation and the possibility for local and extra-local development needs to become mutually supportive.

Contemporary state interest in using and developing lands now owned by indigenous peoples has created opportunities for indigenous accumulation. Rasmussen and Lund (2017) see frontiers as spaces where existing orders and relations are violently destroyed in order to make way for new modes of access and control. Yet since dynamics of both destruction and construction can coexist, it is possible to imagine a scenario in which an elite group of those whose existing relations were turned upside down, in this case the Inuvialuit, become the new "frontiersmen" who profit under a new spatial ordering. Indigenous control over lands and resources can provide a degree of legal certainty that allows an influx of outside investment, whether public or private, and business alliances for development (Anderson, 1997). Not all land claims and indigenous titles are respected or properly or fully implemented. But in certain instances, the establishment of indigenous title, particularly in combination with the creation of indigenous corporations, can set the stage for indigenous-led industrial development, even though this can open up new tensions within indigenous communities. When the Kluane First Nation was negotiating its land claims with the Canadian state in the Yukon, for instance, some members were uncomfortable with Euro-Canadian notions of property and land claims, which conflicted with traditional ideas of land (Nadasdy, 2002). Similar tensions arose in Papua New Guinea, where indigenous squatters in the Gazelle Peninsula opposed the indigenous bourgeoisie's efforts to accumulate land as a means of production rather than as a means of subsistence (MacWilliam, 1986).

In certain instances, the state actually views devolution and indigenous empowerment as strengthening rather than weakening the state thanks to greater possibilities for market expansion. As Usher explains, "These modern treaties provide for Aboriginal involvement in the management of the entire territory, but not their exclusive governance over any of it. This is a vision of integration and participation, rather than of separation and coexistence" (2003, p. 379). Even where the state has indeed shifted from a vision of territorial control towards one of economic integration, it has not completely abandoned the former aspiration. Efforts to reincorporate indigenous-titled lands through market development can in fact be read as a form of reterritorialization that contributes to nation-building. The Canadian Auditor General Report from November 2003 proclaimed, "Through land claims agreements, self-government agreements, and devolution, Indian and Northern Affairs Canada, on behalf of the Government of Canada, is leading the federal strategy on a course of nation building in the North at an unprecedented rate" (Office of the Auditor General, 2003, p. 3). The report goes on to say that whereas indigenous peoples opposed the Mackenzie Valley Pipeline in the past, today, they are "leading the effort" to build it, just as they have done with the ITH.

At the local scale, then, the strategy for indigenous peoples seeking funding for development projects may be to fit their locale and project into national imaginings and global markets. This involves a project of re-imagining their lands, which may have been cast off as marginal, worthless, or outside of state concern precisely as a result of land claims agreements, as possessing importance beyond indigenous and local interests. This time, however, indigenous and local elites are directing this re-imagining of their land as a "frontier" of bigger relevance rather than outsiders. For the state to willingly finance development on a remote periphery, it must be convinced of its national importance and relevance to global markets. In short, possibilities for indigenous accumulation within neoliberal states emerge through the indigenous pursuit of discursive strategies that mobilize old ideas about the state and new ideas about global connectivity, along with material strategies that make the most of opportunities afforded by devolution and land claims.

3.5 Making a local road global

In 1974, two years after the discovery of a gas field south of Tuktoyaktuk, Public Works Canada began the first route survey for a highway in the area. In 1977, the agency proposed a potential road alignment for the ITH (Transportation Planning Division, 1999). Many informants in the communities were familiar with these plans. A middle-aged man working in the tourism industry in Inuvik recalled, “I saw maps of the route when I was younger, when I was a kid” (personal communication, June 27, 2016). A downturn in petroleum exploration and the Berger Commission’s recommendation against the construction of the Mackenzie Valley Pipeline halted the government’s initial interest in building the road. Over the following decades, state enthusiasm waxed and waned in relation to political and economic conditions at various scales, from local political leadership to the price of oil. At a community consultation meeting in Tuktoyaktuk in January 2010, a resident recollected, “Twenty years ago, we discussed the Highway and it got surveyed. Later, the Hamlet Council changed, and our dream was gone” (Kiggiak - EBA, 2011, p. 16). So why did it take “thirty to forty years to get the shovels in the ground,” as one informant in Tuktoyaktuk noted? At first glance, changes in national politics and global markets would seem to provide sufficient explanatory power. Solely attributing the highway’s development to federal government strategizing and global commodities cycles, however, would dismiss the role of indigenous agency in building the road.

The global and national imperatives of oil and Arctic sovereignty were repeatedly offered as reasons for building the ITH by interviewees from various demographics, whether in Inuvik or Tuktoyaktuk, and whether they worked for the government or not. Beginning in the early 2000s, the price of oil rose steadily except during the 2008-2009 recession. From 1998 to 2008, Canada's oil rents as a percent of GDP rose nearly seven-fold (World Bank, 2017). Prime Minister Harper, a staunch advocate of the industry's growth, took to branding Canada "an emerging energy superpower" (Way, 2011). In 2007 and 2008, extensive oil and gas leases in the Beaufort Sea just north of Tuktoyaktuk were sold to BP, ExxonMobil, and Imperial Oil. Drawing a direct connection between these leases and the highway, an employee of the territorial government working on oil and gas issues suggested, "One of the impetuses for the Harper decision was the awarding of exploration rights to Imperial and BP in the neighborhood of $1.5 billion over a two-year period" (Interview 1). The road, then, might seem to provide the missing link needed to develop these leases. Yet as he and other informants pointed out, significant discoveries of oil and gas were made offshore in the 1970s in the absence of a road. Ice runways were built for cargo planes atop the frozen Arctic Ocean, and "you could drive up next to the [drillships] and it was like being next to a skyscraper, just frozen into the ocean," recalled one informant from Inuvik who had worked in the oil industry (personal communication, June 29, 2016).

Although the neoliberal state's mission is arguably to "facilitate conditions for profitable capital accumulation" (Harvey, 2005, p. 7), the economic rationale for the ITH is unclear for a number of reasons. First, government reports suggest that "the project is not viable from a strict economic perspective," with a $66 million loss forecast in 1999, when the road was estimated to only cost $100 million. Second, since the ice road only costs $129,000 to build each winter (Department of Transportation, 2010), the $300 million budgeted for the ITH could cover 2,325 years of its construction – far more time than would likely even be necessary given the rate of Arctic climate change. Maintenance of the ITH is expected to cost a further $1.5 million annually (Holland, 2015). Whereas Campbell (2012) views poorly planned Amazonian roads as turning into permanent projects for state officials and rural migrants, the ITH will in fact turn into a permanent project for the two Inuvialuit subcontractors that built it, as they will be tasked with maintenance. Third, interviews with territorial government officials revealed their deep skepticism about the ITH's ability to attract more industry to the region. An employee of the territorial government tasked with oil and gas issues admitted that the road would benefit oil and gas projects. ConocoPhillip's anchor field lies right along the route, for instance, and the corporation would probably enjoy reduced costs as a result of the road's existence. However, he explained, "That project is on hold not because of a cost issue, but because of a commodity price issue. And unless we see the North American continental prices of natural gas in excess of six bucks, the project is not viable" (Interview 1). Global markets rather than individual local or national efforts to improve infrastructure seem to determine whether oil and gas is developed.

If the highway is not really about improving the economic environment for fossil fuel extraction, then Arctic sovereignty could arguably have been a reason for building it, one that would be difficult to put a price on. The highway's construction has been awash in national symbolism from the start, with Harper breaking ground on its construction one blustery day in January 2014 in Inuvik. Addressing the town, he stated that the ITH was "the last step in completing the dream of Macdonald and Diefenbaker – the dream to see all Canadians linked from coast to coast to coast, all the way from the Atlantic to the Pacific, and to the Arctic Ocean" (CBC News, 2014), pausing to emphasize the final coast. Government documents and press releases also emphasize the ITH's potential for "supporting Arctic sovereignty" (Infrastructure Canada, 2014).

Interviews with indigenous residents also initially confirmed the view that the highway was another example of the Canadian state pushing its way north to boost access to oil and Arctic sovereignty. One Inuvialuit/Gwi'chin female who had survived the residential school system, expressed, “The government does what the government does. It pushes its way anywhere and anywhere it wants to. And the people don’t have really much to say about it” (Interview 2). Yet her next comment underscored the role of capital, rather than the government, in making the road a reality. She continued, “The people with the money are the people that do something. The little people left behind that give their comments is not taken into consideration much. ‘Cause money talks” (Interview 2).

In the case of the ITH, the “people with money” are the two Inuvialuit-owned construction companies that were awarded the contracts, each worth approximately $150 million, to build the highway: Inuvik-based Northwind Industries Ltd and Tuktoyaktuk-based E. Grubens Transport Ltd. These are just two of the 27,000 for-profit small Aboriginal businesses in Canada. In the Northwest Territories, construction is one of the largest sectors for Aboriginal businesses, with 11% of them falling into this category. While the government supports indigenous entrepreneurship, it is not liberally doling out money to all indigenous corporations or businesses, let alone communities. In a neoliberal, entrepreneurial society, they have to compete with each other and convince the state of why their project is worth funding. The Member of the Legislative Assembly for Nahendeh, a district in the middle of the Northwest Territories far from the newly strategic Arctic coast, complained in reaction to reports of the government’s reimbursement to the ITH’s contractors for cost overruns: “Every time I ask for infrastructure for my communities, such as a school for Trout Lake, additional highway infrastructure for Highway 7 or the Fort Simpson Health Centre, which has been red-flagged for a few years, [our government] is saying, ‘Oh, we don't have the money.’ But at the same time, when a contractor comes crying they've got no problem dishing out millions of extra dollars” (Hudson, 2015). For Inuvik and Tuktoyaktuk to win funds for a highway in a time of Conservative government austerity and state withdrawal from providing for indigenous welfare, local elites needed to reframe a road they sought to meet local needs as fulfilling national ambitions.

3.5.1 Local needs

"Inuvik is dead," one construction worker remarked on a cold winter morning. "If it weren't for the road, there would be a lot of desperate people" (personal communication, April 1, 2017). Numerous people told of how they, their husband, or their sons had driven rock trucks or hauled gravel on the road and how grateful they were for the work. While driving up to the construction site one winter's morning (Figure 3-3), two road workers discussed what would happen once the work on the ITH wrapped up. One jokingly raised the possibility of a new road being built from Inuvik south across the tundra to the other worker's town, Aklavik. The Aklavik-born worker reacted negatively to the suggestion even though he had earned good wages from working on the ITH as an environmental monitor. "The road will ruin my land," he grumbled, a few minutes after pointing out how the sprouting willows were signs that grizzly bears were starting to emerge from their winter dens. The other worker responded, "I don't care. It fed my family for five years" (personal communication, April 1, 2017). To him, the land still provided sustenance albeit indirectly, through wages. For many in Inuvik and Tuktoyaktuk, the road has served as a make-work project, one designed to provide employment and wages for a few years as a stop-gap measure against deepened decline in a region that many felt had no real economic future.

If short-term local needs were decent, well-paying jobs, medium-term hopes within the community were for the road to facilitate access to services, facilities, and cheaper groceries and fuel. In Tuktoyaktuk, prices tend to be 10% higher than in Inuvik, where a gallon of milk is typically $10. Outside of winter when the ice road is open, the availability of fresh fruit, vegetables, and meat can be much less, too, if flights aren't able to land. Speaking of what would the road would bring, one woman in Tuktoyaktuk hoped, "They're gonna have fresh meat like Inuvik" (personal communication, July 9, 2016), illustrating the community's dual reliance on imported groceries and country food. At the same time, the government's savings are estimated to be $456,000 (Department of Transportation, 2010), as once Tuktoyaktuk is connected year-round by road, it will likely no longer be eligible for the federal Nutrition North program, which subsidizes the delivery of healthy food to remote communities. Cheaper fuel, too, will help power the pick-up trucks people use to get around the surprisingly sprawling hamlet, four-wheelers for hunting caribou, and boats going whaling or out to fish camp, again demonstrating the blending of capitalist and subsistence economies. Parents also expressed hopes of being able to take their kids to the pool and library in Inuvik. Tuktoyaktuk does not have nearly as many facilities, reflecting that it is both a smaller town and not the seat of the regional government or indigenous corporation. A mental health worker based in Inuvik expressed how Tuktoyaktuk would be easier to reach now if a crisis like a suicide occurred. At the same time, however, he and many others continually underscored how the road would make it easier for bootleggers to bring alcohol and drugs to Tukyotaktuk, where the sale of alcohol is prohibited. Such ambivalent views highlight the ambivalence of roads, as corridors filled with "perils and possibilities" (Klaeger, 2013, p. 359) and "objects of both fascination and terror" (Masquelier, 2002, p. 831).

Over the longer term, informants, particularly in Tuktoyaktuk, expressed hopes for a revitalization of the regional economy, possibly through tourism. On my last day in Tuktoyaktuk, I watched the owner of a small shop hang up a new sign for his rechristened shop. Its new name was "The End of the Road," and he hoped to attract adventure travelers driving to the Arctic Ocean. Yet at a cost of $300 million, Ottawa would not have been convinced to build a road just to meet the needs of the local community and economy. After all, government after government had ignored many other issues, from dilapidated housing to poor schools, even though these would be much less costly to address than building a highway. Many indigenous informants also complained that the Inuvialuit Regional Corporation had not sufficiently assisted the community, either. It hadn't helped to cut the cost of rising gas prices despite a subsidiary, Inuvialuit Petroleum Corporation, owning a third of the town's gas utility. IRC also owned the liquor store in Inuvik despite a major alcoholism problem in the community. A woman in Tuktoyaktuk offered, "It's not like a long time ago, [people] hunt and share. Now they don't. It's really bad here" (Interview 3), drawing attention to the divisions between the haves and the have-nots in the community. The indigenous and local elite, who would fall into the "haves" category, are likely aware of the many needs in the community. Also cognizant, however, that asking for money to fix local issues would not be a convincing strategy, when they went to lobby for the road, they appealed to the aspirations of the federal government: to access oil and enhance Arctic sovereignty.

3.5.2 National ambitions

To lobby for government funds, indigenous and local authorities strategically took advantage of the changing global and national context of the Canadian Arctic. As Anderson (1997) points out, the interaction between local managerial bourgeoisie and national or international powers does not "occur in the abstract," with underdeveloped places negotiating with developed ones. Instead, this interaction "is played out in real time, in a real place, by real people with particular objectives producing unique outcomes" (Anderson, 1997, p. 1487). In the case of the ITH, a combination of individuals from the Inuvialuit Regional Corporation, municipal government, the two construction companies, and a few key advocates with ties to territorial and federal governments like Nellie Cournoyea, an Aklavik-born woman of Inupiaq descent who is an experienced land claims negotiator, former premier of the Northwest Territories, and former IRC chair and CEO. These individuals noticed that the federal government was increasingly turning its attention to the Arctic both in person and on paper. Canada's former Governor General traveled to Inuvik and Tuktoyaktuk in March 2008, where she presented Cournoyea with the Northern Medal for her extraordinary service to the polar regions; Harper visited a few months afterward during his annual visit to the Arctic. In 2009, the government published the high-profile "Northern Strategy," which declared, "Northerners also need crucial infrastructure to move their goods to markets in southern Canada and other parts of the globe" (Government of Canada, 2009, p. 17). Under Harper, the government began to reimagine the Canadian Arctic less as an empty, marginal space home to indigenous peoples and more as a frontier that needed to be connected, protected, and developed (Bennett et al., 2016).

Although over three decades of work had already gone into planning for the road, which would be brought up over the years in various municipal and territorial government forums, the push under the Harper administration made the highway a reality. In its final, successful effort, indigenous and local lobbying for the road to the Arctic Ocean relied heavily on visuals that paid tribute to twentieth-century ideals about Canadian nationhood as being based on a western destiny, only in the twenty-first century, the geography of that destiny had shifted northward. In an interview, an IRC employee involved in the lobbying effort described a ten-minute video called "From Sea to Sea To Sea" that the mayors of Inuvik and Tuktoyaktuk had produced using funds from a government agency established under Harper, the Canadian Northern Economic Development Agency, in order to convince the government of the highway's relevance to Canada. A helicopter was leased to capture footage over the proposed route, while town councilors, businesspeople, and Cournoyea, then chair and CEO of IRC, provided testimonials. Once the short film was finished, the IRC employee explained, “We took this DVD kind of on the road with us” (Interview 4). They brought still photographs, too, of pingos, the ice-covered mounds unique to the region, the picturesque Husky Lakes along the proposed route, and the Arctic Ocean. A delegation from Inuvik and Tuktoyaktuk booked a table at Stephen Harper’s barbecue at the annual Calgary Stampede in Alberta and, as the IRC employee recalled, “presented [the video] to as many ministers as would look at it. Then we went to Ottawa…we visited Industry Canada, Infrastructure Canada, the Prime Minister’s Office, Senator Dennis Patterson – we presented this DVD and said look – we talked about [how] this road to the North could be what the railway was for the West. Once you’re opening up the Arctic, obviously, you’re talking about sovereignty. What better way to establish sovereignty in the country then to build infrastructure on the coast?” (Interview 4). This narrative espoused the belief of many Canadians in the 20th century that only a railway “would ensure the firm connection” of the West to the rest of Canada (p. 123) while also portraying the Arctic as the modern iteration of the Western frontier, a place that could be transformed, settled, and controlled through infrastructure. While high-modernist Canadian governments had championed this ideology in the 1950s, now, indigenous actors were pushing this view, which trickled down to the community level as well. In one house in Tuktoyaktuk, magazine clippings of stories about the coast-to-coast-to-coast highway papered the wall. Although the Inuvialuit own much of the land on which the road is being built and are working towards self-government, they mobilized a promise of expanded state sovereignty in the wider Arctic in order to attract funding. In essence, this exemplifies the indigenous deployment of state logics in order to benefit their own cause and a possible reconciliation of state and indigenous interests.

Other informants supported this account of how the road was funded. While driving on the soft roadbed of the yet-to-be completed Inuvik-Tuk Highway (Figure 3-4), a senior employee of one of the two indigenous-owned subcontractors elaborated on how the road came to be. "Inuvik and Tuk, they rallied and went after the federal government, and the federal government agreed to let it go. So we kind of went about it backwards. The design was here for 30 years, we wanted to build it, we wanted something to do. They call it the 'Road to Resources' – so I mean there's gas fields out there, oil fields out there, this'll just make access much easier. Plus there's a deep sea port potential – there's just so much hook to it" (Interview 5). The "hook" used to lure the government involved sovereignty, resources, and, importantly, a legacy – the very word Harper used in his speech in Inuvik marking the start of construction on the highway. The IRC employee drew attention to this notion of a legacy, explaining, "We talked about a legacy project for the government… so in the DVD, we talked about Prime Minister Diefenbaker's legacy, what this current project would mean to the government" (Interview 4).

Ultimately, the project did mean something to the Harper government. While he is no longer prime minister, and it will be Prime Minister Justin Trudeau who sits in the convoy that makes the first journey up the highway once it is completed, the Harper government managed to leave a material legacy in the Mackenzie Delta. Although this highway reflects national ambitions to expand Canada's Arctic sovereignty and access to oil and gas, more importantly, it demonstrates the determination of Inuvialuit elites to finally obtain funding for the road after three decades, even if that meant reimagining their hard-won lands as a space for Canadian state rather than indigenous sovereignty. In fact, the IRC even negotiated land exchanges with the Crown so that it could obtain the public road right of way. Some beneficiaries in both Tuktoyaktuk and Inuvik were deeply skeptical of transferring land in exchange for royalties and funds, which many noted was prohibited by the land claims agreement. Even transferring land for other lands was frowned upon, as the new lands might be far away or for “the good of all Inuvialuit as opposed to Tuktoyaktuk beneficiaries primarily” (Kiggiak - EBA, 2011).

In some ways, traditional indigenous values were compromised to make way for new indigenous values of economic development. This suggests that conceptualizing indigenous values requires problematizing, for they are far from homogenous and sometimes at odds within the same community. In Inuvik and Tuktoyaktuk, once the highway was approved, the indigenous and local elite and federal government were eager to break ground. As a result, some of those opposed to the road, if not in principle at least in how it was done, described a rushed process without proper consultation. A member of the Inuvik Hunters and Trappers Committee explained, “We haven’t been consulted, nothing. A lot of things that went on with the construction of that road were kinda pushed right over our heads, rammed down our throat – we always found out about certain issues not after the fact, whenever we had questions, we didn’t know who to ask, whenever we asked a certain agency, they always gave it to someone else…” (Interview 6). Separately, an employee working as an environmental monitor for the government explained, “We got here and they were starting construction basically… It got rushed through and pushed through with a lot of political pressure to the point that sometimes there wasn’t proper surveying done for streams and stuff like that, proper baseline information with regard to pretty much everything” (Interview 7).

Finally, some of the strongest opponents to the road, and to industrial development in the Arctic in general, are non-indigenous residents. Informants from this demographic exhibited traits of environmentalism on the one hand and paternalism on the other, for some simply did not think that Tuktoyaktuk, with its substance abuse problems, is ready for the road. Other critics of the ITH, typically in Inuvik, argued that it would become “the world’s longest boat launch.” They feared that the project was a massive boondoggle that would not withstand the environmental shifts wrought by rising temperatures, thawing permafrost, and coastal erosion. The IRC, however, is actually hoping to take advantage of climate change by capitalizing on the opportunity to use the road as a boat launch, effectively, by building a deep-water port in Tuktoyaktuk. As the future for oil and gas in the region looks bleak, indigenous and local elite informants expressed hope that this would be the next megaproject on the horizon. Such infrastructure would likely open up tensions between the Inuvialuit who seek the right to continue traditional maritime practices undisturbed, like whaling and fishing, and those who seek the right to develop their lands and waters in line with the logics of the state and capital.

3.6 Conclusion

Roads have long been considered a quintessential form of the state's extension of its political and economic reach. Yet they now also embody new territorial dynamics such as the rise of indigenous land claims and the subsequent emergence of implicit indigenous claims to the right to develop. A former executive of the Assembly of First Nations in Canada once argued, "The economic future of First Nations is not…dependent on geography. Rather, improved access to resources and capital represent the keys to Aboriginal prosperity" (in Kendall, 2001). However, the construction of the ITH illustrates the centrality of geographic, place-based dynamics to economic development on indigenous lands. Just as Papua New Guinea in the late 1980s became a new resource frontier where outside interests like the state and multinational firms sought to incorporate a seemingly disconnected but suddenly lucrative space into global networks of production (Tsing, 2004), the Arctic is now a new frontier for development, only one where indigenous peoples and their corporations and organizations have more rights than in previous eras of frontier development.

The construction of the ITH is taking place on Inuvialuit lands in the Arctic, a place the Canadian state once saw as empty and marginal and to which it agreed to assign Inuvialuit title. Yet at the beginning of the twenty-first century, geopolitical and geoeconomic shifts as a result of global climate change and commodities cycles remade Canada's coastal Arctic into an area the state sought to reintegrate and redevelop. For thirty years, the government had largely ignored the desires of indigenous elite and non-elite residents in the communities of Inuvik and Tuktoyaktuk to build an all-weather road. Now that the Arctic had become a site over which the state sought to exercise sovereignty and tie into global markets, it became interested in funding the first public highway in North America to the Arctic Ocean. Inuvialuit corporate and political elites, whose power can be directly traced to the land claims process and corporatization, successfully drew the state's attention to their proposed highway project through strategic lobbying that appealed to government imperatives to access offshore oil and gas resources and strengthen Canada's Arctic sovereignty. While they played up the benefits to the state of building the highway, in fact, many of the benefits are accruing locally rather than nationally. Two Inuvialuit-owned corporations won the contracts to build the $300 million, 140-kilometer highway that will connect a community of fewer than 900 people to the rest of Canada. A significant number of new, albeit temporary, road construction jobs were created, too. The highway should thus perhaps be viewed as an example of indigenous actors marshaling state logics for their own goals rather than a state incursion onto indigenous territory.

The case study of the ITH thus reveals how indigenous local stakeholders who sought a highway strategically leveraged state interests in Arctic sovereignty and resource extraction under former Prime Minister Harper to achieve their immediate agenda of road-building and stimulating the local economy. Whether the ITH will benefit their long-term economic future, however, is less certain. The road will require constant maintenance, may create more social ills and permanent environmental damage, and, while it created jobs over its construction period, has not yet spurred greater regional development and a significant number of permanent jobs. As Demenge (2015) underscores, although the development community tends to assume that more roads means more development, this has not actually been shown to be the case. Lastly, although the land claims agreement, in its neoliberal approach, seeks to create seeks to integrate Inuvialuit into Canadian society by fostering economic self-reliance, in fact, the highway project demonstrates the continued reliance on government funding to promote economic activity.

Indigenous peoples act in ways that can be "interpreted sometimes as resistance, sometimes as accommodation, sometimes as instrumental" (Bebbington, 2000). Researchers tend to focus on indigenous resistance. But paying attention to livelihoods that are sometimes instrumental to the state and capital and those that have allowed accumulation (Bebbington, 2000) can help provide a program of constructive engagement, which Agarwal (1996) claims is missing in most poststructural critiques of development. Case studies that illustrate how indigenous peoples, their corporations, or organizations have managed to push forward their own development projects with or without state or corporate assistance may help show how indigenous peoples can prosper within existing power structures. This is particularly important in the neoliberal era, where the state is generally withdrawing from providing for indigenous public services and instead encouraging indigenous entrepreneurialism and economic self-sufficiency. It may also draw attention to where new inequalities and class tensions within indigenous communities may arise.

3.7 Figures

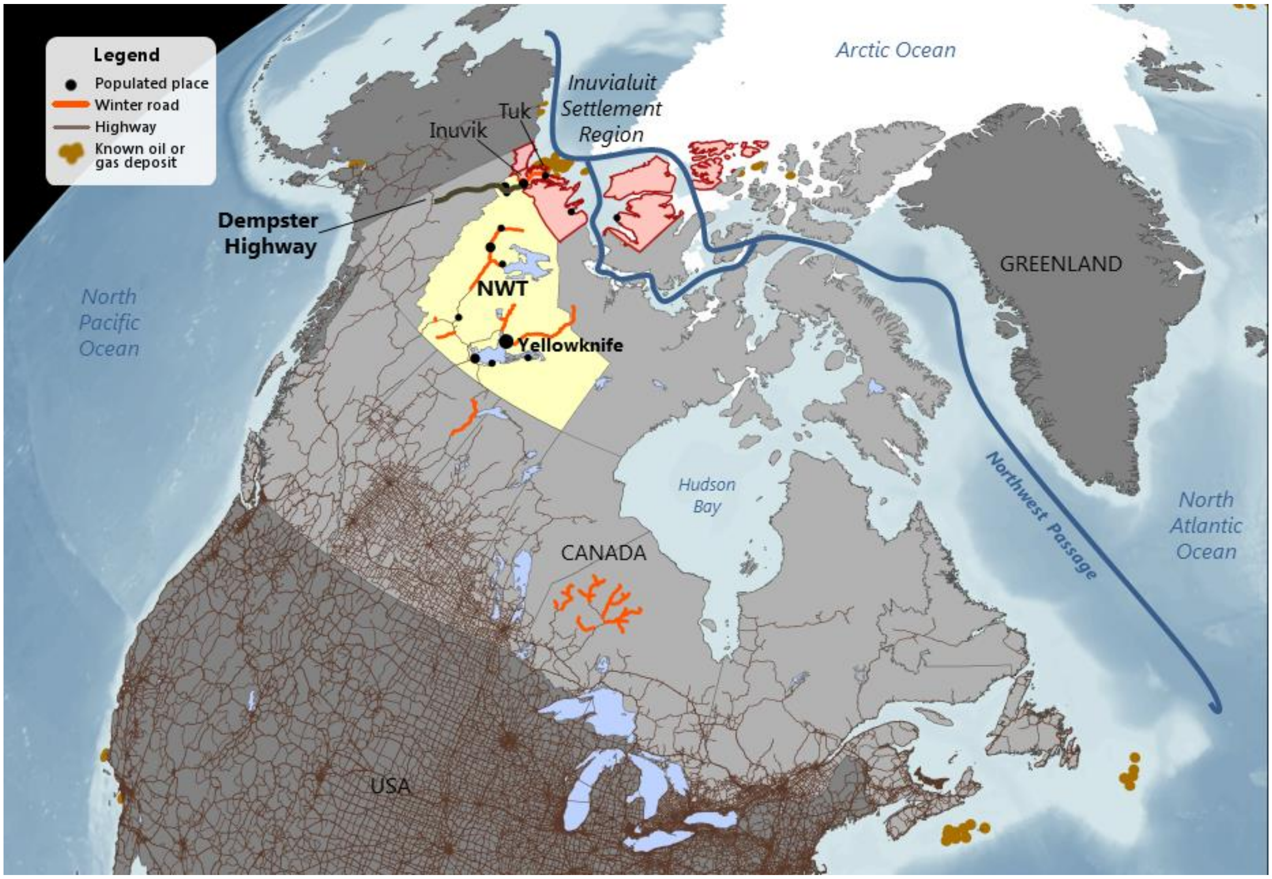

Figure 3-1. Map of Inuvik-Tuktoyaktuk Highway in regional context.

Figure 3-2. The seasonal ice road along the frozen Mackenzie River, which will no longer be maintained once the highway is complete. Source: Author, March 2017.

Figure 3-3. Work going on at a gravel pit off the ITH. Source: Author, April 2017.

Figure 3-4. The highway cutting across the tundra through the sensitive Husky Lakes area, with a gravel pit visible to the left. Source: Author, July 2016.

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3.9 Appendix: Interviews

Reference no.	Affiliation	Residence	Date of interview
1	Representative (1) of NWT Department of Industry, Tourism and Investment	Inuvik	June 28, 2016
2	Inuvialuit/Gwich'in artist	Inuvik	June 27, 2016
3	Local resident	Tuktoyaktuk	July 9, 2016
4	Representative of Inuvialuit Regional Corporation (1)	Inuvik	March 28, 2017
5	Representative of ITH contractor (1)	Inuvik	June 30, 2016
6	Representative of Hunters and Trappers Committee	Inuvik	July 6, 2016
7	Environmental monitor for government department	Inuvik	July 7, 2016

Table 3-1. Cited recorded interviews.

Reference no.	Affiliation	Residence	Date of interview
8	Department of Transportation employee overseeing ITH project	Inuvik	June 30, 2016
9	NWT government employee working on housing issues	Inuvik	June 28, 2016
10	Representative (2) of NWT Department of Industry, Tourism and Investment	Inuvik	June 30, 2016
11	Representative of ITH contractor (2)	Tuktoyaktuk	July 11, 2016
12	Representative of Gwich'in Tribal Council	Inuvik	June 29, 2016
13	Representative of Inuvialuit Regional Corporation administering lands (2)	Inuvik	July 7, 2016
14	Municipal official	Inuvik	July 6, 2016
15	Mental health worker	Inuvik	June 29, 2016
16	Representative (3) of NWT Department of Industry, Tourism and Investment	Inuvik	June 30, 2016
17	Territorial government representative	Inuvik	July 6, 2016
18	Public services official	Inuvik	June 29, 2016
19	Reindeer herder	Inuvik	June 29, 2016
20	Reindeer herder (second time)	Inuvik	March 30, 2017
21	Municipal official working on economic development and tourism	Inuvik	June 30, 2016
22	Territorial official working on tourism development	Inuvik	April 25, 2017

Table 3-2. Uncited recorded interviews.

Chapter 4

Singapore: The "Global" City in a globalizing Arctic

4.1 Abstract

Singapore's Arctic interests are typically explained by its limited regional market and the government's stakes in shipping, maritime infrastructure, and global governance. Yet the city-state's polar pursuits also reflect the government's strategy of crafting a global national identity in step with its expansion of overseas economic activities. In this paper, based on review of government speeches, documents, and press releases, observations at Arctic development conferences, and expert interviews, I first describe three regional shifts in the Arctic that have made Singapore's involvement possible: the globalization of the Arctic economy, a transition from national government to global governance, and the production of the Arctic region as an investment frontier. Second, I elucidate the export-oriented industrial drivers of Singapore's Arctic interests. These have led to the economy's deterritorialization, which state discourses projecting Singapore as a "Global City" support. Third, I analyze how these two transformations – the Arctic's globalization and Singapore's deterritorialization - have together created an opportunity for the Singaporean government to "jump scale" in Arctic cooperation, specifically by shedding light on its partnerships with indigenous peoples' organizations. As climate change accelerates, the Singaporean government's Arctic efforts suggest that it sees the increasingly maritime region as a new scalar fix for overseas investment that it is securing through unconventional partnerships while living up to its quest to view the world as its hinterland. Singapore's involvement in the Arctic may globalize the region's economy, but it may also deepen northern dependence on place-based sectors like natural resources and shipping.

4.2 Introduction

In 1965, Singapore separated from the Federation of Malaysia and became an independent state. Singaporean politicians at the time, including Prime Minister Lee Kuan Yew, had not anticipated this turn of events. Quickly, the ruling People's Action Party turned Singapore into a small and vulnerable nation-state sandwiched between two regional heavyweights: Malaysia and Indonesia. Since the nineteenth century, Singapore had come to rely on profits generated from exporting Malaysian tin, rubber, and petroleum via the Port of Singapore (Huff, 1994). The borders erected in 1965 disconnected the city-state from its hinterland of the Malay Peninsula, for Malaysia was not interested in sharing a common market. With Singapore's problems compounded by its lack of natural resources and limited agricultural potential, the government of the newly isolated island looked beyond its region and instead across the planet to foster national economic growth. Through rapid industrial development and the state's global pursuit for markets and resources, Singapore eventually leapfrogged its occasionally hostile regional environment and transformed into a city-state that today wields influence in places as distant as the Arctic.

Singapore has partnered economically with Arctic countries like Russia for decades. Yet the government only began to deliberately involve itself in Arctic affairs in the late 2000s (Storey, 2014a). Following the 2011 publication of the Nuuk criteria for observers in the Arctic Council, the region's leading intergovernmental organization, the Singaporean government began investigating how it could gain observer status. It also began claiming to be an Arctic stakeholder, underscoring national interests in climate change, maritime issues, and global governance. In 2012, the country's Ministry of Foreign Affairs appointed a Special Envoy for Arctic Affairs (Tonami, 2016). The following year, Singapore, along with China, Japan, South Korea, India, and Italy, became an observer. Distinctly, Singaporean officials have reached out to the Arctic Council's

Permanent Participants, which represent indigenous peoples' organizations. This can be viewed as part of the government's broader effort to jump scales in Arctic development by cooperating with non-state actors that have risen to prominent roles in Arctic governance and development.

Singapore's Arctic pursuits also reflect the government's decades-old discursive strategy of presenting the country as a city with a planetary perspective. In 1972, cabinet member and future Deputy Prime Minister Sinnathamby Rajnaratnam declared Singapore to be a "Global City." He borrowed the idea from British historian Arnold Toynbee well before the idea of "global cities" came into vogue with urban scholars (Haila, 2015). The subsequent development of Singapore's identity as a "Global City" (Yeung and Olds, 1998; Olds and Yeung, 2004) – one for which the "world is its hinterland," as Rajnaratnam (1972) proclaimed, accompanied its rise to prominence as one of the world's top ports by volume. This catapulting through the ranks of maritime hubs resulted from a combination of Singapore's geoeconomically strategic location along the Strait of Malacca, a historically important shipping lane between Asia and Europe, and the government's push to turn the port into a world-class port.

Despite the seeming importance of location to the Port of Singapore's success, government discourses seem to suggest that geography is irrelevant to the realization of Singapore's activities in the Arctic and beyond. To illustrate, in 2015, Singaporean Prime Minister Lee Hsien Loong gave a speech in which he commented about the possibility of Arctic sea ice melt. He surmised, "It may come to pass or it may not. But it probably will, and if it does, we will be there" (Prime Minister's Office, 2015). "Being there" does not mean Singapore will claim any Arctic territory, for it has no such pretentions. Instead for Singapore, "being" in any such hinterland can be interpreted as meaning that its public and private capital, expertise, and infrastructure are present and operating to ensure the continued economic growth of the Southeast Asian island state, even in a climate-altered world. Notably, it also appears that for Singapore, quietly delivering infrastructure and investment to the Arctic takes precedence over carrying out a major scientific expedition or establishing a permanent scientific research base, as fellow Asian Arctic Council observers of China, Japan, South Korea, and India have all done in Svalbard.

Over the past several years, Singaporean officials have carefully delineated the country's interests at forums and Arctic development conferences. Some of the most high-profile proponents of the country's Arctic interests are Prime Minister Lee Hsien Loong, Acting Director General and Europe Directorate for the Singapore Ministry of Foreign Affairs Kamal Vaswani, former Special Envoy for Arctic Affairs Tony Siddique, and Minister of State Sam Tan Chin Siong. Though Singapore's Arctic strategy has not been expressed in official terms through a white paper or policy document, these officials regularly draw attention to five main concerns in the Arctic: 1) Singapore's vulnerability to climate change as a low-lying island state and the Arctic's ability to serve as a bellwether; 2) the importance of upholding freedom of navigation across the world's oceans, including in the Arctic; 3) the potential for increased development in the Arctic to present new economic opportunities to Singapore; 4) the country's ability to contribute to a pool of knowledge about the Arctic; and 5) the fact that Singapore serves as a stopping point during the annual migration of Arctic shorebirds. Whereas the interests regarding climate change and migratory shorebirds can be perceived as an attempt to promulgate geo-environmental rhetoric that draws Singapore closer to the Arctic, the other three interests suggest a more globalized, borderless, and ultimately profit-driven view of the region as hinterland and investment frontier.

