Data centres as logistical facilities:
Singapore and the emergence of production topologies

Brett Neilson and Tanya Notley

Brett Neilson is a Professor in the Institute for Culture and Society at Western Sydney University, New South Wales, Australia.
Tanya Notley is a Senior Lecturer in the School of Humanities and Communication Arts at Western Sydney University, New South Wales, Australia, where she is also a member of the Institute for Culture and Society.

ABSTRACT
Data centres mobilise server–client architectures to disperse and draw in labour from across industries and nations. In doing so, they provide an infrastructural fix for capitalist actors seeking to bypass traditional labour actions, by designing logistical routes around which to redirect production processes. In this article, we build on research that investigates the data centre industry in Singapore to consider how these facilities drive processes of global circulation and establish new kinds of labour relations and processes. We point to limits in conceptualising these relations according to dominant models of the supply chain or the production network. We argue that understanding the client footprint enabled by data centres as a form of territory allows us to approach these facilities as political institutions that influence the operations of power across wide geographical vistas.

KEY WORDS
data centres, logistics, labour, territory, Singapore, supply chains, production networks, revenue farms, extraction, social cooperation

From distribution centres to data centres

Recent critical studies have approached logistics as a mode of power active in the production of space and subjectivity. Emphasising the historical origins of logistics in military activities and the late twentieth-century 'logistics revolution' that made distribution a constitutive part of productive processes, this work has mapped the

expanding frontiers of logistics well beyond the spheres of transport and communication. Nonetheless, the iconic materiality of the shipping container has exerted an influence on these studies. In its empirical moments, critical research on logistics has frequently been conducted in sites such as shipping ports or distribution centres. Despite a strong discussion of how data information systems coordinate logistical movements, the focus has been on the storage and transport of goods and not the storage, transmission and processing of data. This article reverses this situation by investigating the role of the data centre as a key infrastructural site of logistical coordination. Drawing on research conducted in Singapore as part of a project examining the relation between data centres, labour and territory in Asia, the aim is to understand how data centres drive contemporary processes of global circulation and create relations between labour forces that might otherwise seem disconnected.

The role of data centres in logistical processes can be illustrated by considering the operations of a company like Walmart. In *The Rule of Logistics*, Jesse LeCavalier (2016) describes how Walmart runs both data centres and distribution centres. The latter are large warehouses where the company receives, stores and dispatches the merchandise sold in its stores. Given the firm's commitment to efficient inventory management and thin operating margins, a large proportion of goods are not deposited in these facilities but directly cross-docked from truck to truck. A system of conveyors, rollers, shelves, struts, sensors and actuators processes the company's merchandise. Voice-directed software instructs workers known as pickers to select, scan, sort and consolidate the goods. As LeCavalier explains, 'the goods in transit through these buildings must be physically moved and are inherently material' but 'Walmart manages merchandise as if it is immaterial – as if it is only information' (157).

Data centres are discrete facilities that house the computing hardware that performs this information management. Highly securitised and located to minimise land and energy costs, these installations 'provide the "intelligence" for the company's logistical operations' (90). Examining Walmart's facility in McDonald County, Missouri, LeCavalier explains that the 'building acts as an information pathway because, even though it houses Walmart's collection of servers, it also stores and transmits the company's constant stream of proprietary data' (93–94). In this sense, the data centre 'is not a building full of computers but rather a computer with architectural qualities' (96).

Numerous retail and logistics companies follow this model of dual ownership of distribution and data centres. However, such a combination of facilities is by no means a standard, for these firms and data centres have many other uses besides the coordination of merchandising activities. Amazon, for instance, maintains both distribution and data centres, but the latter in this case house not only the hardware that stores and processes data for the company's retailing activities and other service platforms but also physical computers and virtualised servers that are hired out by Amazon Web Services – the world's largest cloud provider. Large tech companies like Google and Microsoft also own and operate data centres. These facilities host the machines that run the many service platforms operated by these firms as well as making public cloud services available on a paid subscription basis. By contrast, firms like Equinix run multi-user data centres that not only offer public cloud services but also hire out space in which clients can locate their own equipment to benefit from

economies of scale related to energy costs and other variables, as well as peering arrangements that allow direct exchange of information between machines. Facilities of this latter kind provide the focus of our research in Singapore.

Clients of multi-user data centres range from governments to firms and individuals. These facilities support a wide array of activities, including financial services, enterprise resource planning, telecommunications, social media networking, big data analytics, smart city operations, machine learning and artificial intelligence, just to name some of today's most prominent business propositions. Among these, the coordination of the physical movement of goods and people is only one field of action, even if it makes use of many of the techniques and technologies listed above. Logistics firms, in other words, are a limited subset of data centre clients. Nonetheless, data centres can be characterised as logistical facilities because they enable the coordination of business and governmental activities across space and time. Take finance, which, in its immediate operations, appears more concerned with the manipulation of highly abstract qualities than the circulation of materials or information. Recent technologies of high-frequency trading, however, rely on rapid data transmission to take advantage of arbitrage opportunities between financial markets. Logistical considerations such as the placement of cables, servers and data centres take priority. When trafficked through data centres, finance becomes a logistical game. A similar point can be made about social media networking, smart city initiatives, and many other contemporary business operations. Data centres reckon with the logistical dimensions of a whole range of commercial, governmental and industrial activities.