Existing literature on Singapore's role in the Arctic has largely recapitulated the interests expressed by government officials. Drawing on Low (2001), Watters and Tonami (2012) categorize Singapore as a developmental state, finding that the government's oversight of the economy and industry has motivated its Arctic engagement. Similar motivations could be found for developmental states with Arctic interests such as South Korea and Japan. More specifically, analysis has determined that Singapore can provide energy and maritime expertise, particularly in the areas of offshore technology, shipping and maritime logistics, and maritime law (Chen, 2015; Storey, 2014a; Storey, 2016). Solli, Wilson Rowe and Yennie Lindgren (2013) and Storey (2016) also draw attention to Singapore's participation in global governance forums, especially as they relate to maritime issues and climate change. Some scholars point out that while the Singaporean government may see opportunities arising from Arctic development, unlike China, Japan, and South Korea, it is also closely eyeing potential threats to its dominance of global shipping networks posed by the melting of the ice cap and the development of the Northern Sea Route, which promises to reduce the distance between Europe and Asia (Watters and Tonami, 2012; Fang, 2015). Storey (2014b), however, is more skeptical of the supposed threats from Arctic routes to Singapore's dominance of Europe-Asia container shipping. Even with melting ice, shipping via the Northern Sea Route will likely remain expensive and risky (Meng et al., 2017), and the route lacks the infrastructure, reliability, and ports and markets en route to make it competitive with the Suez Canal (Buixadé Farré, 2014).

While existing research clearly spells out Singapore's Arctic interests, little work has addressed how the country's activities in the Arctic reflect and indeed depend upon the material and discursive rescaling of Singapore as a global city-state and the Arctic as a coherent environmental and economic region. On the one hand, this process involves the deterritorialization of the Singaporean economy and its reterritorialization in places beyond its borders that are open to foreign investment and global governance. On the other hand, contemporary discourses and actual governance of Arctic development have shifted from the national to regional scale, in the process creating a new regional investment frontier. This dialectic makes a relational framework useful for understanding what Singapore's involvement may mean for the future of the Arctic economy and conversely, what the country's polar participation means for the tropical city-state apart from *realpolitik* concerns of economic growth and geostrategic positioning in a climate-impacted world. For a government for which "urban, national, and global ambitions are all intertwined" (Kong, 2007, p. 390), participating in Arctic development may in some small way underwrite the city-state's nation-building strategy of building a global identity.

Against this backdrop, this paper attempts to explain and analyze Singapore's involvement in Arctic development from three different angles. The first section examines how regional shifts within the Arctic, including the transition from national government to global governance, have created opportunities for outside intervention and investment. I demonstrate how the process of Arctic region building has created a new scalar fix for capital in a frontier whose economy is increasingly globalized but persistently territorialized, meaning that development continues to rely on place-based natural resources. The second section traces how Singapore's history of economic development has laid the material drivers of its Arctic interests. Starting from its initial export-oriented industrialization in the 1960s, the economy has scaled up and "deterritorialized" by way of significant overseas investments, joint ventures, and land purchases. The third section discusses how these two transformations – the Arctic's globalization and Singapore's deterritorialization - have combined to create an opportunity for the Singaporean government and its affiliated companies to "jump scale" in Arctic development, drawing on Neil Brenner's concept (1999). Contrary to its conventional practice of government-to-government cooperation at the expense of partnering with local officials (Yeung, 2000), I show how the Singaporean state and government-linked companies (GLCs) strategically partner with non-state actors in the Arctic, including indigenous stakeholders. In this section, I also examine how Singapore's engagement with the Arctic supports its own nation-building and branding efforts to be a "Global City." In conclusion, I reflect on how investment by deterritorialized economies like Singapore in territorialized ones may enhance the recipient area's level of globalization but deepen its reliance on place-based resources.

Methodologically, research for this chapter is based on review of government speeches, documents, and press releases, largely from the Singapore Ministry of Foreign Affairs. Several of these speeches were heard in person at Arctic Circle development conferences in October 2013 and 2014, while observations were also made during visits to Singapore in March 2014 and September 2015. Two expert interviews with individuals involved in Singapore's Arctic activities were conducted in Singapore in September 2015. One additional expert interview was conducted in Alaska in September 2015 and one by telephone in January 2016 (Appendix 1). All interviews were conducted under the condition of anonymity.

4.3 Arctic economic development and the production of a regional frontier

While the Singaporean government laid the industrial foundations for its Arctic activities, three key regional trends have opened the door to the city-state's involvement in northern development. The first is that while the Arctic economy has long been globalized, it is not deterritorialized. The second is that there has been a shift in the Arctic from national government to global governance. The third is the ongoing production of the Arctic as a frontier for economic development, one which requires infrastructure investment to cohere into a connected region as envisioned.

First, while the Arctic economy has long been globalized, it is not deterritorialized. Even before European contact, archaeological evidence indicates that indigenous peoples in the North

American Arctic acquired metals from Eurasia, potentially through trade (Cooper et al., 2016). From the fifteenth through early twentieth centuries, European merchants, traders, and frontiersmen traveled north in search of commodities from furs to whale oil (Greenberg, 2009). These activities further embedded the Arctic into global circuits of trade and transportation. During the Cold War, due to its location between North America and Russia, the region became more of a closed space serving as a militarized national hinterland for states with Arctic territory rather than an economic periphery for the globe (Farish, 2009; 2013; Josephson, 2014). While some Arctic resources were still exported to global markets, national impulses to conquer or civilize northern areas for the strategic purposes of nuclear deterrence and the establishment of early warning systems motivated Arctic development. In the post-Cold War Arctic, national borders have softened, most visibly in the economic sphere. Whereas states previously directed processes of nationally scaled Arctic development, a range of stakeholders has since joined them in a more regionally scaled effort in what Oran Young (2005) calls a transition "from cold war theater to mosaic of cooperation."

Despite the involvement of a myriad of state and non-state actors in Arctic economic development, the region's economy remains deeply territorialized in that it depends on fixed, place-specific resources (Storper, 1997). In the Russian, American, and Canadian Arctic regions, mining and petroleum account for 56.9%, 33.2%, and 27.7% of gross regional product, respectively (Glomsrød, 2009). The territorialization of Arctic economies looks set to continue, too, for regional development trajectories are firmly directed towards expanded fossil fuel production as the offshore frontier moves north (Kristoffersen and Langhelle, 2017). Norway, for instance, where neither mining nor petroleum has been a major contributor to the northern economy in recent years (Glomsrød, 2009), has opened the world's northernmost offshore oil field, Goliat, in the Barents Sea. The government has controversially considered opening the Lofoten Islands to production as well (Kaltenborn, Linnell, and Lindhjem, 2017). Even if trans-Arctic shipping routes are developed in the future, these will also be place-dependent, leveraging the Arctic's central position between Asia, North America, and Europe. As a result, although capital is increasingly flowing into the Arctic from afar, the region's economy is not becoming deterritorialized. While investment by countries like Singapore in Arctic infrastructure and natural resources may further globalize the region's economy, they may deepen its territorialization, too.

The second regional trend that has made possible Singapore's Arctic engagement is a shift from national government towards global governance in setting goals for Arctic development, even if sovereign states still ultimately determine their realization. Duffield (2001, p. 44) defines global governance as having "a reality not in a single institution but in the networks and linkages that bring together different organizations, interest groups and forms of authority in relation to specific regulatory tasks." Notable examples of the stakeholders involved in the emerging landscape of Arctic global governance include indigenous peoples' organizations and corporations, major development conferences like the Reykjavik-based Arctic Circle and spinoffs like the Arctic Circle Singapore Forum, and the Arctic Economic Council. Based outside the Arctic, non-Arctic states, transnational corporations, intergovernmental organizations like the European Union and International Maritime Organization, international organizations like the World Economic Forum, and environmental non-profits all play important roles.

Links between Arctic and non-Arctic entities in regional development are increasing, too. Prior to sanctions, Russian companies Rosneft and Gazprom entered into agreements with foreign corporations like U.S.-based ExxonMobil, Norway-based Statoil, and Italy-based Eni to develop oil and gas resources on Russia's continental shelf (Stephenson and Agnew, 2016). The northern frontiers that are opening for foreign investment present new business opportunities to entrepreneurial countries like Singapore, which “reflects the world economic environment, and benefits from world growth” (Krause, 1990, p. 55). Singapore is also actively involved in global governance initiatives, especially in the areas of ocean management, international shipping, and maritime legal regimes (Storey, 2014a). This preexisting participation helps legitimize the country’s participation in the Arctic, especially given the region’s increasingly maritime dimension. Singapore has supported the work of various Arctic Council working groups and task forces. In the Arctic Council’s Emergency Prevention, Preparedness and Response Working Group, the Maritime and Port Authority of Singapore has shared its knowledge of managing oil spills off its coast, while Singapore’s National Parks Board has provided input on the Arctic migratory birds which stop in Singapore with the Conservation of Arctic Flora and Fauna Working Group (Ministry of Foreign Affairs, 2016a). In other frontier regions where global governance and maritime issues are salient, like the Indian Ocean, Singapore also actively participates in related forums (Kelegama, 2002). By contrast, in frontier regions where global governance is less prevalent and maritime issues less salient, such as Central Asia or the Amazon, Singapore is less likely to play a significant role.

A third trend within the Arctic that has allowed the Singaporean government to carve out a polar niche is the discursive framing of northern development at the scale of the entire Arctic region. The emergence of the Arctic as an economic region in the 2000s can be traced to the recognition of the Arctic as an environmental region, a process that began in the late 1980s and 1990s (Keskitalo, 2004; 2007). Today, officials from Arctic states at various levels of government and representatives of international organizations promote the Arctic as a homogenous investment frontier, eliding local distinctions within a region that includes places as varied as the highly developed Norwegian city of Tromsø, the oil fields of Alaska's Prudhoe Bay, and the reindeer pastures of northern Siberia. In recent years, the Arctic Council has moved away from its initial goals of promoting environmental protection towards fostering globally-oriented, market-based development predicated on new infrastructure investment. Former Norwegian Prime Minister Jonas Gahr Støre expressed, "We are beginning to see the development of broadly shared norms as the Arctic emerges as a global investment opportunity" (Gahr Støre, 2016). These norms include the Investment Protocol on the Arctic, published in 2015 by the World Economic Forum's Global Agenda Council. This document advocates building resilient Arctic societies through sustainable economic development and states, "The Arctic is a diverse, rapidly-changing and environmentally sensitive region that is home for its four million residents and also an emerging global investment opportunity" (World Economic Forum, 2015). Such rhetoric echoes both the increase in "development" as a major theme at the Arctic Circle (Johansdottir and Cook, 2017) and narratives issued by organizations based within the Arctic like the Arctic Economic Council, established by the Arctic Council in 2015. Of the five themes listed in its Strategic Plan published in 2016, the first is "establishing strong market connections between the Arctic states," while the second is "encouraging public-private partnerships for infrastructure investments" (Arctic Economic Council, 2016). Infrastructure appears to be the missing link that is imagined as transforming the Arctic into a smoothly functioning, well-connected region. Private investment firm Guggenheim Partners, which traces its heritage to the Guggenheims, a family involved in the early days of resource development and railroad building in Alaska (Alley, 1993), has identified $1 trillion worth of infrastructure needs (Guggenheim, 2016).

Growing recognition from within the Arctic of the region as a place with shared values, experiences, concerns, and needs, particularly in the realm of climate change, also has an external dimension (Stokke, Honneland, and Schei, 2007). Popular and elite discourses about the Arctic have increased awareness among non-Arctic states like Singapore of the threats the region faces, along with the opportunities it presents to the rest of the world. As Minister of State Sam Tan expressed at the Arctic Frontiers conference in Norway in January 2017, "While we have no interest in any resource or territorial claims in the Arctic, the development of the Arctic presents opportunities not just for the region, but for the world" (Ministry of Foreign Affairs, 2017a).

In essence, the production of the Arctic as a region of global environmental and economic importance has engendered a new scalar fix for intervention and investment by non-Arctic states, especially those with deterritorialized economies like Singapore. Such partners are imagined by Arctic and non-Arctic developmental interests as being able to provide the infrastructure and capital to make visions of a coherent Arctic economic region a reality. Yet when that partner is Singapore – a city-state that inhabits both the urban and territorial state scales which increasingly form the geographical preconditions for capital accumulation (Brenner, 1998) – caution is warranted as to whether its engagement could exacerbate the Arctic's underdevelopment and the continued territorialization of its economy.

4.4 The deterritorialization of the "tiny red dot"

Singapore, often dismissively called a "tiny red dot on the map" (Low, 2007), may appear to have sprung inexplicably from the humid equatorial reaches of Southeast Asia into the northern arena. Even its own officials have remarked on the seeming implausibility of the country's Arctic interests (Prime Minister's Office, 2015; Ministry of Foreign Affairs, 2015a). Yet Singapore's interests stem logically from its experiences in the decades prior to and following Separation.

In the post-war period, Singaporean officials began planning for a future beyond British colonialism predicated on industrialization, export-based development, and union with Malaysia.

The first two plans would endure. The third would ultimately fail and, in a way, launch Singapore out of its region. By the time of decolonization and Singapore's joining with the Federation of Malaya in 1963, industrialization was well underway. This process put the country in a more tenable position when forced out of the Federation two years later. Cut off from its hinterland, Singaporean planners realized that not only was the country no longer guaranteed a role in exporting out Malaysian commodities like tin and rubber: it needed to find new export markets for its own manufactured goods, too. As former Prime Minister Lee Kuan Yew wrote in his memoirs, "Unless we could find and attach ourselves to a new hinterland, the future was bleak" (Lee, 2000, p.49). The 1961-1965 Second Development Plan underscored the country's need to find new export markets for its nascent industrial manufacturing sector, whose growth was driven by the establishment of new entities like Jurong Shipyard Limited following a UN report recommending the country to pursue shipbuilding, among other industries (Lee, 1973). The Singaporean government and Japan's IHI Corporation together established this shipyard, presaging future partnerships between Singaporean government-linked companies (GLCs) and foreign companies – and an eventual role reversal in which Singapore would be providing rather than receiving maritime infrastructure and expertise. Jurong Shipyard turned transport equipment into Singapore's most quickly growing industry in value-added terms at the end of the 1960s (Lee, 1973). Another important GLC established during the 1960s, Keppel Shipyard (later Keppel Corporation), would grow to have various commercial interests in the Arctic. Meanwhile, chemical and petroleum products, transport equipment, and electrical machinery grew to be the Singaporean economy's three biggest sectors. By 1970, industrialization was in full swing. The government's early promotion of the development of sectors that allow long-distance projection of industrial strength endowed Singapore with the ability to deploy infrastructure to support the extractive activities and transportation routes that Arctic and non-Arctic states, corporations, and other stakeholders are planning for the climate-impacted region.

While the industrialization effort of the 1950s and 1960s led to the creation of sectors like shipbuilding and spin-off industries like offshore oil rig manufacture, following a recession from 1985-1986, the Singaporean government set out to fill two niches in the global market: one in high-tech industry and another in information technology (Murray and Perera, 1996). These sectors capitalized on the government's efforts since Separation to improve primary and secondary education in order to create a class of laborers to staff Singapore's industries. While services have comprised around 70-75% of Singaporean GDP and industry around 20-26% since 1960, more advanced service sectors like finance, insurance, business, and information and communications have grown significantly over time (Department of Statistics Singapore, 2017). The government's promotion of the service sector (Olds, 2007) along with its investments in human capital have set the foundation for Singapore to engineer the knowledge- and capital-intensive infrastructure required to penetrate challenging environments like the Arctic. Today, Singaporean companies like Keppel Offshore and Marine, a Keppel Corporation subsidiary, combine advances generated by the older sectors like shipbuilding and the newer ones like high-tech industry to design heavy infrastructure for icy environments like the Russian offshore.

The Singaporean government has pursued both discursive and material strategies of development to take advantage of the worldwide sociospatial restructuring that occurred at the end of the 1980s (Brenner and Schmid, 2015). Around this time, capitalist territorial organization was denationalizing, looking for alternative, "glocal" scalar fixes beyond national borders (Brenner, 1998). In 1998, gross cross-border capital flows constituted less than 7% of world GDP. By 2007, they accounted for over 20% (Milesi-Ferretti and Tille, 2011). Exemplifying Singaporean government discourse surrounding national and global development, in 1991, the Economic Planning Committee released its “Strategic Economic Plan: Towards a Developed Nation.” It declared, “Singapore has the world as its resource. Be it raw materials, information, labour or tourist resorts, Singapore can create products and services that are not bound by traditional concepts of space and other constraints…Globalization doesn’t merely mean doing things overseas. Singaporeans have to embrace the global socio-economic space and endear themselves to the world” (in Murray and Perera, 1996, p. 29). Such rhetoric evinces the government’s keen awareness of how the country can materially take advantage of the spatial ordering of the global economy, which it has pursued since the early days of the republic. As Rajnaratnam (1972, p. 8) proclaimed in 1972, “If we view Singapore’s future not as a regional city but as a Global City then the smallness of Singapore, the absence of a hinterland, or raw materials and a large domestic market are not fatal or insurmountable handicaps… because for a Global City the world is its hinterland.”

Still, Singapore’s claims to be a “Global City” require critiquing for two reasons. First, Singapore is not investing uniformly across the entire planet. There is still a distinct geography to its foreign activities and investments, which reflects how the Singaporean economy is reterritorializing overseas even as it deterritorializes at home. Second, participating in the development of distant frontiers is more than just a matter of sustaining economic growth. It also supports the Singaporean government’s ongoing “city imaging strategy” in which it attempts to portray itself as a global city (Oswin and Yeoh, 2010). Affirmation of Singapore’s global city status through participation in projects perceived as literally or figuratively “on the frontier,” like constructing planned “smart cities” in India and China (Ganapathy, 2014) and developing Arctic resources and shipping routes, helps perpetuate a national image of being a cosmopolitan command and control center in the world economy. This forms a core part of the young country's nation-building efforts (Kong, 2007). Retaining such status also helps Singapore attract capital and recruit talent (Park, 2007), which is key for a country with a deterritorialized economy and few natural resources of its own. Thus, involvement in megaprojects around the world supports the Singaporean government's own project of city imaging and nation building, which are inseparable for the city-state.

The Singaporean government has pursued an aggressive overseas investment strategy that matches its "glocal" rhetoric in which the country is imagined as existing simultaneously at global and local scales. Since Separation, Singapore's economy has become deterritorialized. This process involves "reshuffling the entrenched, nationally scaled configurations of territorial organization upon which capitalist industrialization has been grounded since the late nineteenth century" (Brenner, 1999, p. 62). On the one hand, the government has directly invited global capital to its equatorial doorstep. From the 1960s to the 1980s, multinational companies located and expanded within Singapore, contributing to the country's double-digit growth rates and major increase in manufacturing output (King, 2008). The government has also promoted monetary and financial activities, research and development, tourism, and civil aviation, among other sectors. On the other hand, in an era of globalization characterized by rising cross-border capital flows, tiny Singapore's "space scarcity" (Amir, 2015) may be beneficial rather than detrimental to its economic development by forcing it to look overseas for opportunity. Singapore's net outflows of foreign direct investment represent 12.1% of GDP, ranking it seventh in the world in 2015 (World Bank, 2017).

Transnational corporations are usually the exemplars of this type of "footloose" behavior, a term that describes their arrangement and coordination of globe-spanning production networks, which is a key form of deterritorialization (Brenner, 1999). Yet the Singaporean government and GLCs also engage in footloose behavior. One of the country's two sovereign wealth funds, the Government of Singapore Investment Corporation (GIC), invests "as a rule" outside Singapore (GIC, 2016, p.32). Established in 1981, GIC's mandate is to manage the country's foreign reserves and secure its financial future. It has offices in ten different countries and a reported $354 billion in assets under management in 2016 (Sovereign Wealth Center, 2017), many of which are invested in infrastructure. GIC is an anchor investor in the Infrastructure Asset Management Company's $1.2 billion infrastructure fund (Straits Times, 2013) and has sizeable stakes in infrastructures as diverse as U.S. power lines and utilities (Wille, Polson, and Loon, 2016) and London's Heathrow Airport (Cram, 2016). Infrastructure is of particular interest to both of the Singaporean government's sovereign wealth funds, which rank in a list of ten notable sovereign wealth funds investing in infrastructure (McGee and Sy, 2016).

Aside from infrastructure, Singaporean companies have made numerous large-scale land acquisitions, mostly in Africa and Southeast Asia for agricultural purposes. Their 68 reported deals totaling 3,260,750 hectares make the country the world's third largest investor in land (Nolte, Chamberlain, and Geiger, 2016). Additionally, in 2015, the UN International Seabed Authority awarded Keppel Offshore Marine Solutions an exploration lease for deep sea mining in the Pacific Ocean. In documents submitted to the ISA, the Permanent Mission of the Republic of Singapore to the UN (2015, p. 2) claimed, "Singapore is a developing country with no natural resources." This statement demonstrates the contradictory view within the Singaporean government of being a developing country, and yet one that is technologically advanced enough to exploit distant frontiers. Commenting on the acquisition of a deep sea mining lease, a Singaporean GLC representative remarked that now, "Schoolchildren will learn in textbooks that Singapore has resources of its own" (Interview 1). Singapore's overseas investments in infrastructure, land, and deep-sea mining may suggest that even if the low-lying country were to disappear due to sea-level rise, it could still exert some form of regulatory power if not outright sovereignty over places beyond its borders like Arctic shipping lanes, African farmland, and deep sea mines.

Importantly for the Arctic and other offshore oil frontiers, the Singaporean government has adamantly pursued the development of infrastructure both at home and abroad by partnering with foreign companies. The ship and oil rig building and repair sector has vocally supported the government's overseas investment strategy (Murray and Perera, 1996). Keppel's subsidiaries have cultivated an overseas presence through a strategy of "Near Market, Near Customer," which began in the 1990s in step with globalization's acceleration. One subsidiary, Keppel Offshore & Marine, has 17 offshore and marine yards outside Singapore (Keppel Corporation, 2006). An example of a venture that may inform Keppel's activities in the Arctic in future is a partnership between its subsidiary, Keppel FELS, and the State Oil Company of Azerbaijan Republic. Their joint shipyard in Azerbaijan worked with Keppel Singmarine to build an ice-class floating storage offloading vessel for Russian oil company Lukoil's operations in the Caspian Sea, which freezes over in winter. Keppel's relationship with Lukoil builds on the Singaporean GLC's history of constructing and repairing Soviet ships since the 1970s (New Nation, 1977). In 2016, Keppel expanded its presence in Russia by establishing a Singapore-incorporated joint venture company with Russian state-owned oil company Rosneft and Norwegian drilling equipment firm MHWirth. The company is forming a design and engineering center at the Zvezda Shipbuilding Complex near Vladivostok in the Russian Far East, where the Russian government seeks to develop a shipbuilding cluster to design and build drilling rigs for the Russian offshore in the Arctic and Far East (Far Eastern Shipbuilding and Ship Repair Center 2017).

To date, Keppel Singmarine has constructed a total of seven ice-class vessels for drilling activities in the Arctic and Caspian Sea. In 2008, with the help of Finnish ship design and engineering company ILS OY, Keppel Singmarine undertook its first Arctic shipbuilding project by constructing two icebreakers, *Varandey and Toboy,* to support Russian oil and gas company Lukoil's Arctic activities. In January 2015, the company signed a contract with Luxembourg-based Maritime Construction Services to deliver a S$265 million ice-class vessel, demonstrating that other companies are starting to realize Keppel's ice-class expertise. Three additional ice-class vessels are on order, too (Keppel Corporation, 2015). Yet Keppel has had less success in marketing its ice-worthy jack-up rigs. In 2012, Keppel Offshore & Marine's design and engineering arm partnered with ConocoPhilipps to design the first ice-worthy jack-up rig. It has not yet been put into operation in the Arctic, however, due to the plunge in the price of oil from $100 in summer 2014 to $30 in early 2016 and the resulting economic unviability of Arctic drilling. This challenge demonstrates that as Singapore breaks into new frontiers, its economy may become more vulnerable to global economic vicissitudes as well.

4.5 Singaporean scale-jumping in Arctic cooperation

In 2013, Singapore sent a delegation to the inaugural Arctic Circle assembly in Reykjavik, which has since become one of the leading Arctic development conferences. At the assembly, Senior Parliamentary Secretary Sam Tan delivered a keynote address in which he proclaimed, "Singapore was once a developing country, without resources, struggling to survive. Few people believed that we would make it, but we did. Our founding fathers had the foresight to focus on developing human capital – to train, educate, and guide our people so that our country could develop economically, raise our productivity, and innovate. We believe that the development of human capital is also important for the Arctic, to ensure that the indigenous communities can continue their lifestyle and adapt to these changes that have been thrust upon them" (Ministry of Foreign Affairs, 2013). The emphasis of the country's humble beginnings serves to legitimize its involvement in the Arctic while conveying a sense of altruism to its intentions in the region. In addition, Singaporean officials' repeated emphasis of their country's small size – what Wee (1995, p. 72) terms "the diplomatic advantage of smallness" – may draw a positive contrast from larger countries like China, of which Arctic states may be warier. The Minister of State explained at the Arctic Circle, "Singapore is still new to the Arctic and we are a small country with limited resources" (Ministry of Foreign Affairs, 2015b). The narrative that Singapore, a small country that pulled itself up by its bootstraps and rapidly industrialized, could inform Arctic development has persuaded some. One academic involved in Singapore-Arctic affairs remarked, "I think working with Singapore in the Arctic will be very helpful in terms of applying lessons learned in ways that will create a productive and forward-looking infrastructure in the Arctic" (Interview 2). Similarly, a representative of an Arctic Council Permanent Participant that has worked with Singaporean officials offered, "I think they (Singapore) have a genuine interest in helping the indigenous people of the Arctic" (Interview 3).

In all of its multiscaled efforts at cooperation, more so than the other Asian Arctic observers, Singapore couches its economic interests in terms palatable to Arctic states and indigenous stakeholders alike. A representative of a Singaporean GLC observed, "We are trying to position ourselves to get more knowledge in this area. It's not for us to make strategy in the Arctic. People who are doing it are those with sovereignty over it – obviously we have to align ourselves with the big players. We can't behave in a way that creates frictions" (Interview 4). This view suggests a realization within the Singaporean government and GLCs that even though the country participates in various global forums and arenas, it remains a small state in the world of international relations that must play by the rules.

At the same time, being small allows Singapore to pursue Arctic policy at multiple scales of cooperation and nimbly respond to the continually evolving landscape of Arctic stakeholders. In 2014, Minister of State Sam Tan explained the multi-dimensional nature of his country's approach to regional cooperation at the second Arctic Circle conference in Reykjavik. He explained,

> "There are also other regional or sub-regional platforms for discussions on Arctic issues - including this very forum. They have overlapping involvement and agenda [sic]. This situation reminds me very much of the approach that we have taken in Southeast Asia and the broader Asia-Pacific region. We call it *variable geometry in regional cooperation*. It may give rise to some duplication and competition from time to time, but given the complexity of the challenges in the Arctic, the existence of these different forums with different configurations may be useful. They foster dialogue, forge better mutual understanding and generate initiatives for collaboration. This benefits the region as a whole over the longer term" (Ministry of Foreign Affairs, 2014a, emphasis author's).

This "variable geometry in regional cooperation" takes place at the international, bilateral, and subnational scales. Internationally, Singaporean officials participate in organizations like the Arctic Council and the International Maritime Organization. There, they helped author the Polar Code, which became mandatory for ships sailing in Arctic and Antarctic waters on January 1, 2017. The country also participates in multilateral negotiations on climate that affect the Arctic, including the UN Framework Convention on Climate Change. The country's National Climate Change Strategy, published in 2012, underscores that particularly for "trade-dependent countries like Singapore," a global and multilateral approach to climate change is essential and "far preferable" to a "unilateral, uncoordinated" approach that could "distort trade flows and development, and lead to suboptimal outcomes at the global level" (National Climate Change Secretariat, 2012). Singapore's ability to shape and distort global trade flows to its own benefit, however, goes conveniently unmentioned even as the government attempts to influence the "geometry of regional cooperation" by strategically inserting itself into international and bilateral forums when advantageous.

In the Arctic, the Singaporean government has pursued conventional bilateral partnerships with countries like Norway, Iceland, and Russia on issues like trade, research and development, and oil extraction. Yet most distinctly, Singapore cooperates at a sub-national scale by partnering with indigenous stakeholders, specifically the Arctic Council's Permanent Participants. They must be consulted before decisions are made, a status which sets them apart from observers like non-governmental organizations, intergovernmental organizations, and non-Arctic states, with whom they were categorized under the Arctic Council's predecessor, the Arctic Economic Protection Strategy (Koivurova, 2010). The elevation of indigenous peoples' organizations, some of which span national borders, to the rank of Permanent Participants has created new opportunities for scale-jumping partnerships in Arctic development. Indigenous peoples and their organizations and corporations are powerful players in the Arctic's political and economic landscapes, yet outside actors have often overlooked, disregarded, or worst of all, intentionally exploited them (Nuttall, 1998).

Singapore's work with the Permanent Participants enhances the government's stated goal of "reinforcing international recognition of Singapore as an effective, constructive, and principled partner" (Ministry of Foreign Affairs 2017b, 105). Following its examination of the Nuuk criteria, which promote observer engagement with indigenous peoples (Gracyzk and Koivurova, 2014), the government began cooperating with the Arctic Council's Permanent Participants. Officials were encouraged by how their country was regarded as "having diligently embraced the application criteria" (Tonami, 2016, p.94). One Permanent Participant representative initially believed that

Singapore's interest in working with Permanent Participants would decrease once the country gained observer status in the 2013 Ministerial Meeting in Kiruna, Sweden. But in hindsight, the representative expressed, "That truthfully has not been the case. I'd say the level of outreach we've had with Singapore is every bit as strong now as it was before Kiruna…I think they're genuinely interested in this, in the Permanent Participants as a way to work with the Arctic Council, and that has continued even post-Kiruna" (Interview 2). Singapore's approach to working with indigenous peoples' organizations in the Arctic is distinct from its involvement in economic development elsewhere in the world, where it tends to engage in "G2G," or government-to-government projects. Its subnational strategy in Arctic cooperation may indicate that the Singaporean government has realized the importance of addressing and even leveraging local politics in development. Previously, the country's joint ventures in countries like China faced difficulties arising from the Singaporean government's focus on negotiating with central and national governments rather than local authorities, which caused conflicts during project implementation (Yeung, 2000). Contrastingly in the Arctic, Singapore has looked beyond capital cities like Moscow, Ottawa, and Oslo to indigenous stakeholders for partnership and economic opportunity. Singapore's formal cooperation with indigenous peoples, however, is still limited to the Permanent Participants. This demonstrates that the government's scale-jumping in this area is ultimately shaped by the Arctic Council, which provides the norms that determine which are "legitimate" indigenous organizations.

The Singaporean government engages with indigenous actors in the Arctic in three main ways: through visits, training, and infrastructure investment. Minister of State Sam Tan met with indigenous peoples in Whitehorse, Canada in 2014 (Ministry of Foreign Affairs, 2014b) and visited the Sami capital of Karasjok in Norway in 2015 (Ministry of Foreign Affairs, 2015a). Visits and photo-ops with indigenous peoples in the Arctic serve as an important means of visual currency that communicate to both domestic and international audiences that a country is actively engaged in Arctic affairs, but they do little to set Singapore apart from other countries' representatives who have also spent an hour or two with a Canadian indigenous person or Sami reindeer herder. Instead, where the Singaporean government distinguishes itself is in its invitations to indigenous peoples for funded study visits in the tropical city-state. This is notable, for even in many Arctic conferences that take place in the region itself, indigenous peoples are often poorly represented due to a lack of travel funds provided for their participation (author's observation). Singapore's training of foreign individuals maps onto the country's long-held practice of importing talent and knowledge (Fong, 2006), but in this case that talent consists of Arctic indigenous peoples. This effort also reflects the country's history of providing "South-South" technical assistance under the Singapore Cooperation Programme (Hosono, 2013), established in 1992 by the Ministry of Foreign Affairs' Technical Cooperation Directorate, and the related Third Country Training Programmes in which it partners with other developed countries to train individuals from developing countries. The Singaporean government's establishment of these training programs facilitates its efforts to build a global reputation for the country as a separate but equal player in development. This suggests to developing countries that the island-state was once one of them, but can now train them.

Since becoming an observer, Singapore's training of Arctic indigenous peoples has ramped up. In November 2015, Singapore hosted representatives from the Aleut International Association, Arctic Athabaskan Council (AAC), Russian Association of Indigenous Peoples of the North (RAIPON), Saami Council, and Arctic Council Indigenous Peoples Secretariat to discuss public policy issues ranging from sustainable development to cultural preservation. In September 2016, four AAC representatives participated in a course on "Climate Change Impacts and Adaptation Strategies" (Ministry of Foreign Affairs, 2016b). The Permanent Participant representative, who attended one of the study visits, remarked, "It was quite an extensive program in that they invited the Permanent Participant representatives to Singapore for a week, and it was very busy. It was literally work every day, multiple ministries were visited, tours and explanations of the programs, and we joked about it, that it would look bad that we were going to this tropical place, but in fact it was a lot of hard work because we really covered a lot of ground. So I found it very useful to understand Singapore's approach to the Arctic. Obviously, it is colored by the way Singapore's government approaches everything" (interview #3). Singapore's third study visit, planned for 2017, will focus on heritage and mental wellness (Ministry of Foreign Affairs 2016a).

As another means of providing training, under the Singapore-Arctic Council Permanent Participants Cooperation Package, the Singaporean government provides fully funded graduate scholarships to two Arctic indigenous students a year chosen by the Permanent Participants to study for a master's degree in maritime law, maritime studies, or public policy and administration at a Singaporean university (Ministry of Foreign Affairs, 2016b). The first recipient of the scholarship was a Dolgan representative selected by RAIPON, who enrolled in a Masters in Public Policy at the Lee Kuan Yew School of Public Policy (Ministry of Foreign Affairs, 2016a). While valuable, the Singapore-Arctic Council Permanent Participants Cooperation Programme only trains two people a year and in sectors that may also prove beneficial to the Singaporean economy. No graduate degrees, for instance, are supported in areas like environmental law that might one day serve to contest developmental interests. The training the Singaporean government provides thus arguably supports not only an image of good global citizenship, but also materially may help perpetuate global development, which is key to Singapore's continued growth. In Brazil, where

Keppel's subsidiaries have a stake in the maritime industry, they also train, educate, and employ locals. As a Singaporean GLC representative remarked, "We are invested in sponsoring students from outside countries to study here. We eventually want to have local people run our business" (interview #1). The representative then drew attention to Brazilian laws requiring local content in resource extraction operations. Similar rules adhere in much of the North American Arctic, where indigenous peoples also often possess rights to surface and, though less frequently, subsurface land and resources. If indigenous peoples are trained in Singapore, they may become more receptive to its future involvement in development on their own territory, and more favorable to the idea of development in general.

Singapore's third main area of engaging indigenous peoples, investing in indigenous-owned infrastructure, is less developed but may eventually prove to be an important sector for establishing joint ventures similar to the ones undertaken by Keppel Offshore and Marine. In particular, Singapore has explored the possibility of establishing a foothold at the Port of Adak in Alaska's Aleutian Islands. The Aleut Corporation, one of thirteen Alaska Native regional corporations established in 1971 by the Alaska Native Claims Settlement Act, wholly owns all marine infrastructure at the formal U.S. naval air facility except for the small boat harbor project (Adak Offshore, LLC, 2013). Adak possesses a deep-water port but lacks the additional infrastructure, like cranes, that might help transform it into an Arctic shipping hub. Thomas Mack, President of the Aleut Corporation, was invited to participate at the Arctic Circle Singapore Forum in 2015 – a landmark event sponsored by the Arctic Circle, the Singapore Maritime Institute, and the MFA that underscores how Singapore is bringing Arctic development discussions to its doorstep. In his speech, he explained, "The Port of Adak is perfectly positioned at the crossroads of the Great Northern Route, the Northwest Passage, and the Great Circle Route," (Mack, 2015) engaging in a type of geographical boosterism typical of representatives from numerous aspiring Arctic hubs like Reykjavik and Longyearbyen. Singaporean port officials may see an opportunity in Adak because if the Polar Code makes it too expensive to outfit regular ships for polar shipping between Europe and Asia, then Adak could serve as a transshipment point where goods could be moved between polar-class vessels for transport north of the Aleutian Islands and regular vessels for transport south (Interview 3). Thus, while the Singaporean government may not perceive Arctic shipping routes as an immediate threat to the country's dominance of global shipping networks (Storey, 2014b), investing in maritime infrastructure at a site like the Port of Adak or Russia's aforementioned Zvezda Shipbuilding Complex may help the country stake out a place in future Arctic shipping networks even without exercising sovereignty over Arctic territory. The Permanent Participant representative commented, "I think that they are trying to secure some sort of foothold that gives them a position of, at least a position of leverage in what may be a changing world in terms of shipping" (Interview 3). Should the geography of global shipping networks, which presently convene on the tropical city-state, switch to the Arctic at some point in future, such a foothold may help Singapore (Figure 4-1).

In public and private discourse, Singaporean officials are careful to point towards the global and local benefits of Arctic development. A Singaporean GLC representative argued, "There's no point in saying [the Arctic] is a pristine area and no point in going there. We have to convince critics that this is what we need to do – fulfill the economic needs of the whole world" (Interview 4). The "critics" at whom this statement is likely aimed are environmentalists and conservationists who wish to fence off the Arctic from industrial activity. For the self-proclaimed global city with the world as its hinterland, local economic growth depends on global development and engaging the new array of non-state stakeholders involved in global governance. So does the country's paradoxical identity of being simultaneously everywhere and equally just a "tiny red dot," and both "developed" and "developing." The GLC representative continued, "People living in the Arctic will benefit the most. All the revenues will flow back to them" (Interview 4). While such discourse appears inclusive, it is essentially premised on the denial of a veto power by Arctic peoples over development – a right that has been denied to indigenous and Aboriginal peoples across the North (Dylan, Smallboy, and Lightman, 2013). Globally, even as institutions such as the World Bank have begun to recognize the need to obtain "free, prior, and informed consent" of indigenous peoples on development projects, development still tends to remain a *"fait accompli"* (Baker, 2012). For the Singaporean government, obstructing development is a non-option because not only could it harm their economy. It could also undermine the roots of their national identity. In 1972, Rajnaratnam argued, "Once you see Singapore as a Global City the problem of hinterland becomes unimportant because for a Global City the world is its hinterland" (Rajnaratnam, 1972, p. 8). Yet if development of the hinterland were to stop or slow, then Singapore would almost certainly face a problem.

4.6 Conclusion

Singapore's Arctic ambitions have typically been explained by way of its maritime economic interests and active role in global governance forums. These interests and activities are rooted in Singapore's history of export-oriented industrialization, which plays into the narrative the government tries to sell to Arctic stakeholders of being able to share lessons in developing from the ground-up. Yet equally, Singapore's participation in the Arctic has been made possible by three key transformations in the region: the deepening territorialization of the Arctic economy as fossil fuel and shipping possibilities open, a shift from national government to global governance in shaping development, and the production of the Arctic as an investment frontier.

Notably, in a region increasingly recognized as being globally important due to both climatic and economic imperatives, Singapore has strategically sought to position itself as a small and nimble player. Rather than launch headline-grabbing icebreaker expeditions like China or South Korea, Singapore quietly invites indigenous peoples for funded study visits and training. This scale-jumping cooperation fills a niche left relatively empty by other non-Arctic states. They focus more on bilateral cooperation, although South Korea has recently made small, formalized efforts to engage indigenous peoples (Canadian Studies Center, 2016). The tendency for scale-jumping to occur in Arctic cooperation also suggests that more consideration should be given to how non-state entities outside the Arctic, for instance financial hubs like London or sovereign wealth funds, work with Arctic stakeholders to push forward Arctic development by providing loans or insurance to major industrial projects. As actors with deterritorialized economic activities provide capital for the development of frontiers like the Arctic, such investments will further globalize them. Yet at the same time, these investments may help to ensure their status as resource and transportation hinterlands for self-declared "global cities" like Singapore for the foreseeable future.

Whereas discursive efforts to attract investment to the Arctic depend on the construction of an inherently place-based, territorialized region, the Singaporean government has increasingly sought to distance itself from its geography by pursuing a global, cosmopolitan identity. Its Arctic pursuits support this city-imaging project, which targets both domestic and global audiences. Participation in Arctic development and climate change mitigation make Singapore appear like a concerned global citizen. The government's depiction of the city-state as supporting development in seemingly new frontiers like the Arctic offshore and deep seabed may help the island to retain its global status as a dynamic, future-oriented command and control center of the world economy. And for Singaporean citizens, affirmation of the country's identity as a global city contributes to ongoing nation-building efforts in a city-state that is only a few decades old. Lastly, bearing in mind current predictions of Arctic climate change and sea level rise, Minister of State Sam Tan remarked at an Arctic Circle forum in Greenland in 2016, "If global temperatures continue to rise, many parts of Singapore could eventually be submerged underwater" (Sam Tan, 2016). Taking this forecast to an extreme, in future, legitimation of Singapore's global city status could prove crucial not just for the furtherance of its economy, but for the survival of its national identity and sovereignty, too.

4.7 Figures

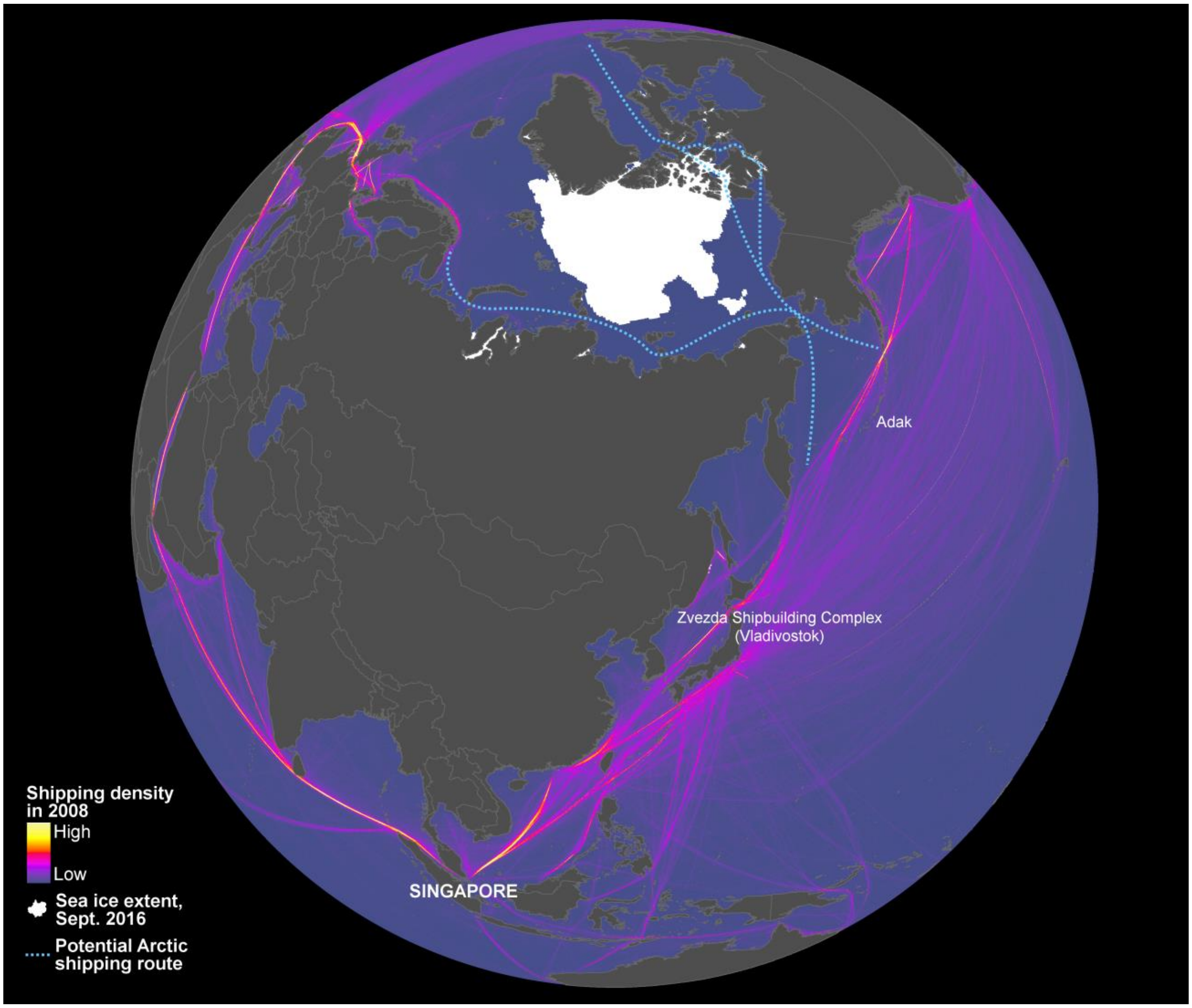

Figure 4-1. Map of Singapore in relation to current global shipping routes and potential Arctic shipping routes along with two key locations mentioned in the text. Shipping data: Halpern et al., 2016. Sea ice data: Fetterer et al., 2016.

4.8 References

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4.9 Appendix: Interviews

Reference number	Description of position	Date of interview
1	GLC representative	September 19, 2015
2	Academic involved in Singapore-Arctic affairs	January 7, 2016
3	Arctic Council Permanent Participant representative	October 4, 2015
4	GLC representative	September 19, 2015

Table 4-1. Expert interviews.

Chapter 5

Advances in using multi-temporal night-time lights satellite imagery to detect, estimate, and monitor socioeconomic dynamics

5.1 Abstract

Since the late 1990s, remotely sensed night-time lights (NTL) satellite imagery has been shown to correlate with socioeconomic parameters including urbanization, economic activity, and population. More recent research demonstrates that multitemporal NTL data can serve as a reliable proxy for change over time in these variables whether they are increasing or decreasing. Time series analysis of NTL data is especially valuable for detecting, estimating, and monitoring socioeconomic dynamics in countries and subnational regions where reliable official statistics may be lacking. Until 2012, multitemporal NTL imagery came primarily from the Defense Meteorological Satellite Program - Operational Linescan System (DMSP-OLS), for which digital imagery is available from 1992 to 2013. In October 2011, the launch of NASA/NOAA's Suomi National Polar-orbiting Partnership satellite, whose Visible Infrared Imaging Radiometer Suite (VIIRS) sensor has a Day/Night Band (DNB) specifically designed for capturing radiance from the Earth at night, marked the start of a new era in NTL data collection and applications. In light of these advances, this paper reviews progress in using multitemporal DMSP-OLS and VIIRS imagery to analyze urbanization, economic, and population dynamics across a range of geographic scales. An overview of data corrections and processing for

comparison of multitemporal NTL imagery is provided, followed by a meta-analysis and integrative synthesis of these studies. Figures are included that visualize the capabilities of DMSP-OLS and VIIRS to capture socioeconomic change in the post-Soviet Russian Far East and war-torn Syria, respectively. Finally, future directions for NTL research are suggested, particularly in the areas of determining the fundamental causes of observed light and in leveraging VIIRS' superior sensitivity and spatial and radiometric resolution.

5.2 Introduction

At night, anthropogenic activities such as the electrical illumination of population centers and gas flaring from Siberian oil fields light up the Earth's surface. These nighttime lights (NTL) can be resolved from space by satellites like the U.S Air Force Defense Meteorological Satellite Program – Operational Linescan System (DMSP-OLS) and its successor, the Suomi National Polar-orbiting Partnership (Suomi NPP). DMSP-OLS is a constellation of military meteorological satellites originally designed for detecting clouds at night. After its declassification in 1972, scientists realized the OLS sensor's ability to image radiance from city lights, gas flaring, fishing fleets, and other illuminated features (Croft, 1978).

Initially, socio-economic applications of NTL imagery were limited. Between the late 1970s and early 1990s, only a few studies using the data were published, namely on urban mapping (Croft, 1978; Kramer, 1994), population density (Welch, 1980) and energy usage (Sullivan, 1989). Systematic studies using NTL did not begin in earnest until 1992, when the National Oceanic and Atmospheric Administration's National Geoscience Data Center (NOAA/NGDC) created a digital archive of DMSP-OLS (hereafter referred to as OLS) data that now extends from 1992 to 2013. Prior to 1992, OLS data were not preserved or available in digital form (Elvidge et al., 1997a) and few studies used the available declassified film formats (e.g. Cahoon et al., 1992). While the satellite program is still collecting data for the military today, NOAA/NGDC are no longer digitally archiving the data because they have switched to supporting the satellite's successor, Suomi NPP VIIRS. With VIIRS data available from December 1, 2011 onward, comparison with OLS data can be made through 2013, when digital archiving of the latter product ceased.

Following the 1992 establishment of the OLS digital archive and the release of “stable lights” (non-ephemeral) composites for the United States beginning in 1997 (Elvidge et al., 1997a), researchers discovered the possibility to correlate lights with known demographic and economic variables (Elvidge et al., 1997b; Imhoff et al., 1997). From these correlations, NTL can be used to predict such variables in places where reliable statistics are otherwise lacking, like cross-border or subnational regions (Henderson et al., 2012), as the data provide a globally uniform and continuous measurement. Coincidentally, as global awareness about the effects of human activities on the environment heightened in the 1990s, a call arose for a “second environmental science” that focused on interactions between humans and the environment (Stern, 1993: 1897). From space, NTL imagery provides a useful window into these interactions while bridging areas of study that were previously the remit of either social scientists or remote sensing scientists, but not both.

A nearly twenty-year record of cross-sectional and multitemporal research has revealed strong relationships between NTL and urbanization (Henderson et al., 2003; Ma et al., 2012; Pandey et al., 2013; Zhang and Seto, 2013; Zhang and Seto, 2011), population (Elvidge et al., 1997b; Raupach et al., 2010; Sutton, 1997; Sutton et al., 2001; Zhuo et al., 2009), and national and sub-national estimates of gross domestic product (GDP) (Doll et al., 2006; Ebener et al., 2005; Sutton et al., 2007; Sutton and Costanza, 2002). NTL research is quickly advancing, too, thanks to the October 2011 launch of NASA and NOAA's Suomi NPP satellite. Its onboard Visible Infrared Imaging Radiometer Suite (VIIRS) has a Day/Night Band (DNB) specifically designed for detecting lights, meeting demands from the NTL remote sensing community for a dedicated satellite (Elvidge et al., 2007). VIIRS can detect NTL at higher spatial and radiometric resolutions than DMSP-OLS and practically eliminates three critical problems that beset the heritage satellite program: saturation, blooming, and a lack of on-board calibration. Despite these improvements, VIIRS still lacks OLS' lengthier data record, making the latter necessary for studies that extend prior to December 2011. In 2017, NASA will launch Suomi NPP's successor, the Joint Polar Satellite System-1, which will also have VIIRS onboard (Zhou et al., 2016) and therefore extend the sensor's data record.

Given these advances in NTL remote sensing technologies and applications, it is timely to review the past two decades of NTL-based examinations of socioeconomic dynamics to determine gaps in the existing and identify future directions. Accordingly, this paper examines progress in using multitemporal OLS and VIIRS imagery to detect, monitor, and predict socioeconomic dynamics at a range of spatial and temporal scales. Specific attention is given to multitemporal NTL imagery because although most research to date focuses on single-year studies (Huang et al., 2014) newer studies, including an emerging subfield in economics, explore relationships between multitemporal NTL and socioeconomic dynamics.

This chapter provides an overview of multitemporal OLS and VIIRS datasets (Section 2); consideration of the main methods used in processing and correcting these data (Section 3); meta-analysis and examination of existing research and its limitations in using NTL imagery to detect and predict trends in urbanization, economic, and population dynamics (Section 4); suggestions for future research (Section 5), and concluding remarks (Section 6). Since NTL are of intrinsic interest both as a remotely sensed dataset and as a dataset that can be used to address social science questions, the two perspectives are explored and synthesized throughout the review.

5.3 NTL data products

5.3.1 DMSP-OLS

DMSP-OLS is an oscillating scan radiometer with a swath width of ~ 3000 km and two spectral bands: Visible Near-Infrared (VNIR), which collects NTL, and Thermal Infrared. The OLS contains two telescopes and a photo multiplier tube, which can detect radiation between 0.47 and 0.95 μm in the visible and near-infrared wavelengths (Lo, 2002). The system has a "fine" 0.56 km spatial resolution mode, but on-board averaging performed in 5 × 5 blocks sends data to NOAA/NGDC in "smooth" 2.7 km resolution. OLS has 14 daily orbits, providing global daytime and nighttime coverage every 24 h (Elvidge et al., 1999). The nighttime overpass occurs between approximately 20:30 and 21:30 (Elvidge et al., 2001). At night, OLS can detect radiances down to 1.54×10^{-9} and up to 3.17×10^{-7} $W \cdot cm^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$ (Cinzano et al., 2000). Data values are reported in digital numbers (DN) on a six-bit scale that ranges from 0 (no light) to 63 (maximum reported light). OLS values are therefore relative rather than absolute measures of radiance. Since 1992, a total of nine sun-synchronous, polar-orbiting satellites named F10 through F18 have collected OLS data, with typically two contributing to the digital archive at a time. In most years, follow-on satellite missions have collected sufficient overlapping data to allow intercalibration between different OLS sensors. For long-term studies, this type of processing is often done since OLS lacks on-board calibration and inter-satellite calibration. Section 3.1.1 describes this method.

OLS data products range from daily images to annual composites that are generated by NOAA/NGDC. Clouds, sun (especially in summer at the polar regions), and moon conditions can prevent daily orbits from detecting certain places. Cloudy days are excluded from annual composites, as are summer days when sunlight prevents imaging of NTL at latitudes farther from the equator. The costs of OLS data vary: a monthly global NTL composite, for instance, costs

$7665, while annual composites are free (NOAA/NGDC, 2017a). It is possible that the high prices of daily and monthly images explain why so few studies have implemented OLS data at sub-annual timescales, though there are some key exceptions (e.g. Filho et al., 2004; Min et al., 2013). Instead, the most widely used product for multitemporal NTL studies is the global annual stable lights composites time series from 1992 to 2013 (Huang et al., 2014), included in the Version 4 DMSP-OLS NTL Series (available at http://ngdc.noaa.gov/eog/dmsp.html). Prior to release of this dataset, typically referred to as the “stable lights composites,” studies relied on earlier products like the 1994–1995 stable lights product developed by Elvidge et al. (2001) or previous versions of the OLS NTL Series. Version 1 covered 1992, 1993, and 2000, while Version 2 covered 1992–2003; however, these products are no longer available for download.

The stable lights composites include all persistent lighting, assign background noise a value of 0, and reduce systematic sources of light from the sun and moon, along with more ephemeral lights like the aurora and fires (Baugh et al., 2010). Each composite is reprojected from the original orbit reference frame to constitute a 30 arc-second grid spanning 180°W to 180°E and 65°S to 75°N, covering most of the inhabited world except for the high polar regions. The composites contain light from settlements and industry, fires, gas flaring, and shipping fleets (Doll, 2008).

The Version 4 series also includes the “average visible” and “average lights times percent” annual composites. The “average visible” product averages each pixel's DN for the year without additional filtering. Although this yields fewer nonzero values for pixels, it also introduces additional noise, rendering estimates less precise (Chen and Nordhaus, 2015). The “average lights times percent” composites multiply the average DN of NTL cloud-free detections for a pixel by its percent frequency of detection within a year, meaning that the value of a DN detected for only six months is halved. These composites form the basis for the intercalibration method (Elvidge et al., 2009) described in Section 3.1.1 but are infrequently used in research. Representing one exception, Mellander et al. (2015) find that even though the “average visible” and “stable lights” products perform similarly, they are weaker than the “average lights times percent” product in estimating population and industrial activity. This finding does not appear to be widely corroborated, however, and it is worth noting that even the average visible and stable lights composites may capture industrial activity differently. For example, a visual comparison of OLS V4 average lights and stable lights products reveals a railroad in Russia's Yamal Peninsula in the former (Figure 5-1a), but not the latter (Figure 5-1b).

OLS data is often saturated in bright urban areas due to the collection of data at high gain settings. Depending on how urban areas are delineated, up to a third of urban pixels have been shown to be saturated at DN = 63 in the continental U.S. (Xie et al., 2014). Thus, the radiance calibrated dataset first developed by Elvidge et al. (1999) is particularly useful for studying change over time in urban areas. This product combines cloud-free OLS data obtained over 28 nights at high, medium, and low fixed gain settings in 1996 and 1997, permitting the detection of brightness variations across space in urban cores. Coverage of low-light areas, however, is weakened as a result. The units in the radiance-calibrated product are still relative due to the lack of on-board calibration and correction for interannual satellite differences (Hsu et al., 2015). Extending the work of Elvidge et al. (1999) and Ziskin et al. (2010), who create a global composite for 2006 by blending fixed-gain data with stable lights data to capture even lower levels of NTL, Hsu et al. (2015) generate a total of eight radiance-calibrated datasets for periods between 1996 and 2011 using both fixed-gain and OLS stable lights data, for which observations were collected at varying gains. There is no possibility of generating radiance-calibrated datasets for 1992–1995 since no data were collected at reduced (“low-gain”) settings. These eight composites are intercalibrated to account for inter-satellite differences and sensor degradation, allowing for multitemporal comparison. Still, even this intercalibrated product only provides relative measurements and so cannot be directly compared with VIIRS. One possible way to compare and possibly even integrate OLS and VIIRS data may be to radiometrically calibrate the former using the latter (Shao et al., 2014). Additionally for the purposes of visualization, tritemporal OLS imagery can be superimposed on VIIRS data to simultaneously visualize decadal change in lights and more precise brightness values (Small and Sousa, 2016).

5.3.2 Suomi NPP VIIRS DNB

Suomi NPP was launched on October 28, 2011 and has five Earth-observing sensors, including VIIRS. This multispectral sensor has 22 bands, with the DNB capturing NTL data – arguably VIIRS' most innovative feature (Hillger et al., 2013). VIIRS' spatial resolution of 742 m, preserved across a ~ 3040 km swath width, is 45 times higher than OLS at nadir and 88 times higher at scan edge. Its radiometric resolution is 256 times finer and its sensitivity to radiance 10 times higher (Miller et al., 2013). VIIRS' ability to resolve lower light levels at smaller intervals, with a measured spectral response of 505–890 nm full width at half maximum (fwhm) (Miller et al., 2012), represents a significant advance over OLS. To put this in perspective, VIIRS' high radiometric sensitivity enables it to differentiate between 1 km^2 that is lit by a single street lamp and one that is not (Seaman and Miller, 2015). While OLS data have been shown to be strongly correlated with ground-based measurements of NTL (Kyba et al., 2013), VIIRS is expected to produce even stronger correlations (Katz and Levin, 2016).

However, VIIRS still falls short of specific calls for a NTL satellite with medium spatial resolution (~ 50 m) and multispectral bands (Elvidge et al., 2007), for the DNB merely collects information across a single wide spectral band. Furthermore, VIIRS is not superior to OLS in all aspects. As some cities begin to switch from high-pressure sodium to more energy-efficient white light-emitting diode (LED) lighting, VIIRS will erroneously detect a reduction in light pollution because of its insensitivity to wavelengths below 500 nm, the bluish part of the spectrum where LEDs emit a substantial amount of light (Falchi et al., 2016). OLS, whose slightly wider wavelength ranges from 0.4 to 1.1 μm, may have a better chance at detecting LED lighting.

VIIRS data has 12- or 14-bit quantization depending on noise levels and are reported in radiance in units of nanoWatts/(cm^2·sr). While VIIRS' specified dynamic range lies between 3×10^{-9} to 0.02 $W \cdot cm^{-2} \cdot sr^{-1}$, actual performance puts the noise floor at 5×10^{-11} $W \cdot cm^{-2} \cdot sr^{-1}$, allowing detection of extremely faint point sources of light (Cao and Bai, 2014). Its three gain stages allow detection of a greater dynamic range of radiance during the day, twilight, and night (Miller et al., 2012). The overpass time occurs approximately after 1:30 am local time (Elvidge et al., 2013a), when there is generally less illuminated activity occurring on the ground than during the 20:30–21:30 overpass time of OLS. This difference should be kept in mind when comparing data from the two satellites (Table 1).

Gathered by a satellite jointly operated by NASA/NOAA as opposed to the U.S. Department of Defense, VIIRS data are freely available to the public. This opens the door to a range of studies using multitemporal NTL imagery, including at sub-annual time scales costly to study with DMSP-OLS data. Raw VIIRS data granules, which include the sensor data records and geolocation information, are available from a number of websites such as NOAA's Comprehensive Large Array-Data Stewardship System (CLASS) (http://www.nsof.class.noaa.gov) and the University of Wisconsin's NASA Atmosphere SIPS server (http://sips.ssec.wisc.edu/). NOAA's Earth Observation Group distributes processed global- and regional-level data, including the VIIRS NTL 2012 product and the monthly Version 1 (V1) Nighttime VIIRS DNB Composites.

Like the OLS composites, both VIIRS products stretch from 65°S to 75°N, though they are divided into a total of six 15 arc-second geographic grids rather than provided as a single GeoTIFF with global coverage. The VIIRS NTL 2012 product was the first cloud-free composite made from data from the new sensor. Released in early 2013, it contains observations made on moonless nights between April 18–26 and October 11–23, 2012. No comparable products for subsequent years yet exist that would allow for interannual comparisons.

The VIIRS V1 composites constitute monthly global average radiance composite images in which cloud cover, lightning, and lunar illumination are eliminated (Mills et al., 2013). Two configurations of the V1 composites are available: a first, called "vcmcfg," which excludes data affected by stray light that enters through the sensor's scan cavity, and a second, called "vcmslcfg," which includes such values after they are corrected for stray light following the method described in Mills et al. (2013). This second configuration is of poorer quality but contains more data coverage near the poles. For both configurations, the number of cloud-free observations used to create each pixel within a monthly composite is provided as a separate image. The V1 VIIRS composites are available for every month from April 2012 onward. Unlike the OLS V4 stable lights composites, aurora, fires, and other ephemeral lights are still included in the V1 VIIRS composites since a robust method of removing them is under development (NOAA/NGDC, 2017b). Generally compared to the heritage satellite, however, VIIRS can more readily distinguish between electric lighting and combustion with appropriate algorithm development (Elvidge et al., 2013a) and between cloud, snow cover, and snow-free land (Lee et al., 2006).

Figure 5-1 compares three types of DMSP-OLS composites and a monthly VIIRS composite of Russia's Yamal Peninsula, which lies above the Arctic Circle. Settlements, industrial areas, and gas flares emanating from the peninsula's natural gas industry are more clearly delineated in the VIIRS image, illustrating its improved spatial resolution and reduced blooming (Hillger et al., 2013; Miller et al., 2013; Miller et al., 2012). Saturation is also much reduced, too. VIIRS captures large and slight spatial fluctuations in anthropogenic lighting, especially in the rural-urban transition zone and in urban cores where OLS data tends to be saturated (Ma et al., 2014c). As a comparison of images of New York City reveals, VIIRS (Figure 5-2b) better resolves urban structure and connectivity by detecting both small, dim lights and bright lights without saturation or attenuation (Small et al., 2013). In the OLS image (Figure 5-2a), the city appears saturated and blooms over the surrounding rivers. In the VIIRS image, it is possible to distinguish brighter and dimmer spots in Manhattan, like downtown and Central Park, respectively. From the snowy and watery circumpolar north to densely populated coastal cities, VIIRS' improvements can assist with examining socioeconomic parameters and dynamics.

5.4 Data processing and interpretation for multitemporal analysis

Drawing inferences from NTL data, particularly OLS, poses challenges due to three key issues originating from the satellite: a lack of on-board calibration, blooming, and saturation (Imhoff et al., 1997; Small et al., 2011; Small et al., 2005). A major issue that originates from the ground is gas flaring (Elvidge et al., 2009). In order to process NTL imagery for cross-sectional or multitemporal analysis, a number of corrections are necessary, which this section reviews. Two of the most common ways to interpret changes in NTL are also explored: changes in intensity versus lit extent.

5.4.1 Data processing

5.4.1.1 Intercalibration and fixed effects

From one year to the next, the performance of an OLS satellite changes due to sensor degradation (Zhang and Seto, 2011). A different OLS satellite may also capture data altogether. The two main methods of reducing measurement errors due to interannual satellite differences are intercalibration (Elvidge et al., 2009) and year fixed effects (Henderson et al., 2012). Remote sensing scientists tend to apply the former method while economists include the latter in their models.

Intercalibration is possible because there is generally at least one year of overlap between any single OLS satellite and its replacement. Still, the method cannot correct for the fact that although the overpass times are meant to occur at the same time of day and night for each satellite, actual overpass times may vary by up to two hours between satellites (Elvidge et al., 2009). This can result in different NTL measurements due to changing ground conditions. Using the “average lights times percent” composites, Elvidge et al. (2009) developed the most widely used intercalibration method. Operating under the assumption that the relationship between NTL in a given year and in 1999 is quadratic, an ordinary least-squares regression model is used to intercalibrate the data as:

$$DNadjusted=C_0+C_1\times DN+C_2\times DN^2$$

with C_0, C_1 and C_2 the empirically estimated coefficients (provided in Elvidge et al. (2009)), DN the original pixel value, and DNadjusted the resulting adjusted pixel value. All composites are intercalibrated to match the values in the F12999 composite, as it has the highest average DN values. To estimate their intercalibration coefficients, Elvidge et al. (2009) use Sicily as their reference area since it radiates light over the full spectrum of values and is assumed to have experienced minimal lighting change over the years. After intercalibration, Sicily retains similar DN adjusted values from one year to the next. Other researchers have modified this method by changing the reference area to a location within their study area where lighting is assumed to be stable across time (Liu et al., 2015a; Pandey et al., 2013). Chen and Nordhaus (2011) draw attention to the fact that many researchers adopt the intercalibration method not for comparing the "average lights times percent" composites upon which it was originally based, but rather the stable lights composites. However, they test the intercalibration method in Elvidge et al. (2009) on the stable lights composites and conclude that the results are satisfactory.

As an alternative method of calibrating DMSP-OLS composites, Bennie et al. (2014, 2015) use a robust regression technique called quantile regression on the median. Compared to the OLS-based method of Elvidge et al. (2009), their technique is less influenced by outliers and assumes that at least 50% of pixels within the reference area maintain constant brightness rather than all of them. Quantile regression on the median may therefore be more appropriate for places experiencing limited directional change in lighting over time (Bennie et al., 2014). For their intercalibration method, the F101994 composite serves as the base year since it has the highest proportion of pixels with the minimum and maximum values (0 and 63).

While most multitemporal studies examine interannual change, comparison of monthly composites benefits from controlling for seasonal factors. To diminish the effects of predictable, seasonal factors like vegetation variation and lunar illumination, Letu et al. (2015) create a time-series of 10-day data for 1999 by compositing the maximum digital numbers. To remove seasonal periodic noise, they extend the noise reduction filter developed by Hara et al. (2010). Their method also helps counter underestimation of DNs due to persistence of thin clouds.

Many economists using NTL data forego intercalibration and instead control for year fixed effects (Chen and Nordhaus, 2011, 2015; Henderson et al., 2012). Henderson et al. (2012) seek to use lights in a predictive manner by obtaining a regression of income growth versus NTL growth. They estimate a log-linear model between the "sum of lights" (a common measure in the literature which adds all of the digital values of the pixels in a given area, hereafter referred to as "SOL") for each country and its GDP. The model includes an error structure that includes year fixed effects, which is written as:

$$\tilde{e}_{jt}=c_j+d_t+e_{jt}$$

for which $\tilde{e}$ is the error for country *j* in year *t*, c_j is country fixed effects (controlling for factors like differences in lighting patterns and investment in outdoor lighting, which are unrelated to intercalibration), d_t is year fixed effects (controlling for interannual satellite differences and changes in global external conditions, like technology and economic activity), and e_{jt} is the remaining error. Unlike intercalibration, which can be applied to NTL data by itself, controlling for fixed effects requires the availability of an alternative quantity of interest, like GDP. This method would therefore not be useful for examining interannual NTL trends in a place for which no ancillary data are available. For instance, to simply make a change detection map of NTL in a remote stretch of desert from 1992 to 2012, intercalibration would be the more applicable method to correct for satellite differences.

5.4.1.2 Saturation

Saturation, sometimes called top-coding (Henderson et al., 2012), is one of the primary limitations with OLS data as it has only 8-bit quantization and low dynamic range. Therefore, the sensor cannot measure brightness levels beyond a value of 63 DN. This is especially problematic for studies of brightly lit urban cores, as saturation prohibits the detection of variation in lighting levels beyond DN = 63 (Small et al., 2005).

In the United States, East Asia, and Western Europe, many metropolitan cores have reached saturation, making further brightening undetectable with OLS imagery. In mainland China alone, Ma et al. (2014b) identify 135 saturated cities. Some studies examine multitemporal NTL imagery without correcting for saturation effects (Chand et al., 2009; Zhang and Seto, 2011). This is acceptable when most light sources fall under the saturated value, as in India (Chand et al., 2009) or Africa, where between 2007 and 2008, a mere 0.00017% of lit pixels were saturated (Michalopoulos and Papaioannou, 2013). However, studies foregoing saturation correction that use NTL as a continuous measure without ensuring that there are no saturated pixels should be assessed critically.

Saturation corrections are essentially irrelevant for studies that simply threshold NTL, but they are necessary for those that use NTL as a continuous measure. When applied, saturation corrections can improve the accuracy of results in studies of long-term socioeconomic trends using OLS data (Letu et al., 2012). Several methods have been suggested. Raupach et al. (2010) propose a probabilistic saturation correction, estimating that NTL intensity (DNs) should be multiplied at the regional scale by an average of 1.15 (ranging from 1.003 for "least developed countries" to 1.570 for Japan, a densely urbanized country with significant saturation) and at the cell scale by an average of 1.23. Letu et al. (2010) find that at a 1-km^2 resolution within nine electric power supply areas in Japan, the median daily DN is linearly correlated with built area. Consequently, they estimate the actual values of saturated areas using a cubic regression equation. Applying this correction for saturated light improves the fit between stable lights and electric power consumption in Japan and 12 other countries in Asia. Letu et al. (2012) enhance this method by finding a strong linear correlation ($R^2 = 0.93$) between the SOL of unsaturated areas in both stable light and radiance-calibrated images. They derive a regression function that more accurately estimates the true values of saturated pixels. This new method modestly improves the correlation between regional SOL in the stable lights image and annual electric power consumption from $R^2 = 0.81$ derived using Letu et al.'s (2010) method to $R^2 = 0.91$. Lastly, after evaluating two regional-level and two pixel-level saturation correction methods, Ma et al. (2014b)conclude that the correction should be chosen depending on the study area. Regional-level methods are appropriate for correcting data in areas with many saturated pixels, while pixel-level correction methods are more appropriate for areas with fewer saturated pixels.

5.4.1.3 Blooming

Blooming (also called spatial blurring or overglow) occurs when the averaging of adjacent input cells to produce output cells causes lit pixels to extend beyond a source's true illuminated area. This issue is especially acute in OLS imagery (Xie et al., 2014) and is more pervasive over water and snow areas, as these reflect nearby lights more than dark ground. Two-fifths of the world's major cities with populations of 1–10 million are located near coastlines (Tibbetts, 2002). Since cities form a popular topic for NTL-based studies, blooming should be of particular concern when examining coastal metropolises, though blooming can occur over land, too. Failing to correct for blooming when using NTL as a proxy can result in overestimation of features such as urban extent, since changes in brightness tend to be bigger in area than associated land cover changes (Small and Elvidge, 2013). Typically, blooming is proportional to the SOL emitted by a light source, such as an urban area. In Australia, Townsend and Bruce (2010)find a strong correlation between a city's SOL and the spread of its lights past the coastline for nine coastal cities ($R^2 = 0.89$).

There is little consensus on how to correct for blooming. Thresholding, whether based on a detection frequency or a fixed or scaled DN value, can reduce the effect of blooming and is the most widely investigated method. Yet there is little agreement on how exactly to apply it (Zhou et al., 2014). Based on an examination of urban areas in the U.S., Imhoff et al. (1997) conclude that a frequency detection threshold selecting pixels lit in 89% of the orbital passes contained within the 1994/1995 DMSP-OLS stable lights composite results in more accurate urban boundaries when compared with 1990 U.S. Census data on urban areas and eliminates blooming. However, this threshold makes many small settlements disappear. Showing how thresholds can vary from city to city, Henderson et al. (2003) determine that the stable lights images of Beijing, Lhasa, and San Francisco are most accurately thresholded at frequency detection levels of 97%, 88%, and 92%, respectively. Also differing from Imhoff et al. (1997)'s claim of the effectiveness of a uniform threshold of 89%, Small et al. (2005) examine 17 cities worldwide in the 1992/1993, 1994/1995, and 2000 stable lights datasets and determine that no single threshold produces spatial extents consistent with Landsat-derived built extent. They instead suggest employing a scale-dependent blooming correction procedure that accounts for the size of the lit area. After imposing a linear relationship between lit area and blooming extent for 10 illuminated islands, they suggest that a scale-dependent correction for blooming may be effective. However, no further research has been conducted on this method's effectiveness and it is unclear whether it would work over non-coastal areas. Finally, the Overglow Removal Model (ORM) developed by Townsend and Bruce (2010) considers the effects of annual atmospheric conditions, topography and elevation, and differences in regional lighting technologies on the extent and influence of blooming. Yet as this information is not always available, especially for locations in developing areas where applications of NTL imagery may provide the most insight, the ORM's applicability may be limited.

Due to the challenges posed by blooming and interpreting very low DN values, the choice of threshold may significantly affect the outcome of many NTL studies whether they measure the intensity or extent of lights. Yet similar to how there is no consensus on a globally uniform standard for a detection frequency threshold to delimit urban areas, there is also no consensus on a globally uniform standard DN threshold. Illustrating the range of DN-based thresholds used in NTL studies, Yi et al. (2014), use DN > 10 to delimit urban areas in China, while Amaral et al. (2006) use DN > 30 to delimit urban areas in the Brazilian Amazon. Based on validation against high-resolution land-cover data, Zhou et al. (2014) find that the optimal DN threshold for delineating large urban clusters like Boston and Beijing is 60, while it is 20 in smaller cities. Optimal thresholds for extracting lit urban area can even vary within one country and over time (Gao et al., 2015). Small et al. (2011) suggest that spatial extent and intensity of development, as proxied by NTL, are continuous rather than discrete in nature and exhibit distinct spatial phase transitions. As the threshold increases from 3 to 60, networks of lit area fragment and shrink due to the exclusion of dimmer lights connecting these regions. The decrease in delineated lit area at a threshold of DN = 8 suggests both a strong sensitivity to delineation of lit area at low DN thresholds (DN < 8) and a sharp decrease in the global frequency distribution of lights around DN = 8. Given the range of potential thresholds that can be used, research that employs thresholding as a method of analysis should also report the sensitivity of results to changes in the value of the threshold.

VIIRS data hardly exhibit any blooming in comparison to OLS and hence require few, if any, corrections. In one of the few studies so far that examines blooming in VIIRS versus OLS, Xie et al. (2014) first normalize an image from each dataset (the 2012 OLS V4 composite and a two-month VIIRS composite from 2012) using a linear stretch to make them comparable. They find that extracting the same sized urban area from these two images requires 4000 continuous lights in the OLS image and 23,000 in the VIIRS image. This is because VIIRS data fragment large urban areas and capture additional small urban areas. Saturation or blooming may affect resolution of these features in OLS. Overall, thanks to the reduction in blooming, VIIRS imagery now depicts brightly lit coastal conurbations like the Northeastern U.S. as a fine web of interconnected cities rather than a blob of light in OLS imagery (Ou et al., 2015).

At the same time, VIIRS' lower limit allows detection of nocturnal airglow, the background luminosity emitted by the Earth's ionosphere (Elvidge et al., 2013a). OLS has not demonstrated an ability to detect this airglow due to its lower sensitivity (Miller et al., 2012). Since airglow varies around the Earth, Kyba et al. (2015) caution that these variations should be taken into account when creating a VIIRS DNB stable lights product. Failure to do so could cause certain regions with persistently enhanced airglow to be observed as brighter than they actually are, reducing reliable prediction of socioeconomic variables from lights at a globe scale.

5.4.1.4 Gas flares

Gas flaring is an industrial practice that results from the combustion of gas at oil production sites that cannot be economically shipped out to market. Gas flares over the Yamal Peninsula in Russia, one of the world's biggest gas flarers, are visible in Figure 5-1. While the OLS V4 stable lights composites contain gas flares, these should generally be removed during pre-processing so as not to affect estimates of socioeconomic variables unless research is specifically examining the phenomenon (e.g. Elvidge et al., 2009). Gas flaring can also be used to approximate carbon emissions (Doll et al., 2000; Ou et al., 2015), but in many other studies such as of population estimates, their inclusion can introduce inaccuracies. For instance, a study using change in NTL over time in Nigeria, another major gas flarer, to predict economic or population growth would be complicated by the activity's strong persistence. Original efforts to use NTL imagery to identify and reduce gas flaring began in 2003 when the World Bank established the Global Gas Flaring Reduction Partnership. Since oil and gas companies' statistics on flaring were unreliable, the World Bank and NOAA partnered to use OLS imagery from 1995 to 2006 to create the first globally consistent satellite survey of gas flaring (World Bank, 2011: 8). The effort also eventually led to the release of the NOAA/NGDC Global Gas Flaring Shapefiles, which encompass most gas flares for the year 2008 (available at http://ngdc.noaa.gov/eog/interest/gas_flares_countries_shapefiles.html) and can be used to mask out gas flares in stable lights composites. However, some areas that represent actual anthropogenic lighting are included in these polygons (Cauwels et al., 2014); Henderson et al. (2012) find that these polygons include 0.3% of world population. It is unclear whether the NOAA/NGDC gas flare shapefiles provided for use with OLS should be used with VIIRS given the latter's higher spatial resolution and the years that have passed since the shapefiles' creation. Gas flares in Russia's Yamal Peninsula illustrated in Figure 5-1, for instance, appear as several small, distinct light sources in the VIIRS image compared to appearing as one large, nucleated light source in the three OLS images. Recent efforts to use VIIRS to identify gas flaring (Elvidge et al., 2015; Elvidge et al., 2013b) could allow updating of these shapefiles. In sum, while gas flaring still requires correcting in studies using VIIRS data to estimate population or other variables unrelated to the activity, the need for intercalibration and corrections for blooming and saturation are almost entirely reduced.

5.4.2 Data interpretation

5.4.2.1 Changes in NTL intensity and extent

Changes in NTL may be the result of actual increases or decreases in artificial lighting that are tied to variables like population or GDP, making them a useful proxy for socioeconomic studies. At the pixel level, NTL is represented by a digital number (DN) in OLS and actual radiance in VIIRS. At larger scales, total NTL intensity is typically measured as the SOL; some derivatives include the average (rather than total) SOL within an area, per capita SOL, and weighted lit area, defined as the "sum of the areas of lit pixels multiplied by the normalized DN value" (Ma et al., 2012: 101). NTL extent is often simply measured as the total area above or below a certain threshold, but as discussed in Section 3.1.3, the choice of threshold can significantly affect results.

While NTL intensity and extent may in certain circumstances grow in parallel, the factors affecting one do not always affect the other. Lights can grow in intensity without increasing in extent and vice versa. The choice of one measure over another can therefore also affect results. For instance, delineating a change in urban area based on change in the amount of lit area would likely detect cities that had expanded outwards. In contrast, measuring a change in urban area based on pixels that have increased in brightness would be more likely to capture cities that had expanded upwards or become denser. Furthermore, it should be kept in mind that changes in NTL may also be caused by alterations in the color, type, or spectra of lighting used. Bennie et al. (2014)identify locations in Europe where deliberate energy and cost savings strategies rather than economic decline led to reductions in light emissions.

A handful of studies use lit area in some form (Doll and Pachauri, 2010; Elvidge et al., 1997b, 1997c; Sutton et al., 2007). This measure can be useful when only the absence or presence of NTL is of interest, for instance to study access to electricity (Doll and Pachauri, 2010). Yet a majority of studies use SOL to measure NTL change. In a study of 35 cities in China using the 1996/1997 radiance calibrated DMSP-OLS image, Lo (2002) finds that SOL is more highly correlated than lit area with nonagricultural population (R^2 = 0.91 vs. R^2 = 0.78), GDP (R^2 = 0.91 vs. R^2 = 0.70), built-up area (R^2 = 0.91 vs. R^2 = 0.84), and electricity consumption (R^2 = 0.86 vs. R^2 = 0.77). While SOL may be the preferred measure for examining socioeconomic variables, in some circumstances, especially in saturated areas, measures derived from lit area are shown to be preferable. Sutton et al. (2007) determine that a more complex spatial analytic approach combining lit area with population data rather than summing NTL more accurately estimates sub-national GDP within all four of their country case studies (China: R^2 = 0.96 vs.0.94; India: R^2 = 0.84 vs. 0.70; Turkey: R^2 = 0.95 vs. 0.58; U.S.: R^2 = 0.72 vs. 0.70).

5.4.2.2 Spatial scale

Making inferences about socioeconomic parameters from NTL imagery requires attention to spatial scale. One challenge is the Modifiable Area Unit Problem, which occurs when different results are observed from the same data at varying spatial resolutions (the scale effect) or when the scale remains the same but variations in zoning boundaries lead to different results (the zoning effect) (Doll et al., 2006). Scale effects can lead researchers to commit an ecological fallacy by making erroneous inferences from coarse-resolution data about finer-scale processes. For example, just because California's mean NTL is brighter than Nevada's does not necessarily imply that Los Angeles and San Francisco are brighter on average than Las Vegas.

While several studies examine NTL across scales (Doll et al., 2006; Forbes, 2013; Gao et al., 2015; Ma et al., 2014a; Small et al., 2005), variations in relationships across scales are not always adequately explained. From 1992 to 2012, Gao et al. (2015) find R^2 values between a composite urbanization index and compound NTL index (the average DN of all pixels in a given spatial unit in China multiplied by the proportion of the unit's lit urban area out of its total area) of 0.96 at the national scale, 0.71 at the provincial scale, and 0.69 at the county scale. They suggest that the extraction of urban lit area by thresholding at the coarser scale of the region (in between the national and provincial scales) may be responsible for the weaker correlations found at finer scales. NTL is not always better correlated with socioeconomic data at coarser scales, however: Forbes (2013) finds that in the United States, SOL and GDP are more strongly correlated at the metropolitan than state scale. To better understand scale effects, Forbes (2013) recommends examining the processes driving relationships between NTL and socioeconomic data at varying scales and across time rather than focusing on correlations at single scales within single time periods.

5.5 Applications of multitemporal NTL imagery for socioeconomic dynamics

5.5.1 Quantitative meta-analysis

We review peer-reviewed journal papers identified by searching ISI Web of Science's archive of all journals using the terms “DMSP-OLS,” “VIIRS,” or “DNB” and “time-series” or “multitemporal” or “panel”. After inspecting the papers and excluding those that did not concern socioeconomic variables while adding others found on Google Scholar, mostly in the field of economics, which did not appear in the ISI results, in total, 63 peer-reviewed studies between January 2004 and July 2016 utilizing multitemporal OLS and/or VIIRS imagery to assess socioeconomic changes were identified. These largely examine urbanization, population growth, and economic growth at a range of time steps between 1992 and 2014. We entered the qualitative and quantitative information for each publication into a database containing 15 fields. Table 2 includes approximately a quarter of these studies as representative examples of research to date.

Geographically, China dominates the literature (Figure 5-3). Twenty out of the 63 studies we identified focus exclusively on the country (Cao et al., 2014; Gao et al., 2015; Fan et al., 2014; He et al., 2012, He et al., 2006; Jiang et al., 2012; Li et al., 2013c; Liang et al., 2014; Liu et al., 2014, 2012, 2011; Ma et al., 2012; Su et al., 2015; Tan, 2015;Tian et al., 2014; Xiao et al., 2014; Xu et al., 2015, Xu et al., 2014; Yi et al., 2014; Zhao et al., 2016), while Sutton et al. (2007) also use it as one of their four case studies. It is important to point out that the strong focus on China may be promoting overconfidence in the ability of NTL to serve as a proxy for socioeconomic dynamics in other areas. Fifteen studies examine multitemporal NTL on a global scale (Alesina et al., 2016; Cauwels et al., 2014; Ceola et al., 2015; Chen and Nordhaus, 2011; Doll and Pachauri, 2010; Frolking et al., 2013; Geldmann et al., 2014;Henderson et al., 2012; Hodler and Raschky, 2014; Li et al., 2013b; Liu et al., 2015a; Keola et al., 2015; Nordhaus and Chen, 2015; Zhang and Seto, 2013, Zhang and Seto, 2011), while an additional two look at a large (> 39) number of countries mostly in the developing world (Gennaioli et al., 2014; Weidmann and Schutte, 2016). Six studies either confine their analysis to the contiguous U.S. or use it as one of their main case studies (Cao et al., 2013; Forbes, 2013; Román and Stokes, 2014; Sutton et al., 2007; Zhang et al., 2014; Zhang and Seto, 2011). Africa tends to be the purview of economists, for the region has been relatively unstudied within their field due to the paucity of economic data (Chen and Nordhaus, 2015; Michalopoulos and Papaioannou, 2014, 2013; Rohner et al., 2013). Reflecting the distressed state of affairs in the Middle East, all but one (Román and Stokes, 2014) of the four studies concerning the region use NTL to examine the impacts of war (Agnew et al., 2008; Li et al., 2015; Li and Li, 2014).

Topically, 24 out of the 63 studies we identified directly concern urbanization processes, 18 focus on economic measures, and three attempt to estimate non-urban populations. The remainder covers a range of topics, which we explore in Section 4.5. More than half (13/24) of the studies on urbanization examine China, whose dynamics, as we discuss below, are not necessarily applicable to the rest of the world. This is why analyses of cities outside China, and particularly outside Asia (e.g. Álvarez-Berríos et al., 2013; Pares-Ramos et al., 2013), are necessary in order to explore whether they exhibit different relationships between NTL and socioeconomic variables. Most studies concerning economics tended to estimate change in economic output at scales ranging from the household to country level. Three others estimated regional or ethnic inequality (Xu et al., 2015; Alesina et al., 2016) or the size of the shadow economy (Tanaka and Keola, 2017).

In terms of NTL data, 48/63 of studies explicitly state that they use OLS V4 composites, with 43 of those using the stable lights product. The other five did not state which type they used. Only four multitemporal studies were published prior to the release of the full multi-year OLS V4 product around 2007 (Filho et al., 2004; He et al., 2006; Kohiyama et al., 2004; Sutton et al., 2007), and only one study used the OLS V2 stable lights composites (Doll and Pachauri, 2010). Prior to 2007, most NTL studies were cross-sectional. This distinction is important because the relationship between, for instance, population and NTL can be very different in the cross-section versus the panel, as we discuss in Section 4.4. OLS V4 data were used in 22/24 of the studies on urbanization (the remaining two did not specify the version of OLS data used) and in most studies on economic growth, although some in the latter area use other datasets like the OLS Global Radiance Calibrated Products alone (Xu et al., 2015) or in addition to OLS V4 composites (Weidmann and Schutte, 2016). Only three studies using multitemporal VIIRS data were identified (Cao et al., 2013; Xi et al., 2015; Román and Stokes, 2014), as this research still appears to be in the exploratory phase.

Another distinction among studies is the choice of using logged or unlogged units. While most NTL studies by economists use logged variables, remote sensing scientists do so less frequently. Whereas a linear relationship between two logged variables (a log-linear relationship) implies that a 10% increase in one is associated with a fixed percentage increase in another, a linear relationship between unlogged variables implies that a fixed absolute increase in one is associated with a fixed absolute increase in the other. This can be problematic when there are large outliers that might skew the relationship, and indeed the distributions for NTL, GDP, and population by country are often positively skewed. Finally, some studies demonstrate a relationship between NTL and a socioeconomic variable (e.g. Ma et al., 2012; Sutton et al., 2007; Zhang and Seto, 2013), while others take a demonstrated relationship and then use NTL to predict that variable in a different place or time with poor or non-existent records. Henderson et al. (2012), for instance, provide updated estimates of GDP for certain countries with poor economic statistics. With these issues in mind, by drawing on the multitemporal studies we identified and additional cross-sectional ones for context, the following section reviews advances made using NTL imagery for examining three key socioeconomic topics: urbanization, economic activity, and population.

5.5.2 Urbanization

Urbanization is a broad concept that encompasses urban population, urban land cover, and urban activities (Zhang and Seto, 2011). Aside from the simple fact that metropolises tend to be brightly lit, the city-centric focus of NTL research reflects an increasing concern in academia with the urban (Lees, 2002) and the dramatic growth of urban areas globally (Cohen, 2006). Early cross-sectional research demonstrated the usefulness of NTL as a proxy for urban population (Sutton, 1997; Elvidge et al., 1997a, 1997c). This has led OLS data to be used as an input in urban population models such as the Global Rural Urban Mapping Project (Balk, 2009). Illustrating the global rural-urban transition under way, between 1992 and 2009 cities experienced a greater proportional increase in brightness than small settlements (Cauwels et al., 2014). Caution is warranted, however, in assuming urban areas to always be light-emitting (Brenner and Schmid, 2014).

Zhang and Seto (2011) carry out one of the first studies of long-term urbanization dynamics at regional and global scales with OLS V4 stable lights composites. They estimate a linear relationship between change in urban population and NTL, with normalized urban population difference between 1992 and 2008 explaining approximately half of the variation in normalized SOL difference. However, since they do not intercalibrate their composites or control for fixed effects, their results do not account for the cross-sensor differences identified by Elvidge et al. (2009). In addition, their use of unlogged values may explain why excluding the outliers of Greenland and Russia (a country that has experienced significant economic upheaval and population decline since the Soviet collapse, potentially confounding typical relationships between these factors and NTL) increases the R^2 from 0.45 to 0.76. In another case, one outlier appears to influence the slope of the linear relationship between the normalized differences in population and urban area (extracted from OLS V4 annual stable lights composites) at the state level in India between 1998 and 2008, as shown in the scatterplot of Pandey et al. (2013), yet it is not investigated. In studies such as Zhang and Seto (2011), Pandey et al. (2013), and others that use regression-based analyses, more transparency in the handling of outliers would help determine whether they possibly share economic or geographic similarities that weaken the correlation between change in NTL and urbanization.

Some of the greatest changes in NTL have occurred in Asia (Small and Elvidge, 2013). From 1992 to 2009, the geographic center of the planet's NTL shifted 1000 km east, reflecting the growth of the continent's metropolises over the past two decades (Cauwels et al., 2014). A stratified random sampling scheme of NTL pixels from OLS V4 F14 stable lights data finds that a quarter of the world's rapid and moderate urbanization between 1997 and 2003 occurred in China (Zhang and Seto, 2013). China's cities attract a high degree of attention within the NTL literature on urbanization (Fan et al., 2014; Gao et al., 2015; Liu et al., 2014, Liu et al., 2012, 2011; Ma et al., 2012; Tan, 2015; Xiao et al., 2014; Xu et al., 2014). Many of these studies find strong relationships over time between change in NTL (both in terms of SOL and lit area) and change in variables such as urban population growth, urban GDP, urban area expansion, and urban electric power consumption in China's cities. However, the quantitative responses of changes in NTL to changes in these variables can differ between cities. Using 1994–2009 weighted lit areas from the OLS V4 stable lights composites for over 200 cities in China, Ma et al. (2012) determine that while the relationship between change in GDP and weighted lit area for cities like Beijing and Nanjing follows a power-law model, a linear model better describes the relationship for other cities in earlier stages of development, like Jinan and Fushun. These results suggest that rather than relying solely on linear functional forms, researchers should instead consider the diversity of responses of NTL to socioeconomic dynamics depending on an area's level of development.

On the whole, China's cities still are relatively uniform in terms of their urbanization patterns, with rapid and moderate urbanization occurring across the country (Zhang and Seto, 2013). In comparison, South American cities exhibit striking differences in spatiotemporal urban dynamics (Álvarez-Berríos et al., 2013). Ecuador and Bolivia's cities are undergoing an “intermediate” urban transition, with higher annual expansion rates of brightly lit pixels (> 52–63 DN) than Peru and Colombia, whose cities are undergoing an “advanced” urban transition. Studies that simply calculate the difference in a city's total SOL miss such nuances of urban change.

The rate of change, or slope, of the relationship between urbanization and NTL also differs dramatically across cities even within a single country. In cases where NTL is used as a proxy, invariance of slope across contexts is possibly more meaningful than invariance of the coefficient of determination (R^2) even though this tends to be the more commonly reported result. Even if the R^2 is uniform across scales or contexts, a varying slope dramatically limits the use of NTL as a proxy. As an example of slopes varying within a single country, Gao et al. (2015) find that in China at national, provincial, and county levels, the compounded NTL index (generated by multiplying the average DN of all lit pixels in a region with the proportion of lit urban areas to total area in the region) increases by 1705.43, 90.52 and 72.81 units, per unit increase in the urbanization index, respectively. Values for the urbanization index are generated by adding various socioeconomic measures pertaining to urbanization.

The slope of the relationship between NTL and urbanization varies between countries, too. Zhou et al. (2015b) regress NTL growth rate from 2000 to 2010 (calculated by the change in the SOL where DN $\geq$ 13) against logged population in 2000 for cities in five Asian countries. India's slope is 0.37 (expressed in units of change in logged population per change in NTL growth rate), Pakistan = 2.33, Nepal = 5.53, Sri Lanka = 0.37, and Bangladesh = 1.73, yet no analysis is made of the widely varying slopes. Using OLS V4 stable lights composites from 1992 to 2012, Liu et al. (2015a) find that the average DN (among pixels whose DN > 30) of rapidly growing cities like Shanghai and Dubai increases mores per year (0.76–1.58 DN) than in sluggishly growing cities like Brussels, London, and Stockholm (0–0.08 DN). The median slope (Theil-Sen estimator) is calculated between all pairs of observations for each city, with the resulting values ranked and classified from sluggish to rapid urbanization. For cities like London, saturation, an actual slowdown in urbanization, or some combination of the two may be the reason(s) for the negligible annual change in average DN. Persistent uncertainties regarding whether changes in observed NTL are happening on the ground or are merely sensor artifacts underscore the need for greater research in this area, which is discussed in Section 5.

Combining optical datasets or even ground-truthing NTL data with surveys and fieldwork (e.g. Amaral et al., 2006; Min et al., 2013; Min and Gaba, 2014) may improve accuracy and reveal the sources of observed light in cities. This is particularly true for the developing world, where NTL less accurately identifies urbanization than in developed countries. In India, for instance, many urban areas still lack electricity, impeding detection by OLS or VIIRS (Zhang and Seto, 2013). Generally, urbanization is less correlated with outdoor and street lighting in the developing world than in industrialized regions (Zhang and Seto, 2013). To identify urban area increase in India, Pandey et al. (2013) stack intercalibrated OLS V4 stable lights composites and SPOT vegetation NDVI data for the years 1998 and 2008. This extends the multi-source image classification method developed by Cao et al. (2009), which largely improves detection of urban area over the use of simple global threshold in part by more accurately excluding vegetated areas and water pixels. Frolking et al. (2013)examine OLS data from 1999 to 2009 and compare the average DN per 11 × 11-cell grid in 100 large cities with backscatter power from NASA's SeaWinds microwave scatterometer. They find that while Indian cities are building outwards rather than upwards, causing growth in lit area, Chinese cities are expanding their material infrastructure in both height and extent, causing increased light intensity as well as growth in lit area. In this manner, further combination of OLS and VIIRS data with other remotely sensed imagery may help better attribute the causes of observed NTL across a range of development levels.

5.5.3 Economic growth and decline

A wealth of studies confirms a strong relationship between NTL and economic activity in a single year (Doll et al., 2006; Ebener et al., 2005; Sutton et al., 2007; Sutton and Costanza, 2002). In cross-sectional analysis, NTL tends to have a stronger relationship with GDP than population (Elvidge et al., 1997c; Zhou et al., 2015b). Across a diverse group of 21 countries, lit area and GDP follow a log-linear relationship with an R^2 of 0.97 (Elvidge et al., 1997c). The linkage of lit area and, more typically, derivatives of SOL with economic activity allows mapping and estimation of GDP from NTL at a range of scales in places where no standard accounts data exists, as exemplified by the production of the first-ever 1° × 1° global map of GDP (Doll et al., 2000). Although Sutton et al. (2007, p. 12) argue that OLS data can only crudely, if still significantly, estimate sub-national GDP due to its coarse spatial and spectral resolution, it has been used to accurately predict household-level wealth in developing countries (Weidmann and Schutte, 2016; Jean et al., 2016).

In a landmark panel study using OLS V4 stable lights composites to predict real income growth in 188 countries over 17 years, NTL and GDP are shown to exhibit a log-linear relationship (Henderson et al., 2012). Globally, the elasticity of SOL to GDP is 0.28 and highly significant. SOL explains approximately 77% of variation in GDP over time within a country (accounting for year fixed effects), although it explains only 21% of variation in GDP after the data is demeaned. Henderson et al. (2012) conclude that NTL growth is a highly useful proxy for both long-term GDP growth and short-term fluctuations and consequently offer amended GDP growth rates for countries with poor economic statistics like Burundi and Myanmar. However, their model assumes that the true relationship between logged NTL and GDP at the country level varies annually by a log-additive constant, which may not always be the case.

Several multitemporal NTL studies in economics build on the work of Henderson et al. (2012). Unlike most NTL research conducted by remote sensing scientists, economists tend to run panel regressions with sensitivity analyses and examine NTL in more unconventionally bounded areas, such as portage sites along the fall line (a geomorphological break between upload and coastal regions) of the Southeast U.S. (Bleakley and Lin, 2012) and ethno-linguistic homelands around the world (Alesina et al., 2016). Economists also employ ancillary data apart from the conventional measures of population and GDP. For instance, in a panel study using the Armed Conflicts Location Events Data and Afrobarometer survey data on trust and socioeconomic characteristics, Rohner et al. (2013) determine that NTL intensity declines following conflict in ethnically fractionalized countries. In another example, in a panel of 38,427 subnational regions from 126 countries spanning the years 1992–2009, Hodler and Raschky (2014) use information on national political leaders' birthplaces and find a 4% increase in NTL in their native region after entering office. Hodler and Raschky (2014) present this as evidence of regional favoritism, illustrating the power of combining NTL data with qualitative information to pursue economic lines of inquiry beyond GDP estimates.

Economists and remote sensing scientists working with NTL imagery appear to infrequently cite each other, but each community could benefit from learning about the other's methods. Since, in effect, NTL data opened up the field of remote sensing to economists, it would be beneficial to expand upon this interdisciplinary work (Keola et al., 2015). Keola et al. (2015) investigate the causal relationship between agriculture and NTL by mapping luminosity in OLS V4 composites against MODIS land cover product MCD12Q1 on a cell-by-cell basis from 1992 to 2009 and integrate the land cover data into the estimation model proposed by Henderson et al. (2012). Areas classified by MODIS as cropland, rice field, and vegetation emit relatively little or no light compared to urban areas. Thus, in countries where agriculture comprises more than half of the economy, the elasticity of logged NTL on logged GDP (including country- and year-fixed effects) is insignificant and only 0.03. This is below the global average elasticity of 0.28 found by Henderson et al. (2012), and far below the highly significant elasticity of 0.67 that Keola et al. (2015) calculate in non-agricultural countries, where farming comprises < 10% of the economy. Even within these highly developed and urbanized countries, however, more work needs to be done to discern the relationships between NTL and the economic sectors often associated with them. Steelmaking, for instance, generally produces more light than software development (Henderson et al., 2012), even though it may contribute less overall to GDP.

The above studies illustrate the challenges with making inferences from log-linear relationships between NTL and GDP at regional and international scales. In a panel of 83 countries from 1992 to 2010, Gennaioli et al. (2014) show that differences in GDP per capita explain much of the variation within countries in NTL, as might be expected. However, actual NTL intensity per capita is 3.6% lower than predicted by regional GDP per capita in the poorest (bottom quartile) regions and 2.5% higher than predicted in the wealthiest (top quartile) regions. Further research into the causes of these prediction errors should help researchers seeking to estimate GDP from NTL to avoid overestimates in highly developed areas and underestimates in less developed areas.

As with urbanization and population, growth in economic activity receives more attention than decline in the published literature. Yet some studies do examine the latter phenomenon. In post-Soviet cities, the decline of NTL over time may be in response to economic conditions (Elvidge et al., 2005). The same may be true in Zimbabwe, where dimming NTL is associated with the severe economic contraction that occurred between 1992 and 2009. Using 500 samples of the rates of change for SOL against GDP within this period for the African nation, Li et al. (2013a) find an R^2 of 0.55 with no major outliers. NTL, however, has also dimmed in places not experiencing economic or population decline like Scandinavia, perhaps instead reflecting successful control of light pollution (Bennie et al., 2014). Overall, Henderson et al. (2012) find that NTL responds symmetrically to both positive and negative income changes between 1998 and 2008, meaning that there is an absence of ratchet effects. Yet over shorter time periods, the dimming of NTL due to economic downturns may be lagged, leading Henderson et al. (2012) to propose that NTL data is best suited to predicting long-term growth rather than its converse: short-term decline.

Finally, despite all the existing research using NTL as a proxy for economic output, marked disagreement remains on the robustness of this relationship in developing countries. Whereas most research examines relationships between NTL and economic activity, Nordhaus and Chen (2015) focus on estimating the reliability of NTL as a proxy for national and regional economic output. In their previous research, they found that OLS stable lights composites add value as an economic proxy for countries with poor economic reporting in both cross-sectional and time-series analyses (Chen and Nordhaus, 2011). However, Nordhaus and Chen (2015) conclude that for time-series analysis, OLS data can contribute very little to estimates of changes in economic activity in any countries where data is available, differing from Henderson et al. (2012). Even in countries with poor or sparse records, Nordhaus and Chen (2015) argue that neither OLS data nor the intercalibration model is refined enough to allow accurate estimations of economic growth from multitemporal NTL imagery. The authors do find, though, that NTL data may have substantial value in cross-sectional estimates of economic output, as most of the sources of unreliability in using NTL as a proxy for single-year economic output come from uncertainties in national accounts data rather than uncertainties in the OLS data (Nordhaus and Chen, 2015). Arriving at a similar conclusion, Sutton et al. (2007) find that most estimation error in correlating NTL with economic growth tends to occur in sub-national regions with very low economic activity, implying either underreporting of GDP or an inability of OLS to detect dim lights associated with low levels of economic activity. For all of these reasons, estimating economic growth for countries with low levels of development remains a challenge with OLS data. Promisingly, VIIRS data are shown to be more strongly correlated with economic output than OLS stable lights data and at finer scales (Chen and Nordhaus, 2015). VIIRS may also improve estimates for places with low or dimly lit economic activity if it is able to detect low levels of light in places coded in DMSP-OLS data as DN = 0. Thus, the higher sensitivity and on-board calibration of VIIRS may help to obtain improved estimates of economic growth and decline from space.

5.5.4 Population change

Most of the world's population growth is occurring in developing countries, where population statistics often lack accuracy. This makes NTL data a potentially key source of information for estimates. Modeling population dynamics in the developing world is challenging, however, because globally, the minimum population detectable by OLS varies. Africa has a lower population density than Asia, Europe, and North America, meaning that the NTL thresholds needed to detect human activities are likely lower. Cross-sectional analysis has shown that the mean population density of unlit areas ranges from 10.05 persons/km^2 in Latin America and the Caribbean to 208.18 persons/km^{2}in India (Doll and Pachauri, 2010). Population density therefore has a weaker relationship with NTL intensity than economic activity. A place with 1000 persons/km^2 will be brighter in a developed country than a developing region, although there is significant scatter in this relationship (Raupach et al., 2010). This variation complicates efforts to estimate regional or global population levels from NTL.

NTL change is largely positively correlated with population change, but this may be because population continues to grow globally. Certain areas with decreasing populations actually exhibit negative correlations with NTL change. In 90% of countries, NTL change from 1992 to 2012 moved in the same direction as change in population, along with GDP (Elvidge et al., 2014). Many of the exceptions are concentrated in the former Soviet Union and Eastern Europe, where population has decreased in a significant number of countries. These exceptions can be divided into two groups. In the first group of outliers, NTL change is positively correlated with GDP change but negatively correlated with population change (so lights stay on even as population declines). Examples of these countries with so-called "GDP-centric" NTL include Albania and Poland. In the second group of outliers, NTL change is positively correlated with population change but negatively correlated with GDP change (so lights stay on even as GDP declines). Examples of these countries with so-called "population-centric" NTL include Russia and Kazakhstan (Elvidge et al., 2014). Further confirming the unusual nature of the relationships between NTL and population in Eastern Europe, using country-level SOL derived from intercalibrated OLS V4 stable lights composites from 1992 to 2012, Archila Bustos et al. (2015) find that only 23% of significant cases of decreasing population reveal coupling with lit extent while 93% of significant cases of increasing population exhibit coupling. For instance, the former Soviet republics of Latvia, Lithuania, and Estonia show consistent increases in NTL despite decreases in population. Archila Bustos et al. (2015) conclude that the strong positive relationship found between NTL and population in single-year cross-sectional analyses (e.g. Elvidge et al., 1997c; Sutton et al., 2001) can break down when examined within a country over time. Even outside of Eastern Europe, NTL and population change are sometimes decoupled. In brightly lit urban areas in South Asia, Zhou et al. (2015a) find no correlation between the growth rates of annual population and SOL ($R^2 = 0.02$). All of these findings indicate the need for caution when predicting population change from NTL.

Despite these caveats, Ceola et al. (2015) use NTL to infer population dynamics. They determine that from 1992 to 2013, human populations have moved significantly closer to rivers around the world by calculating the changes in total and average SOL at a 1-km^2 resolution within five distance classes near streams and rivers. Yet given existing variations in average NTL per capita based on a country's level of economic development, a 5-DN pixel change along the Nile may correspond to a larger population change than a 5-DN pixel change along the Danube. Thus, even if population and NTL change are assumed to be coupled, precisely quantifying the population change remains difficult.

As with NTL-based estimates of economic activity, dark or very dim pixels can impact population estimates. Just as farming and logging do not emit high degrees of light despite contributing to GDP, many places do not emit observable light despite being inhabited. An estimated 1.5 billion people live without any access to electricity whatsoever, rendering their populations, and by corollary any changes in their numbers, largely undetectable in NTL imagery (Doll and Pachauri, 2010). Nordhaus and Chen (2015) determine that in the OLS V4 stable lights composite for the year 2000, nearly a third of 1° × 1° grid cells that actually do have population and economic output are coded as DN = 0. Russia, Canada, and Africa contain 67% of these "zero lights" cells. Although they are estimated to comprise only 0.4% of global population and economic output, the zero lights cells cover a sizeable portion of the world's landmass. Since it is unlikely that population or economic activity occurs completely without light, the zero-lights encoding may be due to the inability of OLS to resolve dim lighting. It may also be due to the stable lights composites' exclusion of areas with unstable lighting, which is common in rural villages in the developed world with low power loads (Min and Gaba, 2014).

VIIRS may help to more accurately detect and estimate populations in both developed and developing regions thanks to its lack of saturation and lower detection limit. Early cross-sectional research demonstrates this potential. Along a 100-km latitudinal transect centered on Beijing, VIIRS-measured radiance also shows a slightly stronger response to urban population than OLS stable lights (R^2 = 0.89 versus R^2 = 0.83, respectively), with the ability to detect variations in the urban-rural transition zone, too (Ma et al., 2014c). At the 1° × 1° grid-cell scale in Africa, the relationship between NTL intensity and population has an R^2 of 0.59 for a two-month VIIRS composite from 2012 compared to 0.27 for an OLS F18 2010 stable lights composite (Chen and Nordhaus, 2015). More time must pass before a substantial record of VIIRS imagery is built up to examine annual population changes, although the potential for decoupling between NTL and population change may still affect reliable estimates of population change. Regardless, based on observed publication trends following the release of the OLS V4 stable lights product from 1992 to 2013, we venture that the creation and public release of annual VIIRS stable lights composites would assist in this regard. Already, the VIIRS NTL 2012 composite serves as an input to the WorldPop global population product (Stevens et al., 2015).

5.5.5 Additional socioeconomic dynamics

Multitemporal NTL data are employed to study a wide range of additional socioeconomic dynamics. Regional inequality (Xu et al., 2015; Zhou et al., 2015a), electricity consumption and access patterns (Cao et al., 2013, Cao and Bai, 2014; Chand et al., 2009; Doll and Pachauri, 2010; Filho et al., 2004; He et al., 2012; Min and Gaba, 2014; Min et al., 2013), power outages due to natural disasters (Cao et al., 2013; Kohiyama et al., 2004; Molthan and Jedlovec, 2013), increases in freight traffic (Shi et al., 2015; Tian et al., 2014), human impacts on the environment (Geldman et al., 2014; Liu et al., 2014), steel stock use (Liang et al., 2014), and the effects of armed conflict (Agnew et al., 2008; Li et al., 2013b; Witmer and O'Loughlin, 2011; Xi et al., 2015) constitute several examples. Multitemporal NTL can also be harnessed to show how an expanding human footprint can impact conservation (Venter et al., 2016) or protected areas (Gaston et al., 2015; Geldmann et al., 2014).

Despite the low spatial resolution of OLS, Witmer and O'Loughlin (2011) are able to associate NTL with large, long-lasting fires and refugee movements in the war-torn Caucasus. This may suggest that with VIIRS, finer scale movements of refugees such as from Syria to Europe may be detectable from space. The Syrian civil war has created a number of opportunities for using multitemporal VIIRS data for humanitarian monitoring. Li and Li (2014) find a 74% and 73% decrease in Syria's SOL and lit area, respectively, between March 2011 and February 2014. They conclude that change in SOL explains 52% of the variation in the number of internally displaced persons in all of the country's provincial regions. Further to their study, Figure 5-4 visualizes the dramatic decline in NTL in Syria between 2014 and 2016 along a highway controlled by ISIS and brightening across the border in southern Turkey, where hundreds of thousands of refugees have fled. Painting a happier picture, Román and Stokes (2014) associate fluctuations in radiance in cities in the United States and Middle East with neighborhood holiday lighting patterns, suggesting that VIIRS data could be used to eventually help generate finely tailored energy conservation strategies. Thus, even more than OLS, VIIRS can inform studies of socioeconomic dynamics from the neighborhood to the global scale.

5.6 Future directions

5.6.1 Understanding the causes of observed light

While NTL data are a valuable tool for studying development, they are subject to a number of basic limitations. NTL depends on economic activity, population density, lighting type, and lighting regulations, all of which vary between countries, subnational regions, and even within cities. This variation makes comparisons across space and time challenging and presents a barrier to understanding the precise relationships between changes in NTL and socioeconomic dynamics. Thus, more systematic analysis of the causes of observed light across regions and developmental contexts is required. It is well understood that NTL is broadly correlated with urbanization, population, and economic output in international comparisons and at the subnational level in highly developed Western countries and in fast-growing China. Yet comparatively little is known about exceptions to these relationships, particularly with regard to how their strength may vary at the subnational level in the developing world.

Further research into the emission of light (or lack thereof) may be done through 1) additional combination of OLS or VIIRS data with other remotely sensed data products; 2) statistical analyses that explore interactions between the variables influencing NTL and more closely inspect outliers; and 3) site-specific analyses through fieldwork. Although these directions have been pursued in certain studies, they have yet to be widely adopted.

First, research should consider integrating other remotely sensed datasets into NTL-based models rather than just using them for validation. Several studies, for instance, validate OLS and/or VIIRS imagery with photographs taken from the International Space Station (Elvidge et al., 2007; Levin and Duke, 2012) or Landsat data (Levin and Phinn, 2016; Castrence et al., 2014; Shi et al., 2014; Small et al., 2005; Zhang and Seto, 2011). But rather than just using non-NTL imagery for examining the “accuracy” of NTL, more insight into the factors driving observed lights may come from combining both datasets into the same model. Drawing on how Keola et al. (2015) use MODIS imagery to quantify the differences in emissivity between typically dim forests and farmland and bright, urbanized areas, more first-order research is necessary to systematically understand the reasons for differences in NTL across economic sectors and regions. Incorporation of other remotely sensed data, like AVHRR, Landsat, MODIS, SPOT VEGETATION, MODIS, or Sentinel-2 could also address how land cover can also affect NTL. The same amount of NTL, for instance, may be less visible when emitted from a forest than a grassland or desert, yet little work has investigated the effects of ground cover on NTL. Lastly, researchers can borrow from methods more typically used by remote sensing scientists to study physical processes, similar to how Small and Elvidge (2013) employ the empirical orthogonal function (EOF), often used in oceanography and meteorology, to examine decadal changes in NTL in Asia. This approach provides a robust and straightforward way to characterize spatial and temporal patterns and does not require the assumption of temporal change taking specific functional forms, such as linear or sinusoidal. More creativity in modeling strategies may be productive for multitemporal analysis.

Second, further exploration of heterogeneity and change in the relationships between NTL and development indicators may more clearly demonstrate how social and economic variables interact to produce lights. This approach would provide an alternative to the current emphasis in much of the literature on explaining variation in the level of light output, as reported in R^2 and goodness of fit statistics. It would also draw on early work like Tobler (1969), who confirmed with satellite imagery that the relationship between a settlement's size and its population differs by country. While this relationship maintains a generally similar R^2 across countries, the correlation of proportionality varies from one country to the next. Societal factors clearly influence patterns of lights separately from GDP and population: for instance, the SOL of an American town of 10,000 inhabitants tends to be three times larger than an equivalent German town, while an American city of 100,000 inhabitants has five times more SOL (Kyba et al., 2015). This may be because German policy tends to be conservative in its use of public and outdoor lighting; the country does not widely illuminate its highway network, for instance. Although sociocultural causes for differences in lights remain understudied, attempts to predict GDP, population, or other variables from NTL data without taking such factors into consideration may lead to inaccurate results.

Additionally, examinations of interactions, which are when the effect of one independent variable depends on the type or level of another independent variable, could prove useful. Rohner et al. (2013), for instance, model interactions to show that for African countries, conflict only negatively impacts development (proxied by decreasing NTL) in those that are ethnically fractionalized. Another example of the types of questions that could benefit from interaction analysis is whether the relationship between NTL and fixed capital investment (FCI), generally defined as the value of new construction, expansion, or renovation to physical capital (i.e. buildings and machinery), depends on a region's dominant economy. This question is motivated by Figure 5-5, which shows how in Russia, certain oil-producing federal subjects (the top-level political divisions within Russia) have unusually low levels of SOL relative to FCI, regardless of whether the variables are logged. Possibly, an over-exclusion of NTL values due to high levels of gas flaring in the Yamalo-Nenets Autonomous Okrug (YNAO), Khanty-Mansiysk, and part of Tyumen results in their low levels of NTL. Yet it may be worth investigating whether some other variable that could be interacted with FCI, like size of the oil industry, is driving their unusual relationships, too.

More attention to outliers is also warranted as they may be theoretically and empirically meaningful, but are frequently omitted from analyses to improve the overall fit of statistical models. Logging can also obscure outliers, which is why data should be carefully inspected and outliers presented before logging variables. Figure 5-5 also illustrates how outliers can become obscured even though their atypical relationships with NTL that are visible before logging may be worth investigating. Leaving aside the three aforementioned oil-producing federal subjects and Moscow and St. Petersburg, which may be outliers because they are geographically small, highly saturated, and highly urbanized federal districts, one outlier still remains: Krasnodar, host of the 2014 Winter Olympics in Sochi and one of the most corrupt regions in Russia (Panifilova, 2016). If the data had only been inspected after logging, then the relatively low amount of NTL that Krasnodar emits per ruble of FCI compared to most of Russia's other regions, an insight which may merit further inquiry, may not have been as apparent.

A third way to better understand the causes of observed light is through site-specific analyses, namely fieldwork. To illustrate with a preliminary demonstration, in March 2016, we conducted ethnographic fieldwork on post-Soviet transportation infrastructure development in the Russian Far East. While no field measurements of light pollution were made, it is possible to pair qualitative observations made during our fieldwork with a map of the region showing the change between OLS V4 stable lights in 1992 and 2012 (both intercalibrated following Elvidge et al. (2009)) (Figure 5-6). Over these two decades, the Trans-Siberian Railway, large cities like Khabarovsk, and small settlements decline. But somewhat uniquely, the city of Blagoveshchensk, which sits directly on the Amur River border across from Heihe, China, has brightened, perhaps thanks to its close cross-border ties with its booming East Asian neighbor. Khabarovsk, which sits 30 km away from the border, has experienced no such increase in NTL. Fieldwork in

Blagoveshchensk revealed Chinese and Russians engaging in significant amounts of cross-border tourism. Many Chinese merchants have also opened businesses in Blagoveshchensk, while this appeared less common in Khabarovsk. These findings in Blagoveshchensk may represent an exception to Pinkovskiy (2013), who finds that both NTL per capita and its growth rate decrease discontinuously when a border is crossed from a faster-growing to a slower-growing country. They should also encourage further work that takes advantage of the boundless nature of NTL data by examining imagery outside of national frameworks and looking, for instance, for the most rapidly growing cross-border regions or ecosystems in the world.

Finally, at the neighborhood scale, differences in NTL match differences in urban development observed during fieldwork in Vladivostok, a city on Russia's Pacific Coast that has received numerous investments in infrastructure and a new university under President Vladimir Putin. Whereas the central business district is flourishing with a waterfront revitalization project and new condominiums, obsolete and abandoned buildings litter the landscapes of outlying micro-districts (*mikrorayon*) such as Podnozhye. In short, combining NTL data with fieldwork opens the door to collaborations with social scientists like anthropologists, political scientists, and geographers. Since NTL imagery provides an important quantitative proxy for socioeconomic activity, involving social scientists beyond economists to contribute qualitative observations regarding the potential causes of observed light could prove enlightening.

5.6.2 VIIRS: future topics, regions, and time steps

A few key topical, regional, and temporal areas of research to pursue that leverage VIIRS' enhanced capabilities are infrastructure growth, the Arctic, and sub-annual activities. First, topically, if predictions that humans will build more infrastructure in the next four decades than they have in the past four millennia (Khanna, 2016) are to be believed, VIIRS data are well-suited to track and quantify its associated light emissions. With its coarse resolution, OLS data can be used to model the expansion of transportation corridors like highways and railways (Liang et al., 2014). But VIIRS imagery can actually reveal the fine-scale socioeconomic impacts of these infrastructures, such as CO_2 emissions along highways (Ou et al., 2015). While Elvidge et al. (2014) encourage using multitemporal NTL for infrastructure mapping, more intriguing might be to use NTL to monitor and predict the intensity and social, economic, and environmental impacts of its use. Especially if paired with GIS-based network models (e.g. Kotavaara et al., 2011), such research could help quantify the effects of the networked infrastructure developments that underlie urbanization processes (Graham and Marvin, 2001).

Spatially, what one might call one of the “last frontiers” for NTL research is applying VIIRS imagery to remote and inaccessible areas like the Arctic, Amazon and the high seas. Although OLS can capture data during the polar night, at latitudes above the Arctic Circle, these data are subject to aurora and significant year-to-year differences in resolved light owing to changing snow cover (Ebener et al., 2005; Henderson et al., 2012). Countries at high latitudes like Canada, Sweden, Norway, Finland, and Iceland also exhibit unusually high levels of lighting relative to their populations (Elvidge et al., 2001). Researchers employing VIIRS imagery still have to contend with these complications, but the sensor more accurately resolves light-emitting activities in the circumpolar north than OLS (Straka et al., 2015). Henderson et al. (2012) note that only 0.036% of the world lives in the Arctic, but as economic activities increase in the warming region, VIIRS may provide insight into the region's development. Finally, the various advances of VIIRS combined with its cost-free nature can empower polar end-users of NTL data in potentially life-saving ways. Straka et al. (2015)demonstrate how VIIRS imagery was used in near-real time to rescue an imperiled crab fishing boat off Alaska. From this vantage point, VIIRS offers new opportunities for knowledge production and practical applications in the Arctic.

Finally, temporally, the cost-free nature of DNB imagery at daily and monthly time steps opens up numerous areas for research. While cloud cover still remains an issue in daily imagery, several studies already use VIIRS data to illustrate monthly and seasonal changes in anthropogenic light-emitting activities, such as holiday lighting (Román and Stokes, 2014) and passenger traffic and aircraft movement at airports (Ma et al., 2014c). VIIRS data could also be used to detect light-emitting activities of short duration but potentially high social or environmental impacts, like unauthorized steel factories, which have been documented on the ground in China (Hilaire, 2016), or illegal fishing. Liu et al. (2015b) demonstrate how nightly VIIRS imagery can detect light-emitting squid and fishing ships and suggest that examining the NTL data against vessel monitoring system (VMS) records could reveal ships that are illegally fishing. Such law-breaking ships would emit NTL, but not a VMS signal. As with many remotely sensed datasets, the geopolitical ramifications of using this imagery for revealing clandestine or illicit activities are potentially serious (Gleason and Hamdan, 2015). Given these challenges, scientists should carefully consider but not shy away from the opportunity to use NTL data to monitor short-duration activities in vulnerable areas from war zones to the high seas.

5.7 Concluding remarks

Multitemporal OLS and VIIRS data allow for globally consistent studies of socioeconomic dynamics such as urbanization, population, and economic activity. With proper corrections for temporal differences (e.g. sensor intercalibration or controlling for year-fixed effects) and attention to saturation and blooming, multitemporal OLS data can provide a reasonable proxy for growth in these parameters. Declining urbanization, population, or economic activity appears more challenging to approximate, as lights do not always turn off when a place's population or GDP shrinks. Thus, future research should continue to investigate the actual causes of observed light and also attempt to determine why certain places, features, and activities remain or become dark. Future research would also benefit from integrating other remotely sensed data products with NTL imagery into the same model, more robust statistical analyses that examine interactions and outliers, and field studies and interdisciplinary collaborations.

With its dramatically enhanced spatial and radiometric resolutions, VIIRS provides a much improved view of the Earth at night compared to OLS. Saturation and blooming are significantly reduced, while measurement of actual radiance and on-board calibration facilitate accurate comparisons of NTL changes over time. The sensor's ability to detect low levels of light may also enhance the accuracy of estimates of population and economic activity in developing countries. The free distribution of daily and nightly VIIRS data and NOAA's production of monthly composites better position researchers to uncover relationships between NTL and various socioeconomic dynamics across finer temporal scales than with OLS data, too. Building on preliminary efforts to integrate OLS and VIIRS data to extend the record of comparable NTL imagery (Shao et al., 2014) would also be valuable for multitemporal studies. With OLS, VIIRS, and its forthcoming successor JPSS-1, the tools now exist to directly study and monitor anthropogenic activities once hidden by cover of night.

5.8 Figures

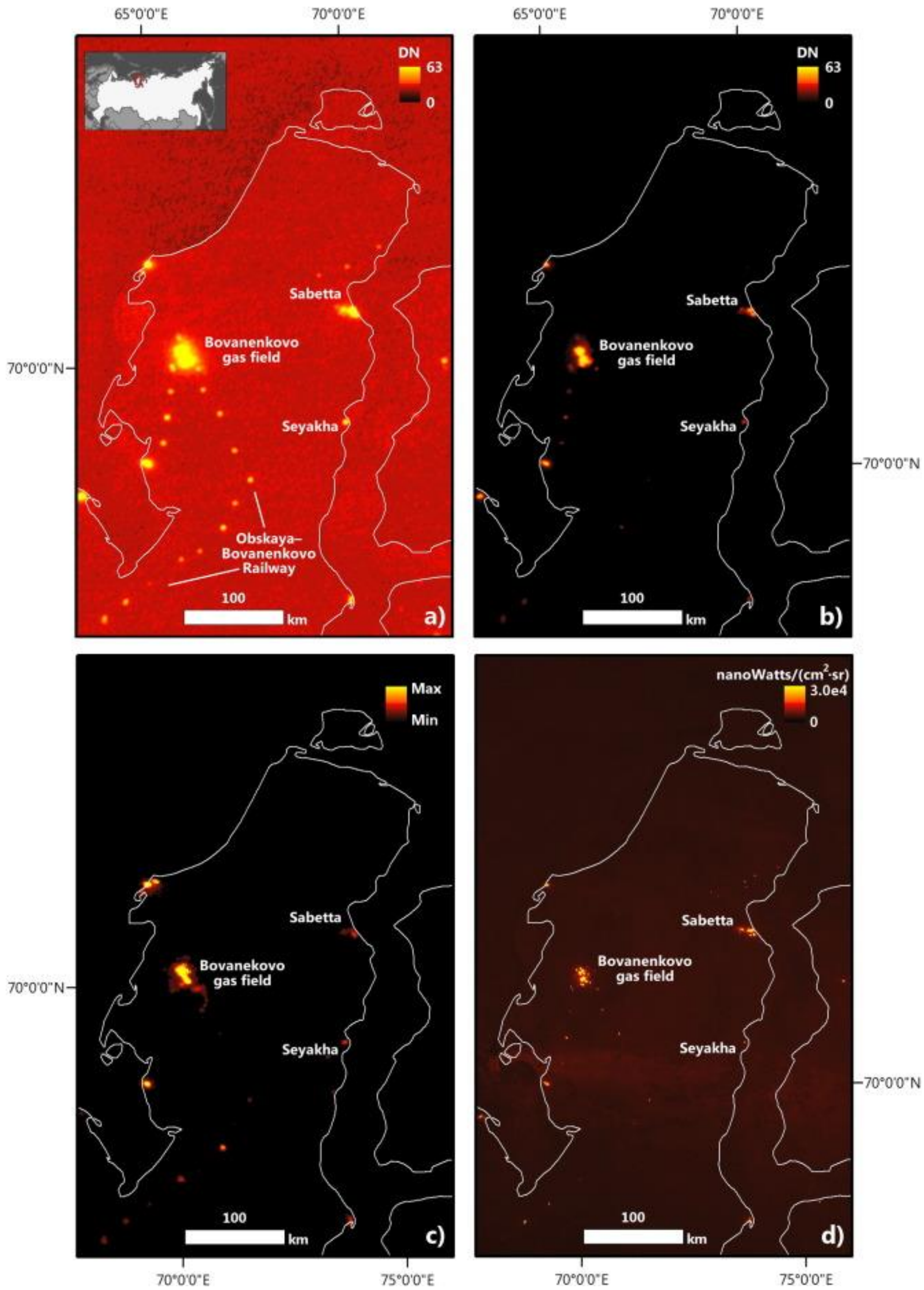

Figure 5-1. a) OLS V4 Average Lights Composite for 2013 of the Yamal Peninsula in Russia, an area undergoing natural gas development. **b)** OLS V4 Stable Lights Composite for 2013. The railway is less visible. **c)** OLS Radiance Calibrated Lights composite for 2010/2011, where railway stations are visible. **d)** Version 1 Nighttime VIIRS DNB Composite for November 2014 reveals improved spatial resolution and more accurate delineation of lit areas, which represent gas flares, settlements, and industrial sites. Map projection: Asia North Albers Equal Area Conic.

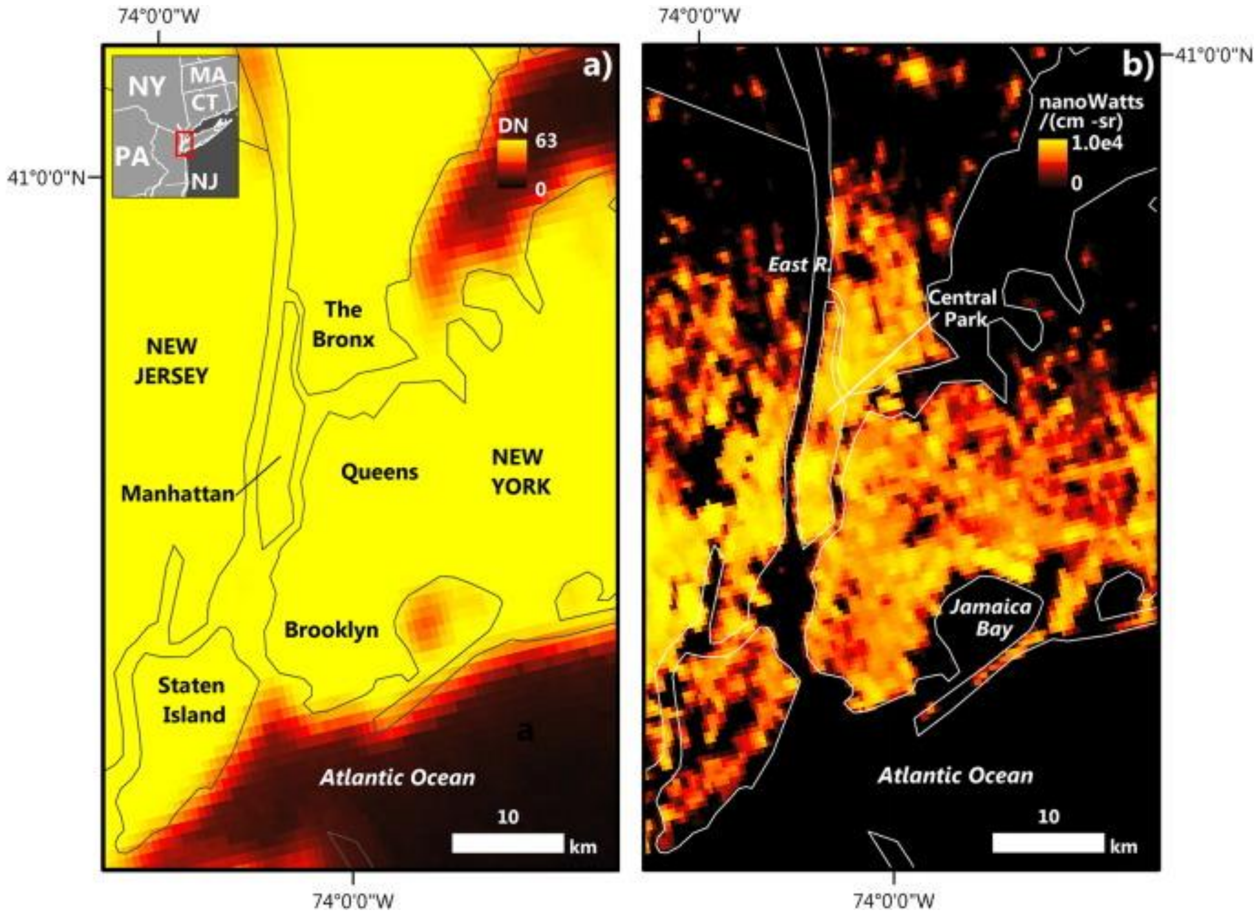

Figure 5-2. a) OLS V4 Stable Lights Composite for 2013 over New York City and environs. Saturation and blooming over water are readily apparent. **b)** Version 1 Nighttime VIIRS DNB Composite for January 2014. Notice the reduced saturation and blooming and ability to distinguish between darker (Central Park, East River) and brighter areas within an area that appears saturated in the OLS imagery. As the OLS V4 Average Lights Composite and DMSP-OLS Radiance Calibrated Lights composite look nearly identical to the Stable Lights Composite, they are not included in this figure. Map projection: North American Lambert Equal Area.

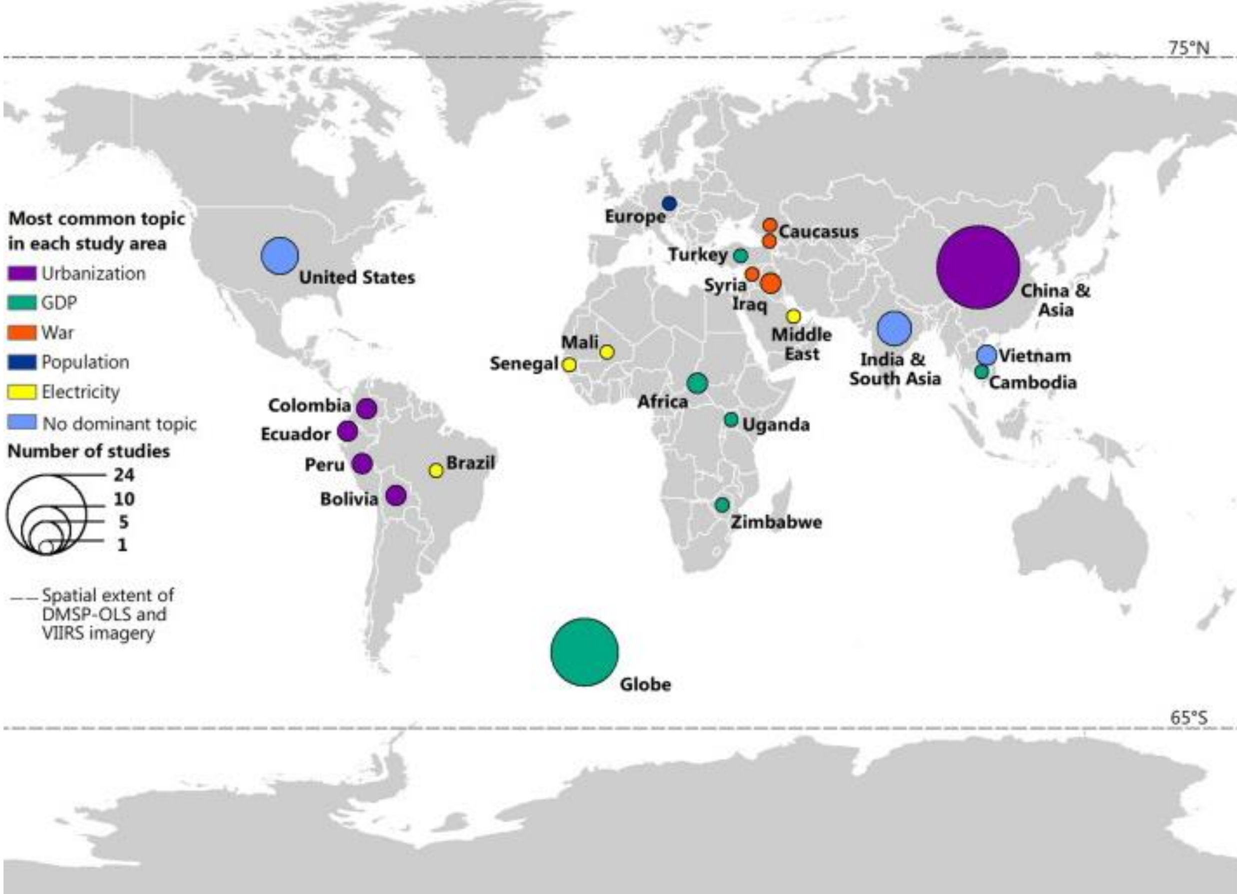

Figure 5-3. Map of all identified multitemporal DMSP-OLS and VIIRS studies symbolized by most common topics.

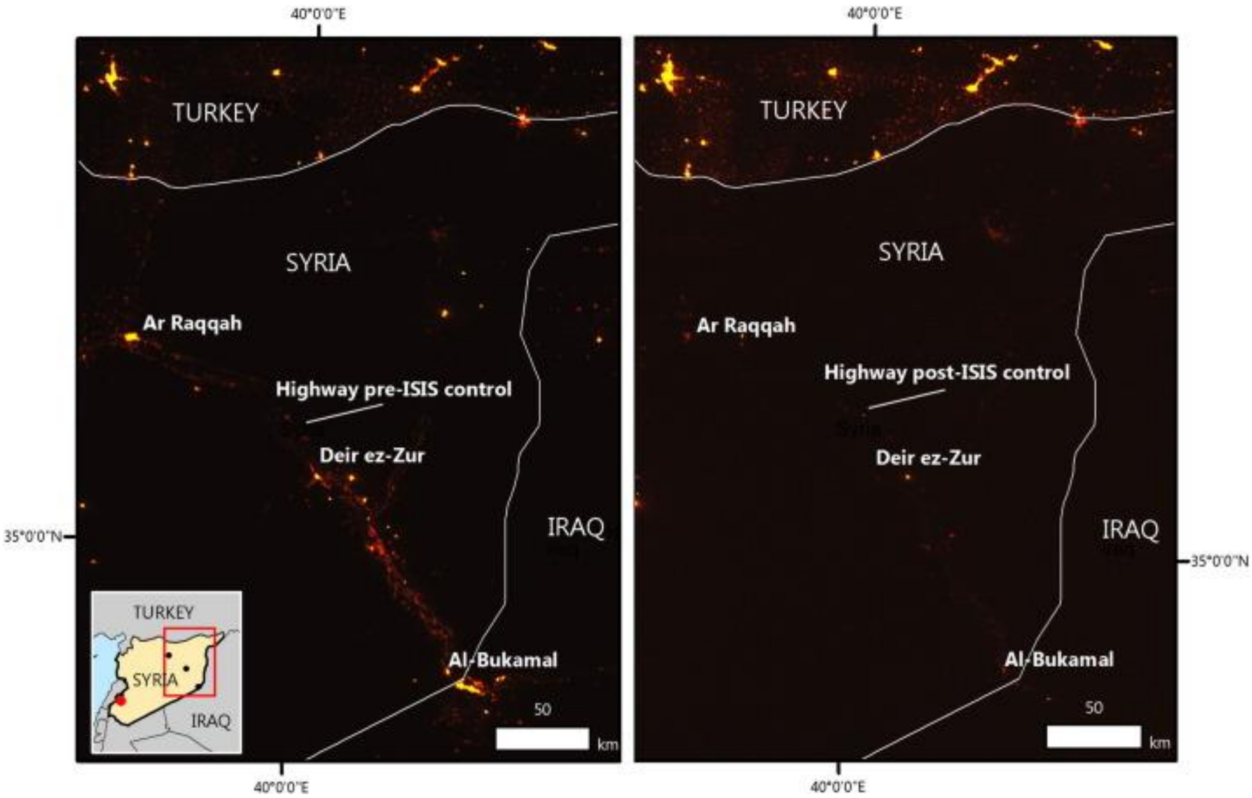

Figure 5-4. Left: April 2014 monthly VIIRS composite of northeast Syria pre-ISIS control of a major highway. Right: April 2016 monthly VIIRS composite of the same area.

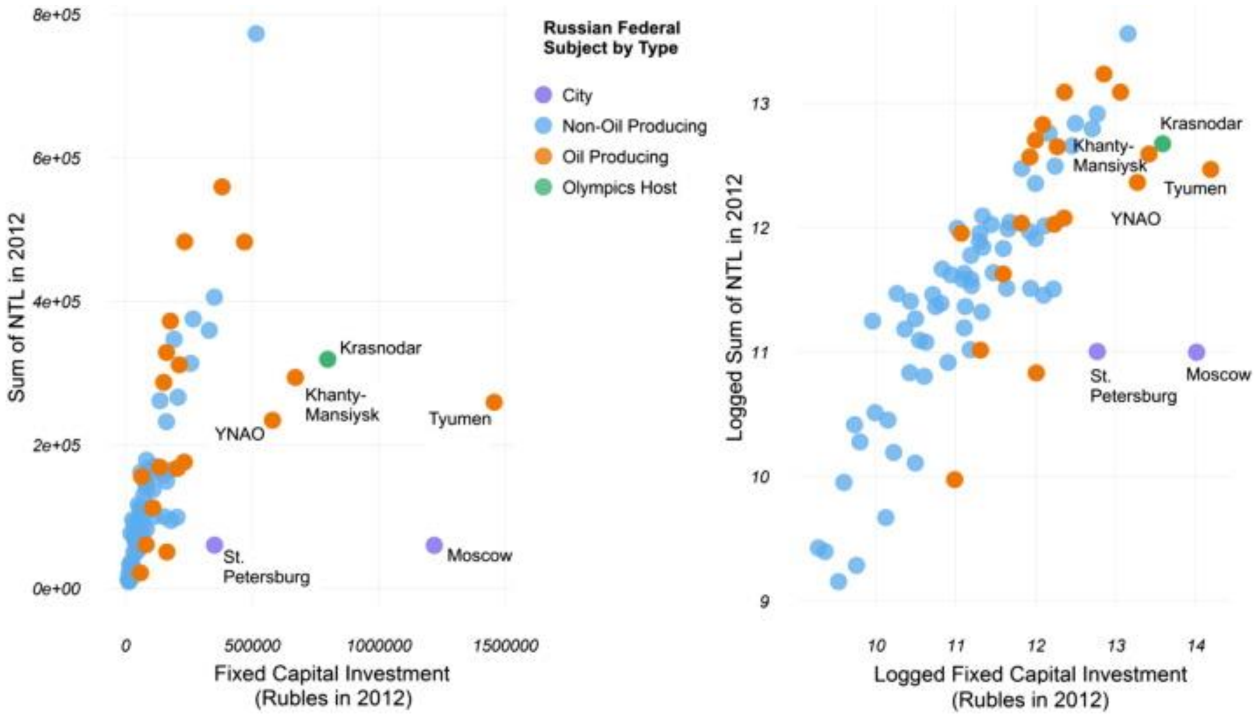

Figure 5-5. Fixed capital investment versus SOL in 2012 for Russia's federal subjects, in unlogged and logged forms. Federal districts are divided into two main categories: oil producing and non-oil producing in 2011. The outliers of Moscow, St. Petersburg, and Krasnodar are highlighted for reasons discussed in the text. Federal districts data: Global Administrative Unit Layers 2015, Food and Agricultural Organization, 2015. Lights data: Zonal sums calculated in ArcGIS from OLS V4 Stable Lights composites with gas flares subtracted. Oil production data: RIA Novosti, 2012. Fixed capital investment data: Russian Federal State Statistics Service.

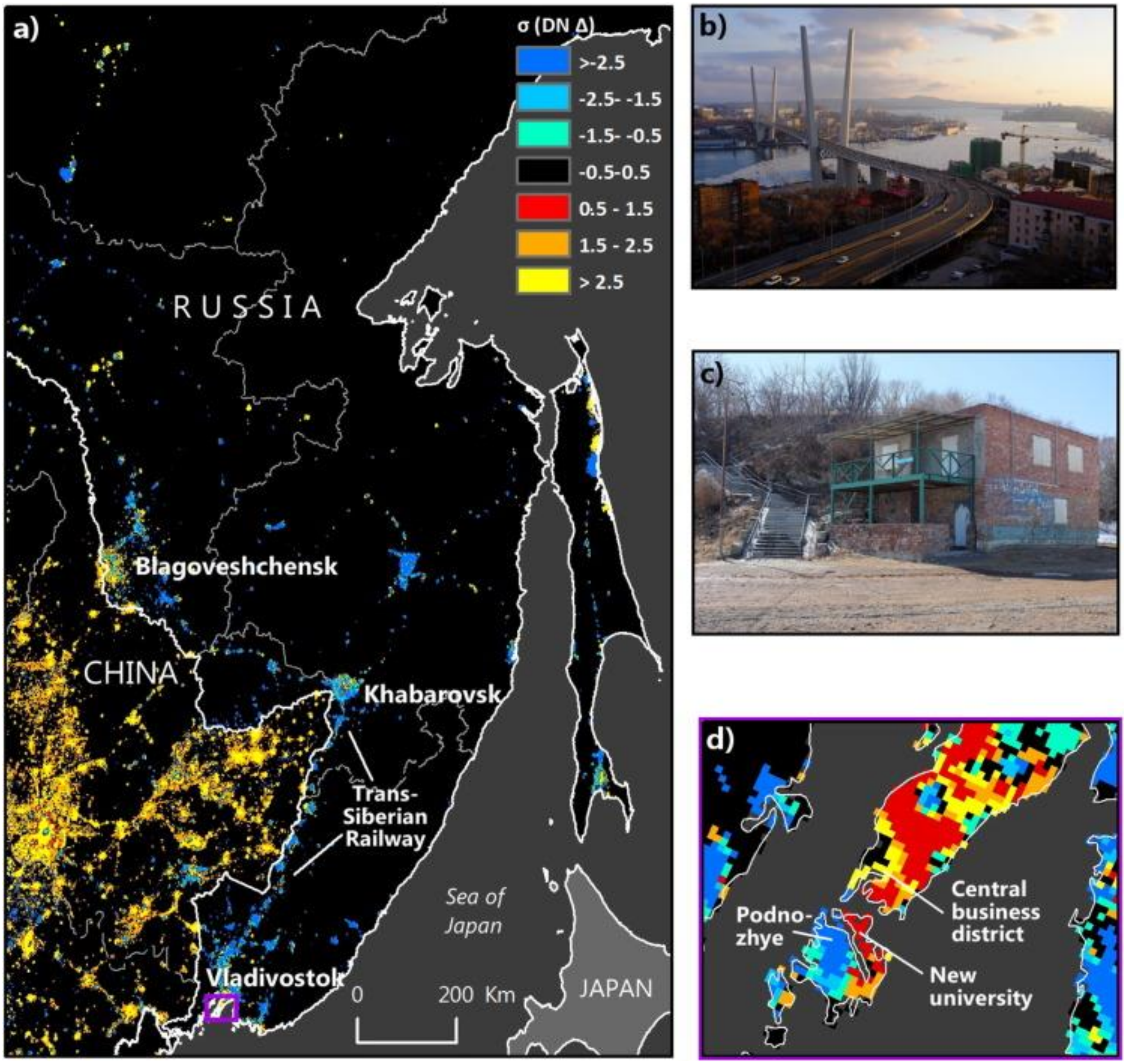

Figure 5-6. Regional change detection map over the Russian Far East and Northeast China, 1992–2012, and inset map over Vladivostok, with corresponding field photographs. **a)** Change detection map over the Russian Far East and Northeast China, 1992–2012. **b)** Spanning from Vladivostok's central business district, the new Zolotoy Bridge leads towards the new university. **c)** An abandoned store at the disused waterfront in Podnozhye. **d)** Inset map of Vladivostok.

5.9 Tables

Satellite (and NTL imaging band)	DMSP-OLS (VNIR Band)	Suomi NPP (VIIRS DNB)
Operator	U.S. Department of Defense	NASA/NOAA
Available years of digital data	1992-present, but new annual composites are not being made available after 2013	December 2011-present
Wavelength range	0.4–1.1 µm	505–890 µm
Spatial resolution	2.7 km	742 m
Temporal resolution	12 h	12 h
Geographic extent	75N/65S/180E/180W	75N/65S/180E/180W
Specified day/night overpass time	8:30–9:30 and 20:30–21:30	13:30 and 1:30
Radiometric resolution	6-bit	12- or 14-bit
Units measured	Relative (0–63 scale)	Radiance (nanoWatts/(cm^2·sr)
Light ceiling	3.17×10^{-7} $W \cdot cm^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$	0.02 $W \cdot cm^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$
Light floor	1.54×10^{-9} $W \cdot cm^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$	3 × 10–9 $W \cdot cm^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$(specified; lower values have been detected)
On-board calibration	No	Yes

Table 5-1. DMSP-OLS VNIR Band compared with Suomi NPP VIIRS Day/Night Band.

Publication year	NTL dataset	Time range	Time step	Variable of interest	Universe of analysis	Scale/Unit of analysis	Measure of NTL	Data transformation	Method of controlling for satellite differences	Main mathematical or	Ancillary data	Author(s)	Title	Journal
2004	Daily DMSP-OLS VNIR and TIR images	July 23–July 24, 1999; 24–26 January	Daily	Urban damaged area	Taiwan; Western India	Pixel	DN	None (daily)	N/A	DN differences	None	Kohiyama, M., Hayashi, H., Maki, N., Higashida, M.,	Early damaged area estimation system using DMSP-OLS night-time	*Int'l. J. of Remote Sensing*
2007	1992/1993 and 2000 DMSP-OLS city lights composites	1992/1993–2000	17/18 years	GDP	India, China, Turkey, and the U.S.	Subnational regions	SOL and lit extent	Log	None	Linear regression	Landscan population and sub-national GDP figures	Sutton, P., Elvidge, C., Ghosh, T.	Estimation of gross domestic product at sub-national scales	*Int'l. J. of Ecological Economics &*
2011	DMSP-OLS V4 stable lights composites (along with raw and radiance calibrated	1992–2008	Annual	GDP	Global	Country-level and 1 × 1 grid-cell level	SOL	Log	Fixed effects	Cross-sectional and panel	World Bank GDP PPP data; G-Econ 3.4 cell data	Chen, X., Nordhaus, W.D	Using luminosity data as a proxy for economic statistics	*PNAS*
2011	DMSP-OLS V4 stable lights composites	1992–2008	Two years	Urban area	Global and China, India, Japan and the	1-km^2	SOL	Normalization	None	Linear regression	1992–2001 Land Cover Change Retrofit Product	Zhang, Q., Seto, K.C.	Mapping urbanization dynamics at regional and global scales using	*Remote Sensing of Environment*
2012	DMSP-OLS V4 stable lights composites	1992–2008	Annual and 1992/1993 vs. 2005/2006 and	GDP	Global	Subnational, national, and supranational levels	Weighted average of lights across pixels in a country (each pixel's weight = share of its country's land	Log	Fixed effects	Panel regression	Economic and population measures from World Development Indicators	Henderson, J.V., Storeygard, A., Weil, D.N.	Measuring economic growth from outer space	*Amer. Econ. R.*
2012	DMSP-OLS V4 stable lights composites	1994–2009	Annual	Urbanization	China	Cities	Weighted light area	None	Intercalibration	Linear, power-law, and	Urban population, GDP, urban built-up area, and electric power consumption from National	Ma, T., Zhou, C., Pei, T., Haynie, S., Fan, J.	Quantitative estimation of urbanization dynamics using time	*Remote Sensing of Environment*
2013	2009 FMSP-OLS V4 F16 annual stable and average lights composites, April and	2009 and 2011	Daily, monthly, and yearly	Rural electrification	Senegal and Mali	Villages	DN	None	Fixed effects	Panel regression	Survey and administrative data on electricity use and electrification	Min, B., Gaba, K.M., Sarr, O.F., Agalassou, A.	Detection of rural electrification in Africa using DMSP-OLS night	*Int'l. J. of Remote Sensing*
2013	DMSP-OLS V4 stable lights composites	1992–2009	Annual	Urbanization	Colombia, Ecuador, Peru, Bolivia	Municipal, national and regional levels	Minimum/maximum DN value in municipality	None	None	Linear regression	Census population data; Google Earth's Quick Bird and IKONOS images	Álvarez-Berríos, N.L., Parés-Ramos, I.K., Aide, T.M.	Contrasting patterns of urban expansion in Colombia, Ecuador,	*Ambio*
2013	DMSP-OLS V4 stable lights composites	1999–2009	Annual	Structure and form of cities	Global	0.05° cells and 11 × 11 and 21 × 21 grids centered on 100 large	Average DN in each cell	None	Intercalibration	*k*-means cluster analysis	MODIS 500m map of Global Urban Extent and NASA SeaWinds microwave	Frolking, S., Milliman, T., Seto, K.C.	A global fingerprint of macro-scale changes in urban structure from	*Environmental Research Letters*
2014	DMSP-OLS V4 stable lights composites	1992–2009	Annual	Regional favoritism	Global	Subnational regions	Average NTL intensity plus 0.01 per region	Log	Country-year fixed effects	Panel regression	CIESIN boundaries, Archigos database of political leaders, additional data on "political	Hodler, R., Raschky, P.	Regional favoritism	*The Quarterly Journal of Economics*
2014	Suomi VIIRS DNB daily imagery	2012–2014	Daily	Total lighting electricity usage during holidays	North America and the Middle	Cities	Radiance	No	N/A	Multiple regression	Daily electric load profiles	Román, M.O., Stokes, E.C.	Holidays in lights: tracking cultural patterns in demand for	*Earth's Future*
2015	DMSP-OLS V4 stable lights composites	1992–2012	Annual	Urbanization	China	National, provincial, and county levels	Compounded Night Lights Index (average NTL brightness of all pixels in region × proportion of lit	No	Intercalibration, intra-annual composition and	Linear regression	Socioeconomic census data from China Population and Employment Statistics Yearbook,	Gao, B., Huang, Q., He, C., Ma, Q.	Dynamics of urbanization levels in China from 1992 to	*Remote Sensing*
2015	DMSP-OLS V4 composites (type unspecified)	1992–2013	Annual	Population	Global	Pixel-level, areas around streams and rivers, continents, and	Absolute and relative SOL	No	Intercalibration	Linear regression	HydroSHEDS river network dataset	Ceola S, Laio F and Montanari A	Human-impacted waters: new perspectives from	*Water Resources Research*
2015	DMSP-OLS annual composites (version and type unspecified)	1992–2009	Annual	GDP (especially of agriculture and forestry)	Global	30 arc-sec grid cell, country and district (agricultural and non-	Light/area	Log	Fixed effects	Panel regression	MODIS yearly land cover product MDC12Q1 and World Development Indicators	Keola, S., Andersson, M., Hall, O.	Monitoring economic development from space: using nighttime	*World Development*
2015	DMSP-OLS V4 composites (type unspecified)	1992–2012	Annual	Population	Europe	Countries	Lit area	No	Intercalibration	Correlation	World Bank GDP and population data	Archila Bustos, M.F., Hall, O., Andersson, M.	Nighttime lights and population changes in Europe 1992–2012	*Ambio*
2015	Suomi NPP VIIRS monthly composites	May–December 2014	7 months	Electricity shortages due to insurgency	Iraq	Urban areas	SOL	No	N/A - determined not necessary for monthly composites	Descriptive statistics	MODIS 500m map of Global Urban Extent and media sources	Xi, L., Zhang, R., Huang, C., Li, D.	Detecting 2014 Northern Iraq Insurgency using night-	*International Journal of Remote*
2016	DMSP-OLS annual composites (version and type unspecified)	1992–2011	Annual	Size of informal economic activity	Cambodia	Grid-level within district-level administrative	Adjusted light intensity and adjusted light share (proportion of lit area relative to total land area)	Log	Light-scaling factors	Panel regression	Business registration data from the Economic Census of Cambodia	Tanaka, K., Keola, S.	Shedding light on the shadow economy: a nighttime light	*Journal of Development Studies*

Table 5-2. Representative examples of studies using multitemporal OLS or VIIRS imagery.

5.10 References

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Chapter 6

Using multitemporal nighttime lights data to compare regional development in Russia and China, 1992-2012

6.1 Abstract

Multitemporal remotely sensed night-time lights data are often used as a proxy for population and economic growth, with China the most commonly researched area. Less is known about how lights respond to socioeconomic decline. Russia, a depopulating neighbor of China that experienced severe economic turmoil following the Soviet Union's disintegration in 1991, provides a useful case study to investigate the relationships between lights, depopulation, and economic contraction at national and provincial scales. We use the U.S. Air Force Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS) V4 annual stable lights composites to compare changes in lights in Russia and China from 1992 to 2012. These two countries share a history of communist planning but have experienced divergent development patterns since the collapse of communism in the early 1990s. At the national scale, the total amount of lights in Russia declined between 1992 and 2012, while China's lights more than doubled. At the provincial scale, Russia exhibited an increase in inequality of lights per federal subject, while China's provinces became more equal to one another, particularly as Western China caught up to the more developed East Coast. To understand what may have driven these changes in lights, relationships with population and gross domestic product (GDP) are examined from 2000 to 2012 using panel regression models. While changes in population and GDP explain 81% of change over time in lights within China's provinces, they explain only 6% of change within Russia's provinces. The strong relationships found between changes in lights, population, and GDP in rapidly growing,

urbanizing China appear to break down in areas undergoing depopulation and economic contraction.

6.2 Introduction

Since the late 1990s, remotely sensed night-time lights data captured by the U.S Air Force Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS) have been used to estimate socioeconomic parameters (Sutton et al., 2001; Small, Pozzi, and Elvidge, 2005; Imhoff et al., 1997; Elvidge et al., 2001). In the late 2000s, a related field of research emerged using multitemporal lights data to approximate changes in these parameters, with the most widely used dataset being the DMSP-OLS Version 4 Annual Stable Lights composites produced by the National Oceanic and Atmospheric Association's National Geophysical Data Center (NOAA/NGDC). Changes in lights have been found to be significantly and positively associated with changes in population (Archila Bustos et al., 2015; Ceola, Laio, and Montanari, 2014; Doll and Pachauri, 2010), economic activity, often measured as gross domestic product (GDP) (Henderson, Storeygard, and Weil, 2012; Chen and Nordhaus, 2011; Weidmann and Schutte, 2016), and urbanization (Zhang and Seto, 2011; Gao et al., 2015; Tan, 2015; Ma et al., 2012), to name some of the most widely studied trends.

If lights are assumed to reflect development, whose components we define for the purposes of our model as a combination of population and economic activity, then changes in lights may be able to approximate changes in levels of development. Given its supposedly global, standardized nature, lights data are arguably useful for examining trends in cross-border and comparative contexts (Henderson, Storeygard, and Weil, 2012). But caution is warranted in assuming lights to be a globally standard predictor of population, GDP, or any other socioeconomic variable for that matter. This is due to three main reasons.

First, national-level institutions affect lights (Pinkovskiy, 2013). A change in lights in China may not necessarily signal the same change in population or economic productivity as a change in lights in Russia. Second, assumptions about the responses of lights to socioeconomic variables may be biased by the fact that one of the most commonly researched areas is China (Bennett and Smith, 2017; Huang et al., 2014), where urbanization and rapid economic growth have been the norm for much of the past two decades (e.g. Yi et al., 2014; Cao et al., 2014; Fan et al., 2014). Even outside of China, DMSP-OLS data are typically used to examine places that are largely growing rather than declining in lights (e.g. Keola, Andersson, and Hall, 2015; Álvarez-Berríos, Parés-Ramos, and Mitchell Aide, 2013; Zhou, Hubacek, and Roberts, 2015). On one level, this makes sense since globally, lighted area increased between 1992 and 2009 (Cauwels, Pestalozzi, and Sornette, 2014). Asia in particular has experienced some of the greatest changes in lights (Small and Elvidge, 2013). Yet the relationships found between lights and socioeconomic variables in fast-developing places like China may break down in places where development is slower or altogether reversing.

This leads to the third reason why more research is needed into how lights respond across a variety of socioeconomic contexts: there may be limits to using lights to estimate a reversal of development that is characterized by depopulation and economic contraction. While Henderson, Storeygard, and Weil (2012) find that lights respond symmetrically to positive and negative changes in GDP, the dimming of lights in response to economic contraction appears lagged. More insight into the responses of lights to negative socioeconomic dynamics is necessary, for decreasing lights are less understood than increasing ones. A handful of studies specifically examine places where lights are decreasing for reasons like war (Li and Li, 2014), light pollution control (Bennie et al., 2014), depopulation (Archila Bustos et al., 2015), and economic contraction

(Li, Ge, and Chen, 2013). But generally, the relative underuse of DMSP-OLS data for studying such trends represents an unusual gap in the research particularly since sensor issues like saturation can limit the data's practicality for studying brightly lit urban areas. DMSP-OLS cannot resolve further brightening in areas where lights have already reached the sensor's saturation point, when the observed digital number (DN) value reaches 63 (Small, Pozzi, and Elvidge, 2005). Thus, DMSP-OLS data may actually prove more valuable for studying places where lights have not yet reached the saturation point, which are often non-urban areas, and places where lights are dimming rather than continuously brightening. However, countries that show unusual relationships between lights and socioeconomic variables like Russia are often simply labeled outliers and discarded from models without further analysis. This is the case in Zhang and Seto (2011)'s study of national-scale differences between normalized urban population and normalized total lights, where the two major outliers of Russia and Greenland are removed in order to substantially improve the model's fit.

Given the lack of attention to lights in areas of socioeconomic decline, this study has two goals. First, it attempts to examine and map how lights change in places known from other socioeconomic data to have declining population and/or economic activity. These negative socioeconomic trends occurred to varying degrees within Russia following the disintegration of the Soviet Union in 1991, right before the first year for which DMSP-OLS annual stable lights composites are available (1992). Post-Soviet Russia there-fore makes for a useful comparison with China, the most common case study in night lights research. Analysis of these two countries is made more compelling by the two countries' shared border and history of communist planning in the twentieth century. Additionally, although many multitemporal night lights studies compare national-scale dynamics, this study focuses on comparing provincial-scale dynamics between these two countries. Studies at this scale may provide insight into levels and trends of regional development, a topic that concerns the Russian and Chinese national governments. Both Moscow and Beijing have launched campaigns to reduce regional economic disparities partly out of concerns that failure to do so could endanger national stability. While there is a small subfield using lights to estimate regional development and economic activity (Hodler and Raschky, 2014; Xu et al., 2015; Doll, Muller, and Morley, 2006), few specifically examine these topics in former socialist and communist countries apart from China.

The second goal of this study is to assess whether changes in population and economic activity correspond similarly with lights in Russia and China. To do so, we take advantage of the availability of official provincial-scale population, GDP, and fixed capital investment records from the Russian and Chinese governments from 2000 to 2012 to predict lights using a panel regression model that controls for province and year fixed effects. These records are not available prior to 2000, which is why the panel does not cover the period 1992–1999 despite the availability of lights data.

This chapter is structured as follows. Section 6.2 presents a brief overview of political economy in Russia and China from 1992 to 2012. Section 6.3 reviews our data sources and methodology. Section 6.4 synthesizes our results and discussion in two main subsections. The first main subsection (Section 6.4.1) examines changes in lights at national, provincial, and pixel scales. At the national scale, descriptive statistics for lights in Russia and China in 1992 and 2012 are compared and evaluated. At the provincial scale, changes in the spatial distribution of lights are explored using a variety of measures, including changes in the Gini coefficient of provincial lights between 1992 and 2012 as a proxy for changes in regional development. Rates of change and path dependence in provincial lights are also examined both visually and statistically to assess whether relative development levels at the provincial scale within a country become "locked in" at earlier stages. At the pixel scale, tritemporal night light imagery from 1992, 2002, and 2012 is compared with high-resolution visible-light satellite imagery from Google Earth to illustrate correspondences between changes in lights and changes in daytime visible light imagery. The second main subsection (6.4.5) discusses the results of the panel regression, which estimates whether changes in population and GDP predict changes in lights within provinces. We also examine interactions between regions and GDP to further assess whether changes in lights reflect differences in regional development. Given the existence of factors such as development strategies and endemic corruption concentrated at the scale of the region rather than the province, regional interactions with GDP may prove important. In this section, we also draw on literature from the social sciences to strengthen and extend our analysis. While this is perhaps unusual for a paper in this journal, incorporation of this literature helps connect and contextualize remotely sensed night light imagery with on-the-ground political and economic dynamics. Section 5 offers some conclusions and suggestions for future research, specifically in the way of using lights data to explore regional development in countries that do not fit the "China model" of growth that consists of rapid economic expansion and urbanization.

6.3 Brief history of socioeconomic dynamics in Russia and China, 1992–2012

After the Soviet collapse, Russia struggled to maintain previously high levels of industrialization during the rapid "shock therapy" transition to a market economy. Demand for industrial products and state subsidies to industry dropped substantially, with real investment in industrial plants, equipment, and infrastructure falling 75% (Peterson and Bielke, 2002). The shrinking of public services hit Russia's northern and eastern regions, which had been forcibly settled to varying degrees in previous decades, particularly hard. Hundreds of thousands of people moved away from these areas, some of which juxtapose China, to the country's relatively more prosperous western economic centers like Moscow and St. Petersburg. Northern federal subjects (the highest-level administrative division within Russia) like Chukotka witnessed severe population declines. Between 1989 and 2002, Chukotka's population dropped 67% to 54,000 people (Thompson, 2004). Overall, the national population dropped 3.6% from 1992 to 2012 (World Bank, 2016). Although Russia's economy began to grow 7–8% annually beginning in 2000, the crash in global energy prices during the 2007–2008 global financial recession brought growth to a halt (Goldman, 2008). Russia's post-Soviet economic expansion has largely relied on the development of oil and gas and a select few metropolitan powerhouses rather than a more spatially even style of regional development as has occurred in China. From space, above the many Russian cities, towns, and factories that have shrunk as the post-Soviet economy and population has retreated to key urban centers and sites of resource production, DMSP-OLS can detect declines in lights.

As the Soviet Union was dissolving in the early 1990s, the Chinese state under the leadership of Deng Xiaoping initiated economic reforms that ushered in average real GDP growth of 9.9% per year according to China's National Bureau of Statistics, although this figure is subject to dispute (Wu, 2007). The reforms privileged the eastern coastal region at the expense of the interior (Holbig, 2004). To reduce this regional inequality, in 1999, the government launched a campaign aimed at advancing social and economic development in China's interior and western regions called "Open Up the West" (Goodman, 2004b). Two additional programs called "Uplifting of Central China" and "Revitalizing the Northeast" were launched in subsequent years (Dunford and Li, 2010). While the extent to which regional inequality has been reduced remains debated, since the mid-1990s, China's interior has received a greater share of project investment, labor-intensive industries have relocated away from the coast, and poverty reduction programs have been established (Wei, 2013). In addition, public investment in infrastructure has transformed the country's landscape, with DMSP-OLS data being used to effectively estimate rising steel use in China (Liang et al., 2014). Skyscrapers, hydroelectric power plants, and industrial facilities have sprung up all across China, emitting light into the sky that DMSP-OLS can capture from space.

6.4 Data and methodology

6.4.1 Study area

The study area covers the countries of Russia and China from 1992 to 2012 at the national, regional, and provincial scales. At the regional scale, Russia has eight federal districts, referred to in this article as regions. China has four economic planning regions in which various development schemes have been undertaken (Figure 6-1). At the provincial level, Russia has 83 federal subjects categorized as 46 *oblasts*, 21 republics, nine *krai*, four autonomous *okrugs*, two federal cities, and one autonomous *oblast*. China has 34 provincial-level administrative divisions categorized as 23 provinces (including Taiwan), four municipalities, five autonomous regions, and two special administrative regions (Hong Kong and Macau). For simplicity's sake, all provincial-level administrative divisions in both Russia and China are referred to herein as provinces. Administrative boundaries for Russia and China's subnational entities were downloaded from the Global Administrative Unit Layers (GAUL) 2015 Set developed by the Food and Agriculture Organization (FAO, 2014). We include Hong Kong, Macau, and Taiwan within China's 34 provinces but exclude areas whose sovereignty the GAUL database categorizes as disputed (Arunachal Pradesh, Aksai Chin, and a handful of smaller areas). China's provinces vary in size from Macau (the smallest) to Xinjiang (the largest), while Russia's provinces vary from St. Petersburg (the smallest) to the Sakha Republic (the largest), which is slightly smaller than India.

The two new federal subjects of Crimea and Sevastopol, which actually bring the total number to 85, are not included in our analysis of Russia as their sovereignty is also disputed. Regardless, Crimea was joined to Russia in 2014, after the end of the study period (2012). As a final note on the study area, portions of Russia's three northernmost provinces (Nenets, Krasnoyarsk, and Sakha) extend above the 75° N limit of DMSP-OLS. Yet since these northern areas account for a fraction of Russia's territory and are largely unpopulated and devoid of economic activity, their omission does not significantly affect our results.

6.4.2 Night-time lights data

DMSP-OLS was initially developed for daily detection of global cloud cover, but the high night-time sensitivity of its sensor permits detection of illuminated anthropogenic activities like city lights, gas flaring, and fishing fleets (Croft, 1978). DMSP-OLS's nightly overpass occurs between 20:30 and 21:30 (Elvidge et al., 2001). Each swath is ~3000 km wide with a nominal resolution of 1 km, resampled from 2.8 km (Doll, Muller, and Morley, 2006). During its night-time overpass, OLS can detect radiances down to 1.54×10^{-9} and up to 3.17×10^{-7} W cm^{-2} sr^{-1} μm^{-1} (Cinzano et al., 2000). With this remotely sensed lights data, NOAA/NGDC produced a dataset of annual stable lights composites from 1992 to 2013 called the DMSP-OLS Version 4 (V4) annual stable lights composites, available freely online at http://ngdc.noaa.gov/eog/dmsp.html. This study uses the V4 annual stable lights composites from 1992 to 2012. The composites capture all persistent lighting emitted each year from −180° W to 180° E and −65° S to 75° N and exclude sunlit and moonlit data, glare, aurora, observations obscured by clouds, and ephemeral events like fires. Data values consist of DNs that range from 0 (no light) to 63 (the maximum value).

Lights data may generally be better suited to detecting negative socioeconomic changes than other remotely sensed data products like land cover. While a significant amount of research compares the two products' abilities to detect increases in land with human presence (Castrence et al., 2014; Small and Elvidge, 2013; Xiao et al., 2014), as far as we know, a comparison of their abilities to detect decreases in land use has not been specifically studied. A land cover product would likely not detect any changes in a built-up area even if its associated population had moved away or economic activity had slowed because signatures from buildings, concrete, and asphalt would persist. Lights data, however, can detect a dimming of lights that may be associated with depopulation or deurbanization. Whereas lights detect fluctuations in radiance that can be associated with inward or outward flows of people, capital, or energy, land cover products tend to capture stocks of infrastructure that do not decline right away even if the flows typically associated with them have.

6.4.3 Population, GDP, and fixed capital investment data

Population, GDP, and fixed capital investment statistics for Russia were obtained from the online database of the Russian Federal State Statistics Service (Rosstat) (2014). At the federal subject level, population and fixed capital investment data are available from 1992 to 2012, while GDP data is only available from 1998 to 2012. Rosstat (Federal State Statistics Service, 2014) reports GDP and fixed capital investment data in nominal rubles, which are not adjusted for inflation. These records were subsequently converted into 2005 US dollars using annual adjustment ratios from the World Bank (2015).

Population, GDP, and fixed capital investment data for China were obtained from the online database of the National Bureau of Statistics of China (2015). Regional-level data is available for all provinces except Taiwan, Hong Kong, and Macau, which is why they are excluded from our panel. GDP and fixed capital investment data at the provincial level are available from 1995 to 2012, while population data is only available from 2000 to 2012. As with Russia, Chinese GDP and fixed capital investment records were converted from nominal yuan into 2005 US dollars according to annual adjustment ratios from the World Bank (2015). Since population, GDP, and lights data are only available for all provinces in Russia and China from 2000 to 2012, this study's panel is limited to that period.

6.5 Image processing and geostatistics

To account for the fact that six different satellite pairs (F10, F12, F14, F15, F16, and F18) captured NTL imagery from 1992 to 2012, DMSP-OLS V4 composites were intercalibrated using an ordinary least squares (OLS) regression model developed by Elvidge et al. (2014). In principle, intercalibration allows for more accurate interannual comparison. The regression model applied is

$$\text{DNadjusted} = C_0 + C_1 \times DN + C_2 \times DN^2, \quad (1)$$

in which C_0, C_1, and C_2 are regression coefficients provided in Elvidge et al. (2014), DN is the value of the pixel in the uncalibrated composite, and DNadjusted is the adjusted pixel value. Elvidge et al. (2014) determine that F121999 has the brightest average values, so all other composites are intercalibrated to match its range. For our choice of an invariant area for the regression, since Russia and China cover approximately 17% of the world's land area, we follow Elvidge et al. (2014)'s global-scale regression in using Sicily.

In ArcGIS 10.3.1, the resulting intercalibrated rasters were clipped to Russia and China's spatial extents based on the GAUL boundaries. Areas with gas flaring, an externality associated with oil and gas production, were clipped from the spatial extents, as their inclusion can introduce inaccuracies into examinations of the relationship between lights and socioeconomic variables (Elvidge et al., 2009). Gas flares were removed based on shapefiles downloaded from NOAA (available at http://ngdc.noaa.gov/eog/interest/gas_flares.html). Gas flares were particularly prominent in the Russian oil and gas producing provinces of Khanty-Mansiysk, Yamalo-Nenets, and Nenets. It should be noted that these shapefiles do not exactly conform to gas flares in years before and after 2008, which may potentially introduce some inaccuracies into the results for areas known to have gas flaring whose levels have varied considerably over the years.

Next, each clipped raster was reprojected to the Asia North Albers Equal Area projection using the nearest neighbor resampling method and a 1 km cell size. Pixels whose DN <3 were reclassified to 0 and pixels assigned a DN > 63 after intercalibration were reclassified to 63.[1] Next, lights were summed for each province in Russia and China, generating total lights per province for every year from 1992 to 2012. For years in which two annual stable lights composites exist due to overlapping satellite records (1994, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009), the mean total lights of the two composites was calculated as the value for that year. In the F142002 composite, many northern provinces had total lights values of 0 due to its apparent failure to include data for a large part of the Northern Hemisphere. The values from the F152002 value were thus retained as the provincial lights total rather than averaged with the zero values from the F142002 composite. This same procedure was applied for a handful of other instances where provinces were coded as having total lights values of 0, notably Nenets and Murmansk in F141997, F141998, F141999, and F142001. This issue may suggest some underlying

[1] Due to differences after intercalibration, the topcode for 1992 is 62, while the topcode for 2012 is 61.

defect with the F14 satellite in detecting lights near the northern polar latitudes that requires further investigation.

6.6 Methods of analysis

We used a combination of statistical analysis and visual inspection to determine national, provincial, and pixel-scale change in lights in Russia and China between 1992 and 2012. First, national-scale descriptive statistics were calculated to highlight changes in the intensity of lights in 1992 and 2012 across various categories of DNs: 0 (representing unlit area), dimly lit areas of DN = 4–6 and 6–10, brightly lit areas of DN = 11–20 and 21–62, and top-coded (saturated) areas of DN = 63. These follow the categories established in Henderson, Storeygard, and Weil (2012). Second, to visualize the differences in lights between the first, middle, and final years of the 1992–2012 time period, the F101992, F152002, and F182012 composites were combined into a single three-band raster in ArcGIS 10.3.1. This resulted in a pixel-scale tritemporal map of lights for Russia and China. This visualization method is based on Small and Sousa (2016), who use OLS composites from 1992, 2002, and 2012 to highlight change in lights in the Himalayas. In Figure 3(c), 1992 values were input into the blue channel, 2002 into the green channel, and 2012 into the red channel, with the raster displayed using a standard deviation stretch (n = 2.5). The resulting tritemporal map was visually inspected for Russia and China to obtain a sense of the geography of changes in lights in each country over the two-decade period.

To examine change in lights in Russia and China from 1992 to 2012, time-series plots of total annual lights at the national level and provincial scale were created. In the provincial lights time series, the natural log (ln) of total lights was used to facilitate comparison between provinces with widely varying amounts of light, particularly in Russia. After each country's provinces with the largest and smallest log differences (a measure similar to finding the total percentage difference) in total light between 1992 and 2012 were identified, specific areas of decreasing, stable, and increasing lights were located in high-resolution Google Earth imagery. One image from as early as possible in this time period (2000-2007) was compared with an image from as late as possible in this time period (2011-2014). This provided insight into what decreasing, stable, or increasing lights represent on the ground. In future, further validation of the ability of DMSP-OLS V4 stable lights composites to detect areas experiencing socioeconomic decline, especially through comparison with daytime visible light imagery, is recommended.

At the provincial scale, various measures were examined to explore how lights changed in Russia and China between 1992 and 2012. First, using the *ineq* package in RStudio 0.99.902, the Gini coefficient of light inequality was calculated to estimate whether a country's provinces had grown more or less equal in lighting from 1992 to 2012. A decrease in the Gini coefficient corresponds to an increase in equality in total lights per province and suggests a trend of more spatially even national development. By contrast, an increase in the Gini coefficient corresponds to a decrease in equality in total lights per province and suggests a trend of more spatially uneven national development. Second, to assess path dependence in provincial lights, Pearson's r and Kendall's rank correlations were calculated for both logged and unlogged total lights per province in 1992 and 2012 in Russia and China.

Additionally at the provincial scale, using a variety of linear and panel regression models, the relationships between the dependent variable, lights per province, and the two independent variables, population and GDP, were examined from 2000 to 2012. All three variables were transformed using natural logarithms due to their positively skewed distributions across provinces in Russia and China. While other studies take lights per area as their unit of analysis (Hodler and

Raschky, 2014; Michalopoulos and Papaioannou, 2014), we did not do this in our study since we only examine within-province change.

First, a multiple linear regression model using ordinary least squares (OLS) was tested to see if population and GDP affect lights. We also initially considered using fixed capital investment in our model, but it was shown to not add much explanatory power so the variable was discarded. The resulting model is written as

$$\text{Lights}_i = \beta_0 + \beta_1 P_{i1} + \beta_2 G_{i2} + \varepsilon_i, \ (2),$$

in which 'Lights' is the dependent variable, logged lights, where i = province; β_0 is the intercept; P is logged population; G is logged GDP; β_1 and β_2 are coefficients for their respective independent variables, and ε_i is the standard error.

Next, using the *plm* package in R, a one-way fixed effects model was tested separately for Russia and China, which assumes that unobserved heterogeneity within provinces is time-invariant. The model is written as

$$\text{Lights}_{i,t} = \beta_1 P_{i,t} + \beta_2 G_{i,t} + \alpha_i + u_{i,t}, \ (3),$$

in which $\text{Lights}_{i,t}$ is the dependent variable, logged lights, where i = province and t = time; P is logged population; G is logged GDP; α_i is the unknown intercept for each province, β_1 and β_2 are coefficients for their respective independent variables; and $u_{i,t}$ is the error term plus the unobserved, time-invariant characteristics of regions (fixed effects). An F-test demonstrates that the fixed effects model offers an improvement over the multiple linear regression model ($p < 0.05$) for both

Russia and China. Although simple and multiple linear regression models are a common method of exploring relationships between lights and socioeconomic variables (e.g. Sutton, Elvidge, and Ghosh, 2007; Zhang and Seto, 2011; Zeng et al., 2011; Ghosh et al., 2009; Shi et al., 2014), a fixed effects model more accurately controls for unobserved effects in multi-temporal data (Henderson, Storeygard, and Weil 2012; Chen and Nordhaus, 2011). Furthermore, since checking for errors among the variables revealed that the data is heteroskedastic, the assumption of homogeneity of variance could be relaxed with the use of a fixed effects model.

Next, within-province variation over time in lights and socioeconomic variables was examined separately for Russia and China using the fixed effects model expressed in Equation (3). The panel data for China is balanced with 31 provinces and 403 observations. The panel for Russia is slightly unbalanced with 83 provinces and 1079 observations, as GDP data is missing for Chechnya from 2000 to 2004. Due to the poor fit of the model in Russia, it was run again separately for the 62 provinces that decreased in population between 2000 and 2012 and the 21 provinces that increased in population. As the model still showed a generally poor fit for both groups, the model was tested again on all observations in Russia and China with the addition of year fixed effects, which were introduced as a dummy variable into the model with 2000 as the reference year.

Finally, to explore whether there is a specific regional geography to the way in which GDP affects lights in Russia and China, time-invariant regional effects were interacted with GDP. The model that examines the effects of regional interactions with GDP on lights in addition to the original predictors of population and GDP is written as

$$\text{Lights}_{i,t} = \beta_1 P_{i,t} + \beta_2 G_{i,t} \times R + \alpha_i + u_{i,t}, \quad (4)$$

in which $\text{Lights}_{i,t}$ is the dependent variable, logged lights, where i = province and t = time; P is logged population; G is logged GDP; α_i is the unknown intercept for each province; R represents the dummy variable for each region, β_1 and β_2 are coefficients for their respective independent variables; and $u_{i,t}$ is the error term plus the unobserved, time-invariant characteristics of provinces (fixed effects).

6.7 Results and discussion

6.7.1 National-level change in lights

Since the disintegration of the Soviet Union and the end of the Cold War in 1991, Russia and China have experienced dramatically divergent development patterns. This is readily apparent in analysis of night light imagery. In 1992, Russia had more total lights than China, but by 2002, China had more lights than Russia (Figure 6-2(a,b)), nine years after its GDP in current US dollars surpassed Russia's (World Bank 2017). Strikingly, Russia actually had fewer lights in 2012 than it did in 1992, whereas China's lights more than doubled during this period. In other words, Russia's lights had not recovered by 2012 to their directly post-Soviet levels (Table 6-1).

Between 1992 and 2012, lights in China spread out across the country and intensified, whereas neither is particularly true for Russia. The percentage of unlit area in China dropped from 92% in 1992 to 82% in 2012, exemplifying the spread of anthropogenic presence and pressure on land across Earth since the early 1990s (Geldmann, Joppa, and Burgess, 2014). The percentage of lights in all other categories increased, too. In Russia, unlit area only declined slightly from 95% to 93%. The percentage of top-coded pixels in Russia increased, which may indicate growth in extent and intensity of lights in the primate city of Moscow and other major metropolitan centers including St. Petersburg, Yekaterinburg, and Novosibirsk, the latter two of which are located in Siberia (Figure 6-3(a–c)). The difference in the percentage of top-coded pixels between 1992 and

2012 in Russia, however, is much smaller than in China. Notably, Russia experienced a decline in the percentage of lights within the two brightest categories of pixels (DN = 11–20 and DN = 21–61/60[1]), which are typically associated with urban areas. This may explain why even though a larger extent of Russia's area was illuminated in 2012 compared to 1992, the country's total lights (in other words, the combined intensity of all lights) dropped. A substantial number of secondary cities like Khabarovsk were brighter in 1992 than in 2012 as depicted in Figure 6-3(c), which may reflect a national trend of urban shrinkage. According to Rosstat population data, eight of Russia's 13 cities with over 1 million people in 2002 have decreased in size since 1989 (Molodikova and Makhrova, 2007). The apparent dimming of many of the country's cities outside of Moscow and St. Petersburg along with the 1% increase in the country's rural population between 1992 and 2000 (Pivovarov, 2003) may also help explain why changes in urban population in Russia do not correspond to changes in total lights in the same manner as most other countries' cities (Zhang and Seto, 2011), though further research at the urban scale is necessary to explore this.

The tritemporal lights map visualizes differences in lights in Russia and China in 1992, 2002, and 2012 (Figure 6-3(a–c)). White pixels represent stable areas of relatively similar brightness in each of the 3 years. Blue pixels represent areas brighter in 1992 than in 2002 or 2012, suggesting decline. Green pixels represent areas brighter in 2002 than at the start or end period, suggesting growth around the new millennium that has since tailed off. Red pixels represent areas brightest in 2012, suggesting recent growth. Visual inspection of the tritemporal lights map highlights the geography of changes in lights within each country. The swath of green and red pixels along the coast between Beijing and Shanghai conveys recent growth at the outset of the twenty-first century. In southern China, the numerous concentrations of red pixels eventually converge on the Pearl River Delta, which includes cities such as Guangzhou and Hong Kong.

Although the Pearl River Delta is the world's fastest growing region (Su et al., 2015), the conurbation appears relatively white, which may due to the sensor not being able to detect further brightening beyond the saturation level. The most obviously red pixels are in western China around cities like Hohhot and Ordos in Inner Mongolia and Urumqi in Xinjiang. A scattering of blue and purple pixels are concentrated northeast of Beijing in the provinces of Liaoning and Jilin, where the proliferation of decaying industries since the 1970s has led to pronouncements of a "Rust Belt" (Li, 1996). Areas represented by blue pixels were brightest in 1992, whereas purple ones may have recently recovered to near 1992 levels following a decrease in 2002.

Russia is characterized by an extensive spread of blue pixels from west to east, signifying the dimming of lights since 1992. These pixels follow the Trans-Siberian Railway and spread outwards from the transportation corridor to numerous surrounding settlements. The highest concentrations of green pixels, which indicate brightening during the early years of Russian President Vladimir Putin's administration, which commenced in 2000, appear within the Volga region, the southern Caucasus, and in northwest Russia around the Arctic port city of Murmansk. Red pixels are most obvious around the edges of Moscow and St. Petersburg, in the province of Belgorod, which has pursued intensive modernization of its agricultural sector since 2000 (Efendiev, Sorokin, and Kozlova, 2014), and northwest Siberia, where the oil industry has expanded in recent years into places like the Yamal Peninsula. Lights in parts of the Northern Caucasus appear purple, suggesting that lights were dimmer in 2002 relative to 1992 but have since began to recover. The dimming of lights in 2002 in the conflict-ridden Caucasian republics of Dagestan and Ingushetia can possibly be explained by the First and Second Chechen Wars (1994–1995 and 1999–2000, respectively), which reduced cities like Grozny to rubble. Multi-billion dollar rebuilding efforts in recent years may likely explain the brightening apparent in 2012.

6.7.2 Regional development and provincial-scale changes in lights

The Russian and Chinese governments have sought to reduce disparities in regional development, with the latter more serious about tackling the issue than the former. In China since 2004, interregional inequality has declined thanks to convergence in provincial economic growth rates (Fan and Sun, 2008). Yet in Russia, the overall speed of regional convergence from 1998 to 2006 was very low by international standards, although high-income regions located in close proximity to one another exhibited strong regional convergence (Kholodilin, Oshchepkov, and Siliverstovs, 2009). The Kremlin has announced policies of regional development over the years ranging from a federal program called "Reducing differences in socioeconomic development of the regions of the Russian Federation (2002–2010)" to more recent efforts to develop eastern Russia through the establishment in 2012 of the Ministry for Development of the Russian Far East. As Russia's relationships with Europe fracture, the government has set its sights on improving Russia's political and economic ties with Asia partly via the development of its regions closest to China, Japan, and South Korea. However, the majority of any related gains in the Russian Far East's development that could potentially be approximated by lights would occur after 2013, when production of DMSP-OLS V4 composites ceased. Night-lights based evaluation of the success of eastern Russia's development thus requires use of the newer Suomi National Polar-orbiting Partnership data, available since late 2011.

Existing findings of increased regional convergence in China and stagnant or decreasing regional convergence in Russia are corroborated by the results we generated using a variety of lights-based measures. The first is the Gini coefficient of lights, whose use to date appears limited to comparisons at the international level (Cauwels, Pestalozzi, and Sornette, 2014; Henderson, Storeygard, and Weil, 2012). In 1992, Russia and China (Macau excluded) had identical Gini coefficients of lights across provinces of .44, respectively. Results for China are examined both with and without Macau since the province is extremely small in size at ~31 km^2, densely populated, and highly developed, making it particularly subject to saturation. By 2012, Russia's Gini coefficient had increased slightly to .45. China's, however, had decreased to .38 (Macau excluded). This indicates an evening of light levels between Chinese provinces and a possible increase in spatially even national development. In Russia, by contrast, the increase in inequality in lights between provinces may be due to the intensification and outward extension of lights in Moscow and St. Petersburg and the dimming of lights in many of the country's peripheral provinces.

The lack of convergence in lights in Russia's provinces between 1992 and 2012 prompts an assessment of path dependence, or whether total lights in 1992 determined total lights in 2012. This was explored using various correlation measures of logged and unlogged lights. The estimated Pearson's r correlation coefficients vary slightly depending on whether the data is logged (Table 6-1). This point is worth mentioning because although transforming lights data can affect results, its implications have not been widely considered. Yet regardless of whether logged or unlogged data is use, Pearson's r correlation coefficients show that lights are more strongly correlated in Russia between 1992 and 2012 than in China.

A separate test that provides the same result for both logged and unlogged data is Kendall's rank correlation, which measures the similarity of how two quantities are ordered. Russia's provinces remain more similarly ordered between 2012 and 1992 than China's. Thus, both the Pearson's r and Kendall's rank correlations indicate a higher degree of provincial path dependence of lights in Russia than in China. This may mean that it is harder for Russian provinces to move up or down in relative development status. It could also suggest that the Chinese government's efforts to stimulate growth in its less developed provinces are actually helping certain areas to overcome initial low levels of development.

Scatterplots of the correlations of total lights per province in 1992 and 2012 show that in the unlogged data in both China and Russia, provinces with mid-range light levels appear to increase the most relative to the other provinces (Figure 4(a)). In the logged data (Figure 4(b)), the correlation appears fairly steady across provinces of varying amounts of total lights in both countries. Yet in Russia, the provinces with some of the lowest amounts of logged lights appear to underperform in 2012 compared to their 1992 levels. More robust time-series analysis of path dependence is necessary to test the hypothesis that relative levels of development among Russia's provinces are more determined by levels reached during the Soviet era than they are China prior to Deng Xiaoping's economic reforms.

Breaking down the national trend in Russia of decreasing lights to the provincial scale, Figure 6-5(a,b) illustrate how total lights in most of Russia's provinces stagnated or declined from 1992 to 2012. Over half (48/83) of Russia's provinces had fewer lights in 2012 than they did in 1992, suggesting weak levels of regional development in much of the country. In contrast, all of China's provinces except for Hong Kong experienced growth in lights during this period. Examination of rates of change in lights also shows how in China, provinces with lower levels of lights in 1992 appeared to catch up to more developed provinces, while the same cannot be said of Russia. Provinces in western and northern China, namely Tibet, Xinjiang, Qinghai, and Inner Mongolia, experienced some of the most rapid rates of change in lights. These initially less-developed western provinces grew more rapidly than coastal provinces like Hong Kong, Macau, Taiwan, Beijing, and Shanghai, which had the lowest rates of change. One exception is Hainan, an island province in southern China that experienced rapid growth in lights comparable to rates in western and northern China. Hainan's growth may be due to its historical lack of development and the recent promotion of sustainable development initiatives and tourism (Stone and Wall 2004). In China's poorer, less populated western provinces, the state-encouraged relocation of both capital and Han Chinese migrants (Becquelin, 2004) may be driving them to catch up in total lights to the wealthier, more populous coastal provinces. Western China also holds significant deposits of resources like oil, gas, and coal, which the government began seeking to extract as part of its regional development strategy beginning in the early 2000s (Woodworth, 2017). In comparison to western China and neighboring Inner Mongolia and Heilongjiang, the northeast Chinese provinces of Jilin and Liaoning – home to the aforementioned "Rust Belt" – experienced slower rates of change. China's provinces may be growing closer to one another in total lights, but regional inequalities remain.

6.7.3 Inferring development from decreasing, stable, and increasing lights

6.7.3.1 Decreasing lights in Magadan

Of all of Russia's provinces, lights in the northeast province of Magadan decreased the most. Total lights in 2012 equaled only 53% of total lights in 1992. Like much of the Russian North, this mining-intensive province has become depopulated through government programs carried out with the assistance of the World Bank to resettle its residents in Russia's more temperate locations, where it is easier for the state to provide services (Round, 2006). Comparison of the tritemporal map over Magadan City, which mostly consists of lights that dimmed since 1992, and the same location in Google Earth reveals encroachments of vegetation, demolished or abandoned infrastructure, and general urban shrinkage between 2002 and 2012 (Figure 6-6(a)).

6.7.3.2 Stable lights in Hong Kong

While 33/34 of China's provinces increased in lights between 1992 and 2012, Hong Kong's lights actually decreased to 91% of 1992 levels. Rather than reflecting a downturn in Hong Kong's level of development, however, this may be due to the sensor not capturing growth beyond the saturation level. As a highly developed and densely populated city-province, most of Hong Kong already appears close to saturation level in 1992. This would limit the ability of DMSP-OLS to detect further increases in brightness beyond a DN of 63, an issue which several studies attempt to remedy with various saturation corrections (Ma et al., 2014; Letu et al., 2012; Zhuo et al., 2015). Alternatively, Frolking et al., (2013) combine DMSP-OLS data with microwave scatterometer data to document the upward expansion of urbanization via the construction of taller buildings, which is common in Chinese cities. Hong Kong's growth could also simply be slower than in less developed or less urbanized provinces in places like western China. Indeed, little change is noticeable in a portion of the densely populated Kowloon Peninsula between 2000 and 2012 in Google Earth imagery (Figure 6-6(b)), and most of the city appears white (representing stable lights) in the tritemporal map. A similar "flat lining" of lights is also apparent in the Russian city-province of Moscow, which already has many pixels at or close to saturation in 1992. Although its population has grown 28% since 1989 and its economy has continued to expand (Argenbright, 2013), the stagnation of total light between 1992 and 2012 does not reflect this.

6.7.3.3 Increasing lights in Altai Republic and Tibet

The largest increase in lights in Russia is in the Altai Republic, a mountainous area that borders China. Lights in 2012 are 208% of 1992 levels. Some of the greatest changes in lights within Altai correspond to the recent completion of the Kosh-Agach solar power facility, whose construction is visible in Google Earth imagery between 2007 and 2014 (Figure 6-6(c)). Altai's increase in lights over this period resembles the general rate of increase among China's provinces, none of which bear any resemblance to Magadan's dramatic decrease in lights. Indeed, the similarity of the trend in lights between China's provinces and the Altai Republic, which borders China, Kazakhstan, and Mongolia, may be related to efforts by Chinese authorities to develop tourism and transportation infrastructure in the impoverished region (Nyíri and Breidenbach, 2008). Over time, the diffusion of Chinese capital across its borders to develop its foreign hinterlands in places like Altai may come to represent an exception to Pinkovskiy (2013). This study identifies discontinuous increases in lights per capita upon crossing a border from a poorer to a wealthier country and particularly strong discontinuities along Asian borders such as the one between Russia and China.

In China, total lights in the southwestern province of Tibet increased the most of any province, with 2012 levels growing to 903% of 1992 levels. Xinjiang, Qinghai, Yunnan, and Inner Mongolia have the next highest growth rates, with 2012 lights all at least five times greater than 1992 levels. In recent decades, these provinces had very low levels of development compared to eastern China. Qinghai, for instance, had the worst economic performance (Goodman, 2004a) and some of the lowest levels of road density of all of China's provinces (Fan and Zhang, 2004). The dramatic increase in total lights in western China, especially in Tibet, may reflect state investment spurred by the national government's "Open Up the West" campaign. Tibet has been the largest per capita recipient of subsidies from the central government. In 2004, $2 billion was invested on building infrastructure (Chansoria, 2011). The large increase in lights around the Tibetan capital of Lhasa corresponds to an increase in built-up area visible in Google Earth between 2004 and 2011 (Figure 6-6(d)). A new, $4 billion public railway from the city of Golmud, Qinghai to Lhasa, Tibet, which opened in 2006, has brought increased numbers of tourists to the province, too (Su and Wall, 2009). With the Chinese government seeking to connect Tibet by rail with neighboring Xinjiang, Yunnan, and also Sichuan by 2020, growth in lights in these western provinces seems set to continue. Whether this type of development is improving the quality of life for ethnic Tibetans, however, remains contested (see, for example, Yeh, 2013).

6.7.4 Cross-border differences in lights

Eastern Russia and northeast China share similar natural environments, peripheral locations relative to their national centers, and economies dominated by the state and agriculture (Ryzhova and Ioffe, 2009). Whereas lights in northeast China substantially brightened between 1992 and 2012, however, they dimmed in eastern Russia (Figure 6-7). Many of the dimming lights indicate the decline of infrastructure and villages along the Trans-Siberian Railway. The border clearly delineates differences in patterns of changes in light, illustrating the importance of provincial and national-level institutions in regional development. Eastern Russia's decline in the 1990s may have even accelerated northeast China's growth: the plummeting in production of consumer goods and food staples in Russian border provinces, for instance, incentivized Chinese production (Alekseev, 2001). The one exception where Chinese growth appears to spill over into Russia is between the border cities of Heihe and Blagoveshchensk, possibly due to deliberate cooperation between the two municipalities to stimulate growth (Ryzhova and Ioffe, 2009).

Northeast China's growth in lights, even if slower than in the southwest, may be due to the national government's "Revitalize the Northeast" development program. The government established this strategy in 2003 to stimulate growth in the "Rust Belt" area that once formed one of China's key industrial bases but began declining in the late 1970s when the government switched its focus to coastal development. The program aims to transform the region into one of the country's four economic engines by modernizing state-owned enterprises, stimulating manufacturing and services, and increasing trade with neighboring countries. In contrast to China's efforts in its borderland regions, the Russian government made few concerted attempts to deliberately spur growth in the Russian Far East until 2012, when it created the new regional ministry for development.

6.7.5 Predicting change in lights with change in population and GDP, 2000-2012

The above examples demonstrate that lights are capable of capturing both positive and negative changes over time in regional development. They can also illustrate stark cross-border differences in lights that may be due to differences in national and regional administration and development policies. When examined systematically, however, it is unclear whether changes in lights respond similarly to positive and negative changes in population and economic activity.

Table 6-2 reports the fixed effect estimates regressing lights on population and GDP for province in China and Russia for every year between 2000 and 2012. All provinces in each country were included except for Macau, Hong Kong, and Taiwan in China, since no GDP or population data were available. We test the model with province and year fixed effects. When only province fixed effects are included, population and GDP each significantly predict lights over time within provinces in both Russia and China, but the coefficients vary. Within Russia, population has a larger effect on lights than GDP. In China, the opposite is true, with GDP having a larger effect than population. Unusually, population appears to have a negative effect, but this may be due to multicollinearity. When only population or only GDP is included as the predictor variable for lights, both coefficients are positive.

Since the variables are all logged, the coefficients can be reported as elasticities. Holding population constant in each country, the elasticity of provincial GDP growth with respect to lights growth is estimated to be 0.07 in Russia and a substantially higher 0.40 for China. Notably, the estimated elasticity between provincial GDP growth and lights growth for China is higher than the estimated global elasticity found between GDP and lights of 0.27 in Henderson, Storeygard, and Weil (2012)'s panel, which consists of 188 countries. Their model differs from ours, particularly since we include population. Yet their estimated within-country coefficient of determination (R^2) of .749 is close to the within-province R^2 of .81 we estimate for China. This indicates that in certain circumstances – perhaps in the context of rapid, urban-centric development – the relationship between GDP, population, and lights may be scale-invariant. Further research is necessary to confirm or deny this hypothesis.

Overall, the ability of population and GDP to predict change in lights is much lower in Russia than in China. These two variables explain 81% of within-province change in lights in China but only 6% of within-province change in lights in Russia. Population and GDP therefore do not just have numerically different effects on lights in Russia than in China: they have little relationship with lights at all over time. This finding may due to a number of reasons explored in the following paragraphs.

The first possible reason is that lights may be coupled with GDP and population when they increase but not when they decrease. A number of studies have observed this tendency. Examining countries in Europe from 1992 to 2012, Archila Bustos et al. (2015) conclude that population decline is not always coupled with decline in lighted area. While ten countries steadily depopulate over this period, only two – Ukraine and Moldova – also experience steady declines in lighted area. Similarly, Elvidge et al. (2014) note that in several former Soviet countries (though not

Russia), even as population declines or lags relative to GDP, lights continue to grow. In China's provinces between 2000 and 2012, population and GDP generally increased from one year to the next, so the possibility of lights decoupling from these variables when they become negative cannot be studied there at the provincial scale. Population did decrease in five provinces in China (Guizhou, Sichuan, Anhui, Guangxi, and Henan) between 1992 and 2012, but this number of observations is too small to fit to a model.

Yet in Russia's provinces, while reported GDP tended to increase annually for all provinces, population dropped for many. The possibility of decoupling can thus be explored. This is done by running the panel regression separately for the 62 provinces where population decreased between 2000 and 2012 and the 21 provinces where population increased over this period. While the model's fit improves to $R^2 = .22$ when only provinces that increased in population are included, population becomes a less significant predictor of lights ($p < .1$). GDP remains highly significant ($p < .01$), although the elasticity of change in GDP with respect to change in lights, 0.094, is still only approximately a quarter of its elasticity in China. This suggests that even in Russia's provinces that are reportedly increasing in both population and GDP, lights still do not respond in the same way to increases in lights as they do in China. The model's fit weakens even more to $R^2 = .02$ when only provinces that decreased in population are included, perhaps illustrating the erratic nature of the relationships between lights, population, and GDP in depopulating places.

The second possibility is that Russia may be experiencing aggregate, national-level shocks that are not controlled by the predictor variables of within-country GDP and population. This hypothesis is examined using year fixed effects. When these are included for Russia, the elasticity of change in GDP with respect to change in lights triples to 0.21, while the elasticity of change in population with respect to change in lights nearly halves to 0.57. All years are significant at p <

.001 except for 2010, which is still significant at $p < .01$. The fit of the model for Russia improves substantially from $R^2 = .05$ to .34. For China in contrast, all but one year fixed effects are insignificant at $p < .01$. When year fixed effects are included, the effects of population and GDP hardly change, while the R^2 also does not improve much. This means that while population and GDP sufficiently explain change in lights in China, they may not in Russia due to the existence of omitted variables at an aggregated, national, yearly level. In other words, although there appears to be a general "background decay" of lights across Russia that appears to reduce the effect of GDP on lights, when this aggregate trend is controlled for with year fixed effects, the effect of GDP on lights within provinces is somewhat more comparable to the effect in China's provinces.

One possible omitted variable that could explain the "background decay" of lights is infrastructure stock, which is deteriorating in many post-Soviet countries. However, including this variable in a model is difficult. As explained in Section 6.4.5, we attempted to use fixed capital investment to represent infrastructure, but it added little to the model. This is likely because the variable was collinear with GDP. In China, for instance, fixed capital investment is a key driver of GDP (Qin et al., 2006). Additionally, fixed capital investment figures may only account for addition to or enhancement of existing stock rather than its depreciation.

Aside from national-level year-fixed effects, a third reason for the poor fit of the model may be regional effects in Russia that influence the relationship between lights, GDP, and population. We interact the eight federal districts in Russia (Central, Far East, Northwest, North Caucasus, Siberia, Southern, Ural, and Volga) and four regional planning districts in China (East Coast, Central, Northeast, and Western) with GDP to see whether its effect on lights varies by region (Table 6-3). In China, regional interactions with GDP are insignificant in Central and Northeast China when compared to the East Coast reference region, which includes Beijing and

Shanghai. However, GDP appears to have a significantly stronger effect on lights in western China, with an elasticity of 0.152 compared to the East Coast. This could mean that the government's "Open Up the West" campaign is resulting in more lights generated per dollar invested in western China than in any other region in the country. Still, since the inclusion of regional interactions with GDP as predictors only slightly improves the model's fit, this means that the relationship between population, GDP, and lights in China can generally be sufficiently explained without incorporating regional variations into this relationship.

Contrastingly in Russia, regional interactions with GDP are significant in several cases and their addition substantially improves the overall fit of the model from $R^2 = .06$ to $R^2 = .14$. Regional effects are highly significant ($p < .01$) in the Far East and Northwest, where lights respond more positively to increases in GDP than in the reference region, Central Russia, which includes Moscow. These significant and positive interactions could reflect the federal government's ongoing efforts to develop the Far East and Northwest regions, both of which include Arctic areas where it is seeking to stimulate the economy and encourage infrastructure construction via federal transfers and increased investment (Russian Government, 2014; Korolev, 2016).

Regional interactions with GDP are also highly significant in the Volga Federal District ($p < .01$) and in the Southern and North Caucasus Federal Districts (both $p < .05$), yet GDP interacts with these three regions negatively compared to Central Russia. Notably, the geography of this effect corresponds to a "southern belt" of corruption stretching from the Southern to Volga Federal Districts. These are two largely agricultural areas which once strongly supported communism (Dininio and Orttung, 2005). Corruption is also a major concern among residents in the North Caucasus (Gerber and Mendelson, 2009). The negative effect of these three regions on GDP compared to the Central Federal District could limit the efficacy of investment-based regional development programs. Future research could examine whether these negative regional interactions may be due to the presence of corruption, typically defined as using public office for private benefit (Taylor, 2007). If this were shown to be the case, then the finding of significant negative regional effects in Russia as opposed to China, where only the Western region shows a significant and positive interaction with GDP, could corroborate findings that corruption is less costly and destructive in China than in Russia (Sun, 1999; Blanchard and Shleifer, 2001).

A fourth and final reason for the relatively poor fit of the model in Russia compared to China may be that Russian GDP and/or population records are inaccurate. Although the fit of the model actually decreases slightly when only GDP (R^2 = .03) or only population (R^2 = 0) are included, the possibility of unreliable standard accounts could be further explored if another independent, provincial-level source of data were used. One possible dataset for future incorporation is Yale University's G-Econ data, which provide GDP at a 1° × 1° resolution at a global scale for four years (1990, 1995, 2000, and 2005) and have been used in a handful of lights studies (Chen and Nordhaus, 2015; 2011). If the replacement of Russian GDP data with the G-Econ data substantially improved the model's fit, this could suggest that Russia's standard accounts are inaccurate and that the typical strong relationship found between GDP and lights could actually hold true in Russia. Then, the model could also be used to predict GDP or population within a certain area or scale of Russia for which statistics do not exist. Refinement of this model could also help better solve a debate as to whether the Russian economy actually "collapsed" in the 1990s or whether economic statistics under communism were vastly inflated, thus making Russia's decline appear more calamitous statistically than it was in actuality (Åslund, 2001).

6.8 Conclusion

The strong, positive relationships between change over time in lights, population, and economic activity found in rapidly growing places like China appear to break down when examined in places experiencing socioeconomic decline. Within China's provinces, changes in development, estimated using population and GDP records, are significant and account for over 80% of within-province change in lights. But within Russia's provinces, changes in population and GDP explain a mere 6% of change in lights over time even though they are significant predictors. The improvement of the model's fit in Russia with the addition of year fixed effects suggests that GDP actually has a stronger effect on lights than initially determined, but additional research is necessary to work out the unobserved variables that constitute these aggregate, yearly effects, which may indicate the broader deterioration of infrastructure that is occurring even as new investments in fixed capital are made. Until this can be done, our model using changes in population and GDP to explain changes in lights may not apply to areas of the world experiencing depopulation, economic decline, or other phenomena associated with a reversal of development such as deurbanization or deindustrialization.

While our study confirms existing research that shows strong relationships between GDP and lights over time in China at various scales (Zhao, Currit, and Samson, 2011; Liu et al., 2012), we also show that the government's campaigns to reduce regional inequality, particularly in the relatively undeveloped region of Western China, appear to be making inroads that are visible in night lights imagery. China's provinces brightened from 1992 to 2012, while spatial inequality in lights between provinces declined. GDP also has a stronger effect on lights in Western China than in any of the other three economic planning regions. In contrast, over half of Russia's provinces, many of which are less developed and located in the country's periphery, dimmed while spatial inequality in lights between provinces increased. This suggests a negative and spatially unequal pattern of development since the dissolution of the Soviet Union. Additional lights-based research could help confirm whether globally, regional development is becoming more or less spatially uniform within the world's countries.

As far as we know, this study is the first to specifically use lights to examine development trajectories in Russia during the transition from communism to capitalism. Further study of this tumultuous period for post-Soviet countries is recommended, especially since DMSP-OLS V4 composites conveniently date back to 1992 – just one year after the global collapse of communism. While a model predicting change in lights in areas that confound the typical rural-to-urban development trajectory requires significant refinement, for now, lights can at least illustrate a more complex story of regional development that might be obscured by the more conventionally used national-level measures of population and GDP. As we illustrate with the use of interactions between GDP and regions, lights data also appear promising for identifying regions suffering from corruption, where despite investment of public capital, light-emitting development is lower than predicted. A model that also better predicts decline in lights could be applied to other places experiencing a reversal of development for various reasons, such as economically depressed Detroit or war-torn Syria. Greater research into the causes of changes in lights in rural, remote, distressed, and slowly developing regions is recommended, for these are often the places for which conventional socioeconomic indicators are least available and where lights data could prove most illuminating.

6.8 Figures

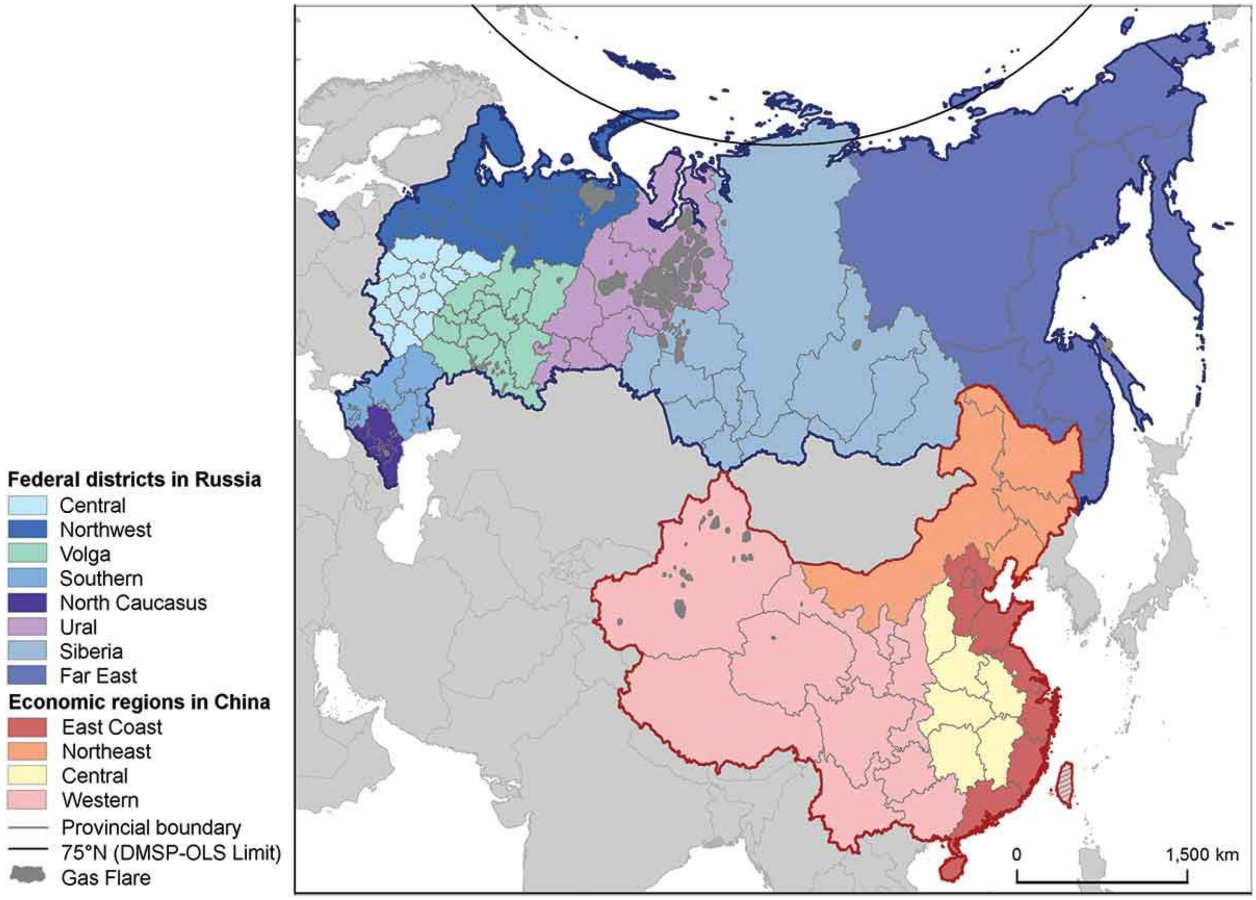

Figure 6-1. Map of study area in Russia and China with sub-national federal districts/regions and provincial-level administrative divisions illustrated. In this map, the region of Northeast China does not include Inner Mongolia, although five of its prefectures are included in the Chinese government's "Revitalize the Northeast" regional development plan.

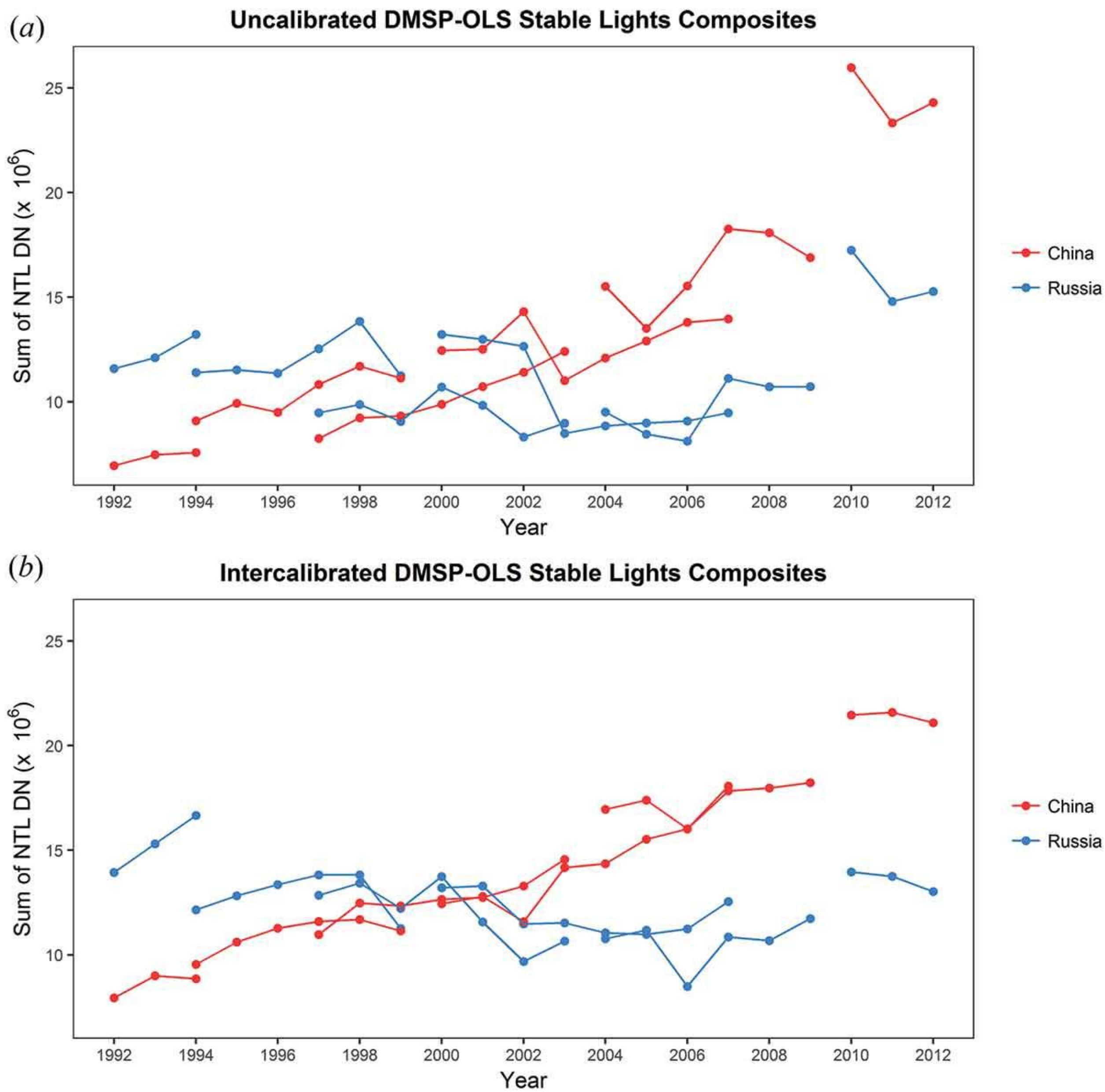

Figure 6-2. Annual total lights for Russia and China before intercalibration **(a)** and after intercalibration **(b)**, following Equation (1), 1992-2012.

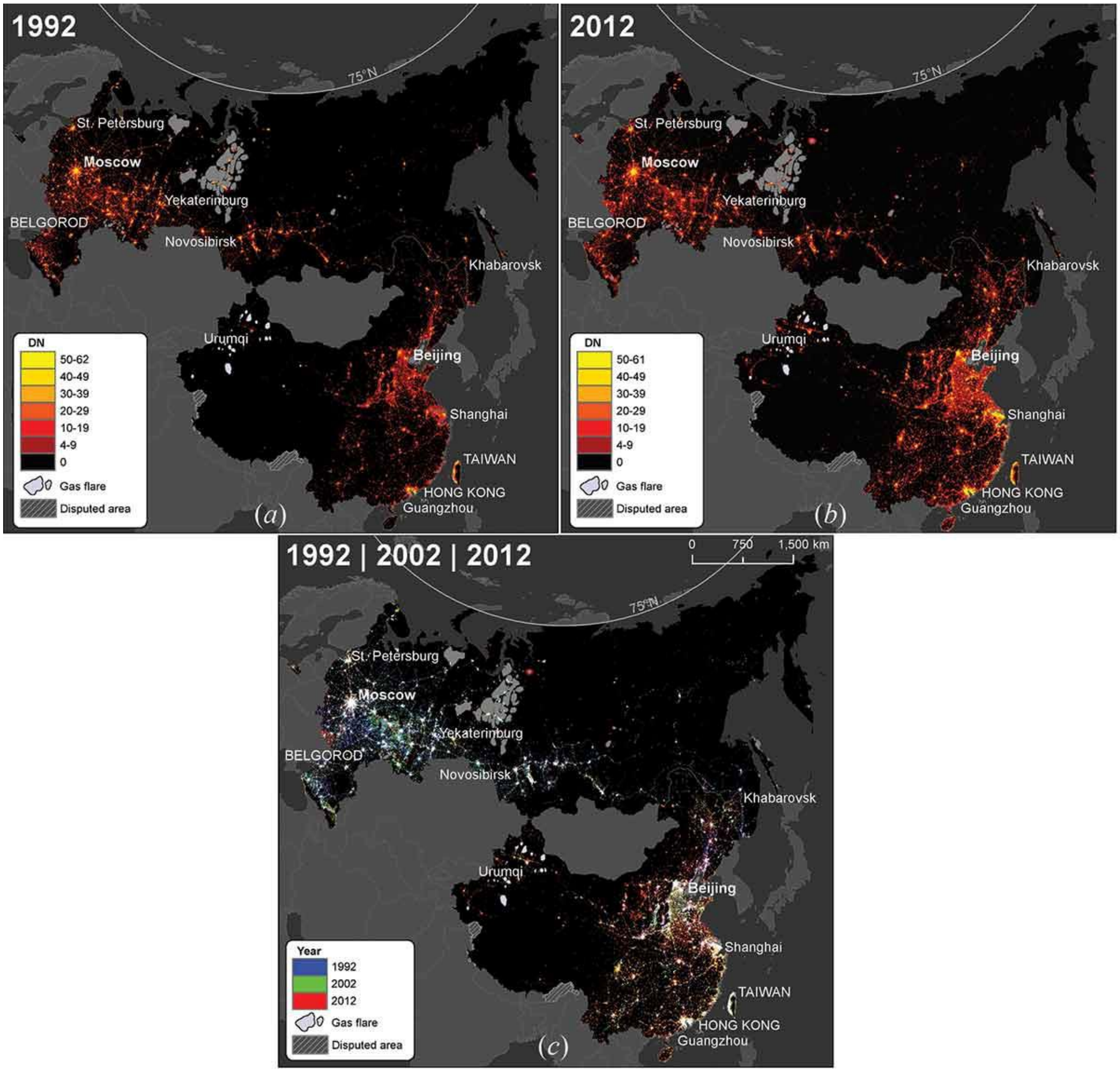

Figure 6-3. (a) Intercalibrated DMSP-OLS F10 1992 image over Russia and China. **(b)** Intercalibrated DMSP-OLS F18 2012 image over Russia and China. **(c)** Tritemporal composite showing F10 1992, F15 2002, and F18 2012 images over Russia and China. Gas flares were removed from all images following the method described in Section 3.4. Projection: Asia North Albers Equal Area Conic.

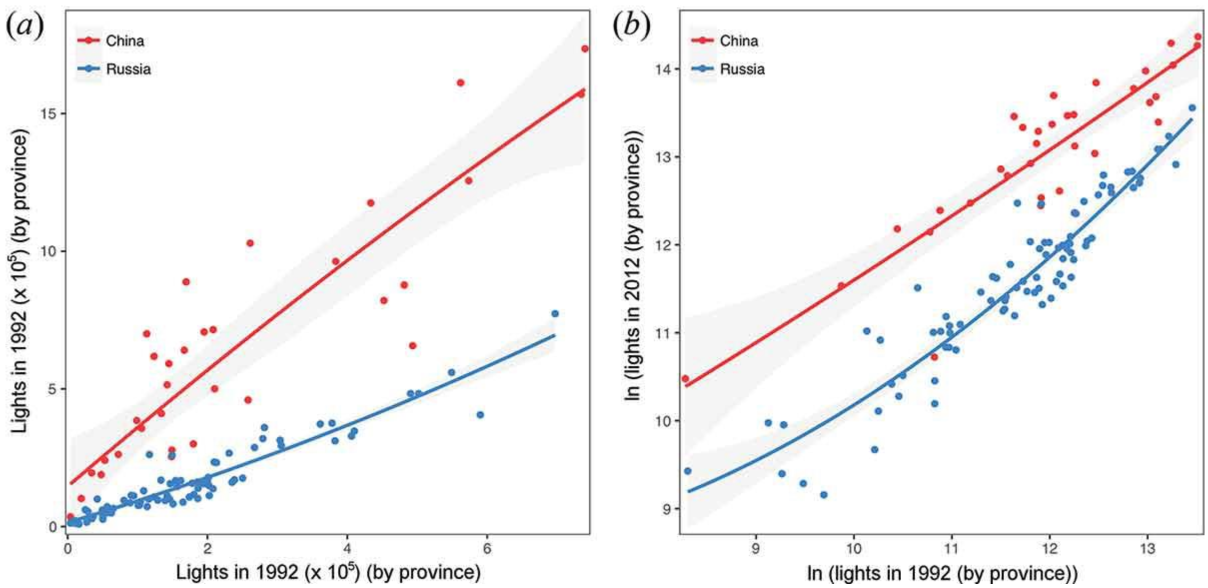

Figure 6-4. Comparison of scatterplots for correlation of (a) unlogged lights in 1992 and 2012 (b) logged lights in 1992 and 2012. Macau is excluded for the purposes of visualization since it emits very few total lights due to its small size. The grey buffer areas represent 95% confidence intervals for the fitted lines.

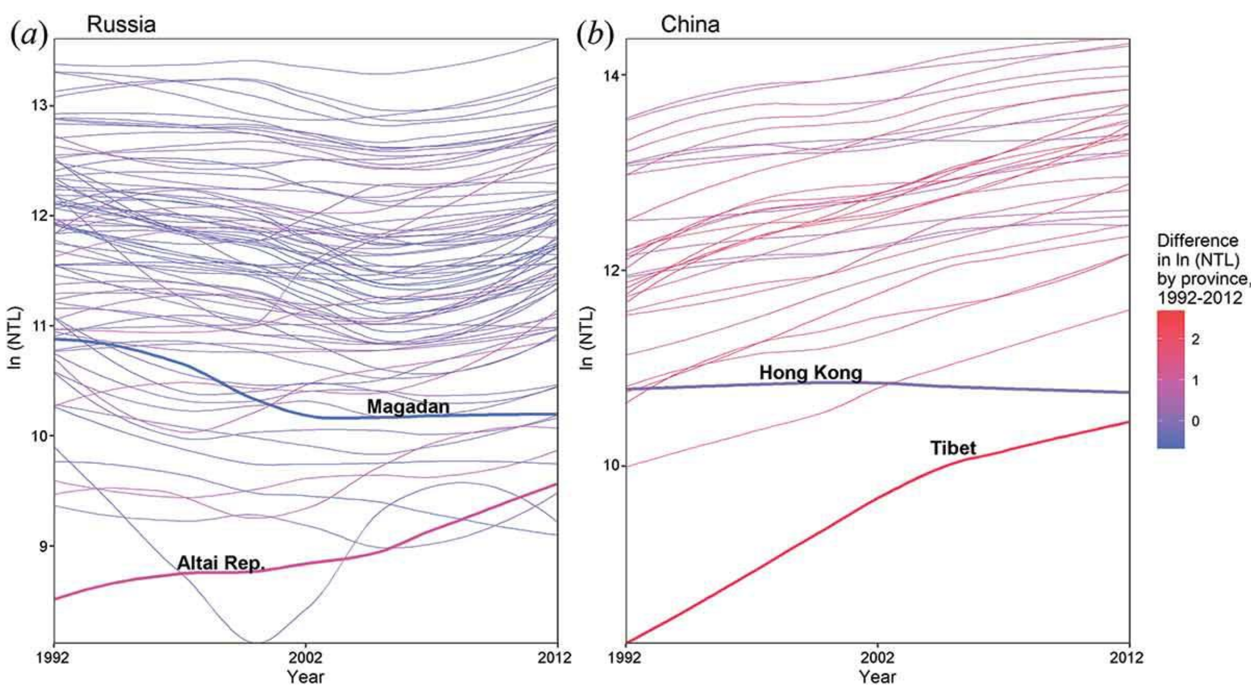

Figure 6-5. Time series of total lights plotted for each province in Russia (a) and China (b). Each time series has been smoothed to highlight general trends. In (a), Altai Republic and Magadan are the Russian provinces with the biggest increase and decrease in log lights between 1992 and 2012, respectively. In (b), Tibet and Hong Kong are the Chinese provinces with the biggest increase and decrease in log lights during this period, respectively.

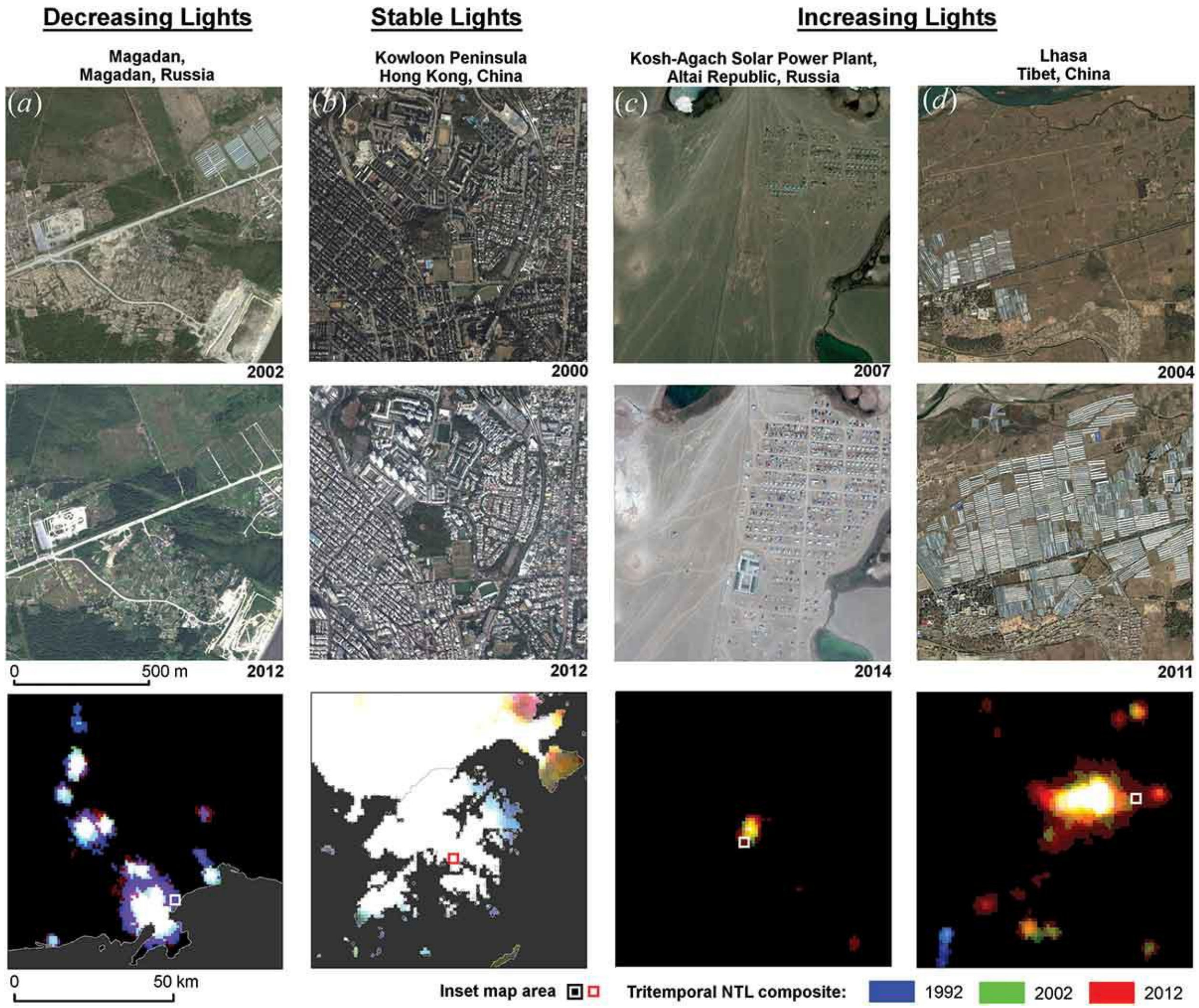

Figure 6-6. Comparison of Google Earth imagery and four key locations within the DMSP-OLS 1992–2002–2012 tritemporal composite. **(a)** Magadan, the province with the largest decrease in lights in Russia; **(b)** the Kowloon Peninsula in Hong Kong, the only province in China whose lights decrease but which is still relatively stable overall; **(c)** the Kosh-Agach Solar Power Plant in Altai, the province with the largest increase in lights in Russia; **(d)** Lhasa, capital of Tibet, the province with the largest increase in lights in China.

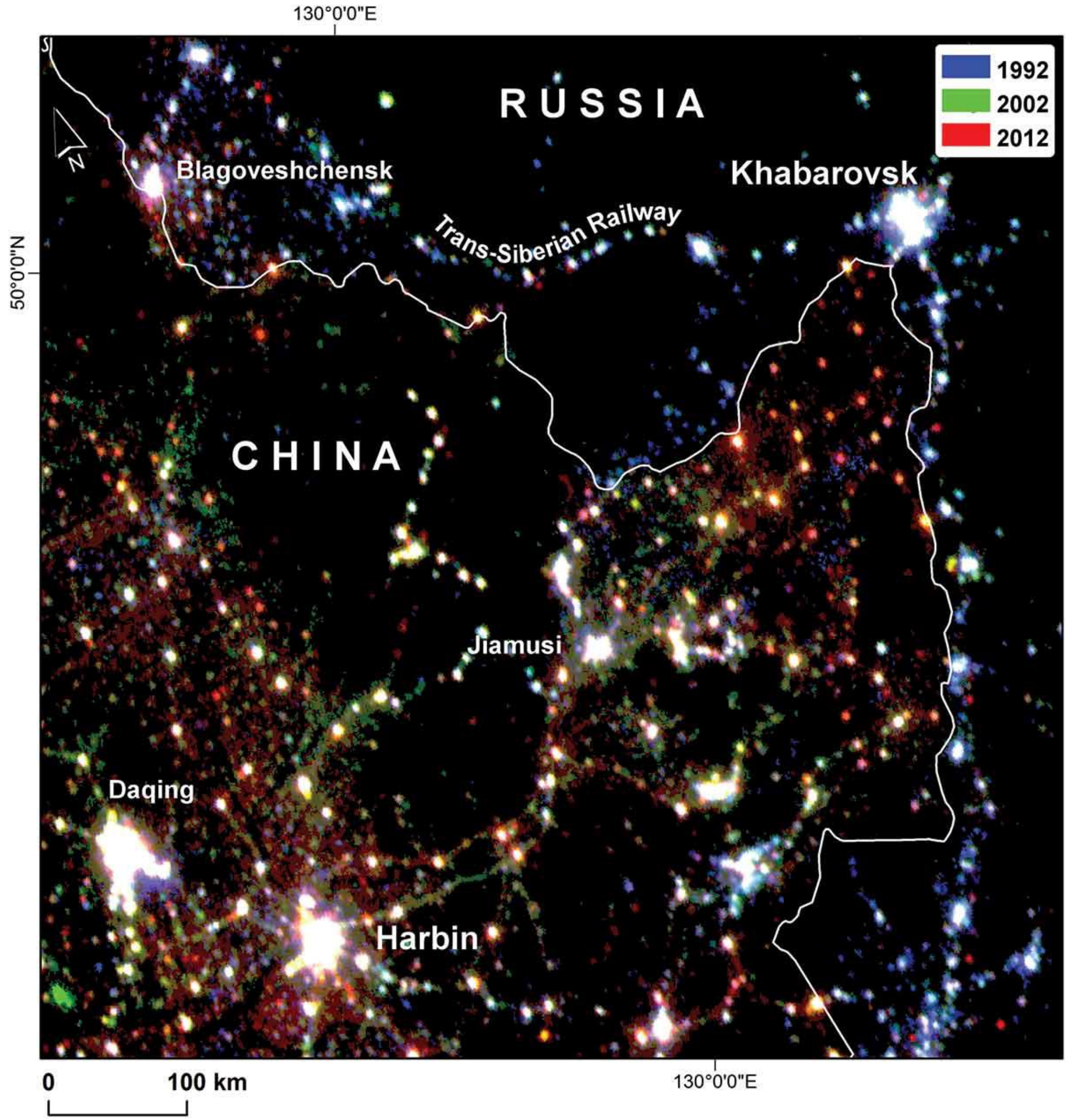

Figure 6-7. In this tritemporal composite, the Russia–China border sharply illustrates the divergence in the two countries' lights from 1992 to 2012, with lights in China generally brightening and lights in Russia generally dimming.

6.10 Tables

	Russia		China	
Attribute	**1992**	**2012**	**1992**	**2012**
Proportion of country with 0 DN (Unlit area) (%)	94.95	92.66	91.09	82.12
4–5 DN (%)	0.09	3.48	3.93	5.94
6–10 DN (%)	1.77	3.35	2.06	6.87
11–20 DN (%)	2.01	0.90	1.14	2.25
21–61[a]/60[b] DN (%)	1.15	0.77	0.94	2.68
62[a]/61[b] DN (%)	0.02	0.05	0.02	0.12
Sum of all lights (DN)	13,933,462	13,021,075	7,942,838	21,089,640
Gini (provincial lights)	0.44	0.45	0.46 (0.44***)	0.40 (0.38***)
	1992 vs. 2012	**1992 vs. 2012**		
Pearson's *r* (lights)	0.95***	0.93*** (0.90***)		
Pearson's *r* (ln lights)	0.94***	0.90*** (0.90***)		
Kendall's rank	0.79***	0.71*** (0.70***)		

[a]Top-code for intercalibrated composite in 1992.
[b]Top-code for intercalibrated composite in 2012.
Number in parentheses is value with Macau excluded.
***$p < .001$.

Table 6-1. Descriptive statistics for lights in Russia and China, 1992 and 2012.

	China	**Russia**	**Russia**	**Russia**	**China**	**Russia**
ln (population)	−0.648***	1.014***	0.772*	0.604	−0.622***	0.566***
	(0.132)	(0.204)	(0.456)	(0.373)	(0.122)	(0.186)
ln (GDP)	0.396***	0.074***	0.094***	0.050**	0.426***	0.214***
	(0.011)	(0.010)	(0.017)	(0.019)	(0.072)	(0.045)
No. of observations	403	1074	268	806	403	1074
Sample	All	All	Pop. increase	Pop. decrease	All	All
			(2000–2012)	(2000–2012)		
R^2	.810	.056	.217	.010	.855	.342
Year fixed effects	No	No	No	No	Yes	Yes

All specifications include province fixed effects. Standard errors are in parentheses.
**p* < .1; ***p* < .05; ****p* < .01.

Table 6-2. Fixed effect estimates regressing lights on population and GDP (constant 2005 US$) for provinces in Russia and China, 2000–2012.

6.11 References

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Chapter 7

The Silk Road goes north: Russia within China's Belt and Road Initiative

7.1 Abstract

Russia, the world's largest country, forms a key part of China's Belt and Road Initiative (BRI). Underfunded infrastructure and vast energy resources into which Western investment is now largely prohibited by US and European Union sanctions also make Russia a logical site for BRI projects. Two are currently under way: the Moscow–Kazan high-speed railway and the Yamal liquefied natural gas plant. These BRI endeavors build on recent Sino-Russia energy cooperation and a longer history of transportation infrastructure partnership in which China is now the investor. However, longstanding mutual suspicions that peaked during the Cold War may challenge implementation.

7.2 Introduction

On 24 July 2016, a Russian KAMAZ truck rolled into Beijing's Tiananmen Square after leaving Moscow's Red Square 16 days earlier. The truck had taken first place in the Silk Way Rally, covering the rugged 10,000 kilometers between the two capitals in under 40 hours (TASS, 2016). 2016 marked the first year that the eight-year-old Silk Way Rally terminated in China. The public spectacle illustrated Russia's deepening, if still fraught, political and economic ties with neighboring China. In large part, the burgeoning bilateral relationship centers on the development of the Silk Road as a revitalized link between the two countries, alongside growing energy cooperation. In Kazakhstan in September 2013, Chinese President Xi Jinping announced the Silk Road Economic Belt strategy, also referred to in English as the "Belt and Road Initiative" (BRI) (*yi dai yi lu* – One Road One Belt in Chinese). This landlocked former Soviet republic sits at the crossroads of China’s designs for a more interconnected Eurasian landmass. BRI is a misnomer, for the strategy actually comprises several networks of roads, railways and pipelines. If built, these will extend China’s transportation infrastructure network westward across land, sea and maybe even ice. China’s National Development and Reform Commission (NDRC) described the transportation network in broad geographical outlines in a document released in March 2015 entitled “Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road.” The Silk Road Economic Belt would consist of a Eurasian Land Bridge and six economic corridors including: China–Mongolia–Russia, China–Central Asia–West Asia, and China–Indochina. The Maritime Silk Road would connect China to Europe via the Indian Ocean and to the South Pacific via the South China Sea (NDRC, 2015). Although not mentioned in the document, another potential maritime passage could go through the Arctic via Russia’s Northern Sea Route, which China sees as an opportunity to diversify its trade routes and develop its north-east region (Hong, 2012). In the year after the project’s launch, Beijing established the US$40 billion Silk Road Fund. Backing the investment vehicle are the China Investment Corporation (the national sovereign wealth fund), the state-owned Export–Import Bank of China, and the China Development Bank Corporation. In addition, the primary task of the Asia Infrastructure Investment Bank (AIIB), which counts Russia as a member, is to provide capital to BRI projects from its US$100 billion in available loans, according to President Xi (Callaghan & Hubbard, 2016). Russia, which critically requires capital infusions in its infrastructure and oil, gas and mining sectors, is increasingly open to Chinese investment as it pivots east. While the rebalancing of Russia’s political and economic ties towards Asia predates the crisis in Ukraine, US and European Union sanctions have made capitalizing on the economy’s eastern redirection more imperative. BRI also dovetails with the efforts of conservatives in Russia in the early 2000s to popularize the idea of

"Eurasia" as a social, political and economic project (Laruelle, 2004) and, more recently, the Kremlin's aspirations to promote a "Greater Asia" rather than a "Greater Europe" (Trenin, 2015). Politically, Moscow champions the Eurasian Economic Union, while it also supports the China-led Shanghai Cooperation Organisation. Economically, the federal government is attempting to develop Eastern Siberia and the Russian Far East and, for that purpose, established the Ministry for the Development of the Russian Far East (Minvostokrazvitiya) in 2012 (Kanaev, 2015). Given these eastern-oriented strategic interests, Russian political officials more often tout the benefits of BRI rather than frame it as a potential Chinese threat to Russian interests. Yet difficulties remain in turning rhetoric into reality. The following section presents a brief history of Sino-Russian trade and transportation links. Then, the primary BRI projects occurring within Russia are reviewed along with key related Russia–China energy agreements. This is followed by a discussion of the risks and outlook for future bilateral cooperation under the BRI initiative.

7.3 A brief history of Chinese-Russian transport links

In January 2016, Russian Foreign Minister Sergei Lavrov proclaimed at a press conference that Sino-Russian relations were the best in history (New China TV, 2016). China is now Russia's largest trading partner (The Observatory of Economic Complexity (OEC), 2016). The improvement of trade and investment relations between Russia and China is notable when compared with relations during the Sino-Soviet split from 1960 to 1989. By 1970, trade volumes were only 3% of their pre-split levels in 1960 (Wilson, 2015). In the three centuries prior to the communist revolutions in each country, however, trade and transport links between the two countries were strong. Russia's expansion into Siberia during the 16th and 17th centuries generated informal trade with China. In 1689, the Treaty of Nerchinsk settled the border between the two countries, and Peter the Great began to organize state-operated caravans that travelled from Moscow to Beijing, a round-trip journey that took two years (Mancall, 1964/2006). Russians exported furs from the Siberian taiga in exchange for Chinese silk, tea and other goods. The 1727 Treaty of Kiakhta formalized the trade, dictating that the caravans, alternately drawn by horses, wagons and oxen (Dudgeon & Lange, 1872), had to go through the Russian border town of Kiakhta, south of Lake Baikal. Yet in the second half of the 19th century, new sea routes (namely from Odessa, then part of the Russian Empire, via the Suez Canal after its opening in 1869 to China) and overland routes like the Trans-Siberian Railway after Beijing's endeavors to stimulate its opening in the early 1900s spelled the end to Kiakhta's role as a trade hub. Mancall (1964/2006, p. 22) writes, "The very condition which made [Kiakhta] so valuable in the eighteenth and early nineteenth centuries – its location on China's Inner Asian frontier – dictated its disappearance in the twentieth century."

Today, in a twist of fate, Asia's interior cities are booming as overland routes fan out from China's inner frontier as a result of Beijing's endeavors to stimulate economic growth in its western regions. Chinese investment is transforming Khorgos, Kazakhstan, into a dry-port that will be connected by rail to the Kazakh port city of Aktau on the Caspian Sea. Similarly, Russian cities near the Chinese border like Blagoveshchensk, Khabarovsk and Vladivostok may benefit from Beijing's desire to promote economic development in its industrial northeast regions. According to NDRC's "Visions and Actions" policy document:

We should give full play to Inner Mongolia's proximity to Mongolia and Russia, improve the railway links connecting Heilongjiang Province with Russia and the regional railway network, strengthen cooperation between China's Heilongjiang, Jilin and Liaoning provinces and Russia's Far East region on sea-land multi-modal transport, and advance the construction of an Eurasian high-speed transport corridor linking Beijing and Moscow with the goal of building key windows opening to the north. (NDRC, 2015)

China's potential construction of railroads in Russia also signals a reversal of the roles the two countries held at the beginning of the 20th century. In 1896, the Qing dynasty allowed Tsar Nicholas II to construct the Chinese Eastern Railway through Manchuria from Chita, near Lake Baikal, to Russia's Pacific port of Vladivostok, cutting approximately 500 miles off an all-Russia route. While China objected to the railroad being constructed as a state enterprise, private industry was allowed to build it. Consequently, the Russo-Asiatic Bank was formed in St Petersburg in 1891 partly for the purpose of building railways in China, including the Chinese Eastern Railway. In a way, the Russo-Asiatic Bank can be seen as a forerunner of infrastructure-focused lending institutions such as the Silk Road Fund and AIIB. But unlike these modern entities, the Russian state ultimately held supervisory power over the railway and had the unusual right to transport Russian military forces along it, while the Russo-Asiatic Bank could build subsidiary railways, telegraph lines and mining explorations (Chia-pin, 1930). In the other direction, Chinese vendors and their wares arrived in St Petersburg (O'Neill, 2014). In short, Imperial Russia had significantly more control over infrastructure construction and operation in Qing China than the Chinese Politburo does over its projects in Russia today. But, perhaps as a warning sign to contemporary China as it makes inroads into Russia, the oft-contested Chinese Eastern Railway played a major role in fomenting the Russo-Japanese War of 1904 and the 1929 Sino-Soviet conflict, when China briefly seized control of the railway from Russia (Wang, 1933). In 1935, the Manchurian government finally bought the railroad from the Soviet Union (Kantorovich, 1935).

Relations between the Soviet Union and China in the years leading up to the Second World War are beyond the scope of this paper. Yet it is important to draw attention to the technical and economic assistance that the Soviets provided to China in the 1950s, for this, too, now seems to be occurring in the reverse direction. This time, while Chinese state-owned newspaper Xinhua (2016) calls new agreements on energy "win–win," the terms do not appear to be in Russia's favor (Chow & Hendrix, 2010). This was, of course, all very different in 1950, when Joseph Stalin agreed to loan China, represented by Mao Zedong and Zhou Enlai, US$300 million. China was to repay the Soviet Union with strategic materials, rubber, and agricultural products, daily goods and hard currency. In exchange for the loan, Stalin also negotiated for a Soviet lease of the importantly ice-free Dalian harbor and the Lushun naval base in Liaoning, alongside additional mining, oil and railroad concessions in Manchuria and Xinjiang (Lüthi, 2010). More than half a century later, all these coastal and border areas form part of China's links with Central Asia, and the Northern Sea Route. From Dalian, the state-owned China Shipping Company sent the first-ever container ship to transit the Russian Arctic shipping passage to its destination in Rotterdam in 2013.

After Stalin's death, Nikita Khrushchev pursued a strategy of more respectful and mutually beneficial relations with China, with cooperation reaching its height between 1953 and 1956. Whereas today it is the Chinese who are providing Russia with designs and know-how for high-speed rail and bridge construction, in the 1950s the Soviets shared their expertise on everything from machine tools to oil extraction to fighter jets with the Chinese (Zhang, Zhang, & Yao, 2006). Thousands of political advisors and technical specialists were sent to China, too (Lüthi, 2010). This economic cooperation, however, was not to last: ideological differences between Khrushchev and Mao, who accused the Soviets of being revisionist and counter-revolutionary, led to the eventual dissolution in 1960 of the Sino-Soviet alliance that had once been declared to enshrine "eternal" "brotherly solidarity" (Li, 2011). The Sino-Soviet split lasted from 1960 until 1989. Tensions along the Amur River border erupted into a seven-month military confrontation in 1969.

Trade and economic assistance, which had formed one of the most important components of the Sino-Soviet alliance, came to a grinding halt. It was not until the 1980s, and particularly when Mikhail Gorbachev took the helm in Moscow, that relations would begin to improve. The long-contested border was settled in 1991 and during the rest of the decade, the countries worked towards improving their relationship. These efforts culminated in the Sino-Russian Treaty on Good Neighborliness, Friendship, and Cooperation in 2001 (Wishnick, 2001). Although the treaty's signing heralded a new era in strategic cooperation between the rekindled countries, three decades of enmity and three centuries of mutual suspicion are not easily erased.

7.4 BRI projects in Russia

In contemporary Russia, road and railroad traffic depends largely on enormous investments made during the Soviet era. During the 1990s, chaotic privatization efforts caused significant drops in state subsidies to public infrastructure. In 2000, the annual rate of gross fixed capital formation was only 49% of the amount in 1993 (Peterson & Bielke, 2002). The oil and gas industries similarly rely on ageing infrastructure, which will require substantial investment in order to push north into the untapped reserves that lie in harsh environments like the Arctic (Solanko, 2011). Russia's expansive but underfunded infrastructure struggles in global rankings: the World Bank (2016) ranks it between Tunisia and Colombia, while China's infrastructure sits between Ireland and Denmark. If Russia's transport network could be improved, China could theoretically have a rapid route to Western Europe with only a handful of border crossings. With the protracted drop in the price of oil and a depreciated ruble, however, Russia lacks funds to improve its roads and railways. A weakened ruble, more so than United States and European Union sanctions, has caused the economic situation in Russia to deteriorate (Dreger, Kholodilin, Ulbricht, & Fidrmuc, 2016).

But sanctions, especially those prohibiting Western investment in Russia's energy sector (except in Sakhalin), have caused Russian oil and gas companies to look east for funding. China, seeking to deploy BRI projects across Eurasia, and Russia, angling for capital, thus make logical partners in upgrading transport and energy infrastructure in the world's largest country. In May 2015, President Vladimir Putin and President Xi Jinping met in Moscow and signed numerous bilateral cooperation agreements. While the 30-year, US$400 billion gas agreement was the most widely reported deal to come out of the meeting, accords on transport infrastructure were also inked. China's NDRC, the Russian Ministry of Transport, Chinese Railways, and Russian Railways signed an agreement on cooperation and financing for a high-speed railway between Moscow and Kazan. An additional trilateral agreement concerned the building of a so-called Northern Rail Corridor from Kuragino, Russia past a coking coal project in Ovoot, Mongolia to the port of Tianjin in China. At a joint press conference with President Xi, Putin remarked, "We think that the Eurasian integration project and the Silk Road Economic Belt project complement each other very harmoniously" (President of Russia, 2015), using an adverb more commonly used in Chinese foreign policy discourse (Zheng & Tok, 2007). So far, significant construction headway has been made on two projects in Russia under the BRI umbrella: the high-speed Moscow–Kazan railway; and the Yamal liquefied natural gas (LNG) facility in the Arctic, along the Northern Sea Route (Figure 7-1). First, the 770-km Moscow–Kazan railway will link the Russian seat of government with Tatarstan's capital, which is the country's eighth-largest city. Eventually, this link could form part of a longer high-speed rail system that connects Beijing to Berlin via Russia. China Railway Group is sinking 400 billion rubles (US$6.1 billion) into the high-speed rail's construction, which will reduce travel time from 14 to 3.5 hours. Chinese and Russian companies have also agreed to cooperate in building high-speed rail carriages in Russia for the route with Chinese expertise. The

Moscow–Kazan project recalls the early years of railway construction in 19th-century Russia, when although the government built and owned some railway lines, a great deal were actually owned by foreign concessionaires and private companies (Ames, 1947). While China will not own the Moscow–Kazan line, the country's involvement is notable given the Kremlin's mobilization of extremist nationalist rhetoric at certain times in support of its own goals (March, 2012). The Moscow–Kazan line arguably forms the highest-profile project in Russia involving Chinese capital and know-how, and future bilateral cooperation on Russian railroads may hinge on its success.

Chinese investment in Russia is also important in the high-cost operating environment of the Arctic, especially for flagship projects like Yamal LNG. Once the project comes online, potentially in 2017 (Paltsev, 2014), LNG from Yamal will be transported via the Northern Sea Route to Asia in summer and Europe in winter. As one of its three major investment projects, the Silk Road Fund has lent US$12.1 billion to the Yamal LNG project in exchange for a 9.9% stake (Russia's Novatek and France's Total are the other consortium partners). Russia has a great deal of expertise in constructing Arctic infrastructure, which the Soviets built with a combination of polar ingenuity and forced labor (Josephson, 2014). In a market economy, however, such projects are much harder to justify given the high costs incurred by remote construction sites, challenging environmental conditions and lack of local labor. Contemporary development of the Russian Arctic largely centers on hydrocarbons, but with sanctions barring this sector from Western investment, Chinese capital may prove crucial in putting Russia's advanced northern knowledge to work in order to develop its Arctic and offshore oil and gas fields. More than finding new markets for Chinese products, BRI is also about connecting China with new resource frontiers like the Yamal Peninsula, which holds 22% of global proven gas reserves (Yamal Oil & Gas, 2016). The Silk Road Fund's loan to Yamal epitomizes how China's investments in Russian transportation infrastructure ultimately may be about accessing new resources rather than accessing markets in Western Europe. Indeed, BRI builds on recent advances in bilateral energy cooperation, from the China Development Bank's US$25 billion loan to Rosneft and Transneft in order to build the Eastern Siberia–Pacific Ocean oil pipeline in exchange for 15 million tons of oil annually for 20 years, to the May 2014 US$400 billion gas deal. Importantly, Yamal LNG, which represents China's first investment in Russia's oil and gas sector, may signal a shift away from these previous agreements, which were made more with China's view of Russia as solely an energy supplier rather than as a place in which to make energy investments. For that reason, China's investment in Yamal more resembles its investments in Central Asia's oil and gas sector (Chow & Hendrix, 2010) than its previous dealings in Russian energy.

Beyond these two concrete investment projects, China is eyeing a number of other possible investment opportunities that would extend its infrastructure into Russia. First, in Primorskiy Krai, which borders China and the Pacific Ocean, Russian political leaders are seeking Chinese investment in two international transport corridors: Primorye-1 and Primorye-2. These corridors would connect the border city of Suifenhe, where the Chinese Eastern Railway once passed, with Primorskiy Krai's seaports like Vladivostok (BRICS, 2016). Suifenhe/Pogranichny, along with other China–Russia border crossings like Heihe/ Blagoveshchensk and Manzhouli/Zabaikalsk, through which the Trans-Siberian Railway passes on its way to Beijing, all have cross-border trade in various goods and services (Holslag, 2010; Ryzhova & Ioffe, 2009) (Figure 7-2). Such ties demonstrate that at least at the scale of cross-border areas, the economic relationship between Russia and China transcends natural resources.

A second project may take place in the capital of the Sakha Republic in north-east Russia. Yakutsk is one of the world's largest cities without a year-round overland connection to a national road or rail system. The construction of a bridge from Yakutsk across the Lena River that could link the city with the rest of Russia's transport network has been deemed one of the most important projects within the Transport Strategy of Russia. In July 2016, President Putin gave his support to a proposal by the region's president to attract Chinese investment to build the bridge (Government of Sakha, 2016). Russian leaders' lobbying of China to build a bridge of such strategic importance suggests that capital investment in infrastructure may overshadow nationalist concerns. This, then, is perhaps the main reason why China's designs for rolling out BRI into Russia have so far provoked more positive than negative responses from its neighbor.

7.5 Barriers to Sino-Russian partnership

Despite Beijing's desire for BRI to promote economic development of Belt and Road countries, "strengthen exchanges and mutual learning between different civilizations, and promote world peace and development" (NDCR, 2015), mutual suspicions and national differences in infrastructure planning and construction may stymie the transcontinental undertaking. First, many Russians remain wary of China. This skepticism is not terribly dissimilar from the suspicions towards China held by people in countries where Maritime Silk Road projects are planned (The Economist, 2015). The term "Yellow Peril," a fear of China overtaking the Russian Far East either demographically or militarily, entered Russian discourse in the 1880s following the influx of Chinese into the region. This paranoia eventually culminated in expulsions and massacres (Siegelbaum, 1978). While such fears are less belligerent in post-Soviet Russia, newspapers and politicians in the Russian Far East have raised old suspicions of a densely populated China expanding north into Russia's sparsely settled eastern frontier (Lukin, 2004). Testifying to the continued lack of concrete cross-border linkages in the region, there is still no bridge spanning the

2000-km stretch of the Amur River that divides Russia and China, along which the Sino-Soviet border conflict flared in 1969. Although the two countries signed an agreement to build a bridge across the river in order to shorten the rail connection between the Kimkano-Sutarsky nickel mine and a steel mill in China, the project remains in limbo (Higgins, 2016). While China finished its 2-km portion in July 2016, Russia has yet to build its side of the bridge even though the local Russian region's governor called it "the continuation of the Silk Road" (5знак, 2016). The half-finished bridge dangling over the Amur illustrates a second issue that could challenge Russia–China BRI projects: Russia's tendency to announce major infrastructural projects but neglect to see them through in a timely fashion, if at all. Such a trend could weaken future Chinese interest in investing in Russian infrastructure.

7.6 The Silk Road's future: between vision and reality

The presidents of Russia and China speak effusively about BRI as if it is a seamless project to integrate Eurasia, but on-the-ground implementation occurs in fits and starts. If and when the Moscow–Kazan railway opens and Yamal begins shipping LNG to China, prospects for continued Sino-Russian cooperation may brighten. BRI represents a significant opportunity on paper for Russia to attract investment in its underfunded infrastructure network, particularly in its northern and eastern regions. The Chinese initiative may also help better knit the vast country together, though the domestic geopolitical implications of foreign-built public infrastructure in an increasingly nationalist Russia remain to be seen. In addition, the environmental ramifications of enormous amounts of steel, concrete and iron being laid across the Russian taiga and of increased exploitation and consumption of newfound oil and gas deposits merit serious consideration.

At the end of the day, all the political speeches and Silk Road rallies in the world cannot make maps of an interconnected Eurasia a reality without willing individuals on the ground. And even when the networked infrastructures, whether they be rails, roads or pipelines, that bind together Russia and China have been erected as was done throughout the first half of the 20th century, this is not a guarantee for a solid relationship. Although Xi expressed to Putin in 2016 that Russia and China should “promote widely the idea of being friends forever’ (Bodeen, 2016), such words ring hollow when the “eternal” “brotherly solidarity” professed in the early days of the Sino-Soviet alliance did not last very long.

7.7 Figures

Figure 7-1. Projects and locations discussed in the paper. Sources: Natural Earth (railroads), OpenStreetMap (additional railroads in Russia and China), and PRIO (oil and gas deposits).

Figure 7-2. Pontoon bridge erected atop the frozen Amur River every winter between Blagoveshchensk, Russia, and Heihe, China. Numerous coaches make the journey in each direction every day, carrying tourists, merchants and goods between the two cities. Source: author, March 2016.

7.8 References

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Conclusion

Frontiers and the *fata morgana* of development

In the late nineteenth century, Frederick Jackson Turner declared, “The frontier has gone” (2010/1920). Four centuries of European and American expansion across the United States had come to an end, and the Wounded Knee Massacre in 1890 brought the Indian Wars to a close. There was no longer a wide availability of arable land in North America that was seemingly up for grabs. After the closure of the western frontier, the forces of settler-colonialism and resource exploitation turned to places like Africa (Barbier, 2010). This global push fueled the development of the modern global economy. Yet these frontiers also eventually came to an end with two world wars and the drawing of borders and decolonization across the lands of former empires.

Now, frontiers are being recast not as free land outside the bounds of state sovereignty, but as known spaces that constitute gaps in the global infrastructure network. The Arctic is one such area, as are the interior hinterlands of Eurasia between China’s booming east coast and European Russia. The creation of new frontiers such as these is more than the result of geophysical shifts like climate change. They also are the result of the scalar politics that emerge out of the interactions of stakeholders as varied as Singaporean government-linked corporations, the Canadian government, and Inuvialuit companies and corporations. Making new frontiers appear to be known yet underinvested entities where nature has been tamed, legal and regulatory frameworks have been determined, and residents are cooperative capitalists, is important for rendering them safe spaces for transportation infrastructure projects.

Compared to the past, national governments and global development agencies are demonstrating stronger recognition of frontiers as lived spaces that are home to indigenous peoples, ethnic minorities, and the descendants of settlers from past periods of exploration and expansion led by outsiders. Recognition of indigenous rights has led to the settlement of land claims between states and indigenous peoples in places like Canada, efforts by countries like Singapore to partner with indigenous peoples in building out the Arctic, and the corporatization of indigenous peoples from Alaska to New Zealand. All of these processes have in no small part helped to enroll indigenous peoples, especially via the creation of an indigenous elite, into the expansion of capital into contemporary frontiers – that is, spaces lacking infrastructure and physical assets that would allow them to be connected into global trade and transportation networks. Despite this mix of both progressive and neoliberal tendencies, old ideas about frontiers sometimes persist: that they are places beyond the remit of government or even contemporary international norms (witness the former president of Iceland's remark that the melting Arctic is like "discovering a new Africa" (Grimsson, 2015)), that their development trajectory is overwhelmingly determined by globally and nationally scaled actors, much to the detriment of the "local," and that the constructive of connective infrastructures in these places like roads, railroads, and ports will deliver higher and irreversible levels of socioeconomic development.

This dissertation has contested three hypotheses about frontier development: first, that the challenges which have prevented the development of places like the Arctic are overwhelmingly environmental; two, that global state and corporate power structures and processes are largely responsible for developing frontiers in a manner that local forces oppose; and three, that bridging global infrastructure gaps will lead to improved development outcomes, with transportation serving as an engine for the growth of peripheral regions. By focusing on the scalar politics shaping the development of remote regions, I have illustrated how local actors sometimes condone and even lobby for the construction of globally articulated infrastructure, even if it may run the risk of hastening the hollowing-out of local economies rather than improving them in the long run. With night light imagery, I have shown how remote sensing can contribute to studies in political and development geography by providing data at scales and timesteps for which no other records may exist. In the case of post-Soviet Russia, night light imagery also illustrates how dimming lights followed directly along the corridors of infrastructure like the Trans-Siberian Railway. This reveals the power of infrastructure to shape the pathways of both growth and decline.

Around the world, sovereign wealth funds, private equity firms, and national governments are seeking to pour money into filling the global infrastructure gap. But for every supposedly world-changing transportation corridor that is built, perhaps nowhere evokes the folly of such dreams more than the Arctic, where sustained development has long proven to be a mirage akin to the *fata morgana* phenomenon observed by sailors on cold days over the frigid ice. Throughout the region's history, its vast white spaces have repeatedly been summoned to evoke ideas of a blank slate. The ice is melting quickly now, and promises are again being made that this time, the Arctic really will be developed. And yet hidden behind the cathedrals of icebergs are rusting oil rigs, abandoned radar stations, and the skeletons of ships that sought a passage to the east. They are reminders of the past and future of frontier development, which is rarely new and rarely forever.

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