With these considerations in mind, the present article explores how data centres in Singapore coordinate the work of labour forces across and beyond the South East Asian region. Unlike distribution centres, which are also highly automated environments, these facilities are largely emptied of human workers. The labour forces that interact with (and are in many cases controlled by) the computers housed in data centres are rather located on the client end of these installations. In the case of Singapore, which has become a data centre hub that hosts approximately 50% of the servers in South East Asia (BroadGroup, 2016), these labour forces are distributed across an array of national spaces. How do data centre operations generate economic territories, and what are the significance of these spatial and technical arrangements for capital's interactions with regimes of labour and life across regional terrains? This article argues that such interactions cannot be easily conceptualised according to the dominant models of the supply chain or the production network. By paying analytical attention to the forms of political power produced and sustained by data centre operations, we seek to extend the debate concerning the rising importance of logistical power and its implications for labour forces, workers and political struggle.

Singapore as a data centre hub

In his historical account of the continuities between Singapore's colonial past and prosperous present, Carl A. Trocki (2005) highlights the relation between opium revenue farming and the emergence of capitalist enterprises in South East Asia. Although Thomas Stamford Raffles claimed that the establishment of Singapore as a British colony on behalf of the East India Company in 1819 offered a *tabula rasa* on which to

experiment with free trade, large 'prefabricated components of Indian Ocean *entrepôt* culture already existed and were ready to slide into place when Raffles cut the ribbon' (70). Precisely because Singapore was a free port where duties could not be imposed, the colonial administration came to rely on revenue farms to support its financial operations. Prevalent throughout South East Asia, this system involved colonial governments delegating or 'farming' out the right to collect tax to a private entity. Run by Chinese business elites, revenue farms also maintained private security forces and through auctions and monthly rent payments, acquired monopoly rights over the distribution and sale of excisable goods. As Trocki (2002:297) explains, there 'were many different types of farms in nineteenth-century South East Asia, including farms for liquor, pork, prostitution, gambling, markets, tolls, capitation taxes and others'. But opium generated the highest level of cash flow, creating large pools of capital that were linked to racialised forms of labour control and commodity production.

In Singapore, where opium farming provided the largest single source of government revenue from about 1824 to 1910, revenue farms were central to the system of colonial extraction. The syndicates that ran these organisations purchased opium on the open market and sold it to Chinese migrant workers known as coolies, who provided labour for the plantations and other businesses that these syndicates ran. Proceeds from sales allowed recapture and recycling of labour costs. Although the colonial government eventually closed the revenue farms, these organisations enabled Singapore's emergence as a regional trade centre. Not only were they a source of capital for other ventures, but they also made the island a crucial labour exchange point. Revenue farms are usually understood as transitional institutions between pre-market Asian mercantile practices and the corporate systems of the twentieth century. But, as Trocki (2002:314) comments, it is necessary to ask 'what elements of these economic structures actually survive in present-day or at least subsequent institutional structures'. Logistically speaking, there are affinities between revenue farms and Singapore's present-day data centres, at least insofar as the control of a key commodity and the establishment of regional labour networks are concerned. However, understanding how Singapore has become a data centre hub also means exploring the infrastructural conditions and present policy settings that have facilitated the industry's expansion.

An important factor leading to the expansion of the data centre industry in Singapore is the presence of undersea cable landings. In 1871, Singapore was connected to London (via Madras) and Hong Kong by telegraph cables, laid by the British Indian Submarine Extension Company and the China Submarine Telegraph Company respectively. Part of what Nicole Starosielski (2015:31) calls 'copper cable colonialism', telegraph cables augmented colonial state formation and the centralisation of imperial command. This recasting of state and imperial power not only altered the institutional structures of colonialism but also established routes of infrastructural connection with path dependence effects. Telegraph lines followed existing trade routes and set paths for future cable rollouts, including the coaxial cable that dominated in the Cold War period and the fibre optic cable that carries most of today's digital messages. Telegraphy also introduced new ways of doing business. Prior to its arrival most transactions required in-person negotiations. Following the telegraph these acts were depersonalised since buying and selling could be carried out anonymously and *en masse* (Carey, 2009).

Today Singapore hosts three clusters of fibre optic cable landings: Changi North, Tanah Merah and Tuas. Singtel, a public listed company (through Temasek Holdings) with majority ownership by the Singapore government, listed in 2015 that it part owned 33 cables, including 11 of the 18 cables that land in Singapore.[1] In this way, the Singapore government plays a role in building and maintaining the undersea cables that support the island's digital economy. Having so many cables land in Singapore (more than any other country in South East Asia), means that the country's data industries have a distinct advantage in terms of current and future capacity to move and receive data to and from the rest of the world. As Starosielski (2015:1) writes, 'Cables drive international business: they facilitate the expansion of multinational corporations, enable the outsourcing of operations, and transmit the high-speed financial transactions that connect the world's economies'.

Singapore's emergence as a data centre hub also needs to be understood in the context of its post-independence development. With separation from Malaysia in 1965, a focus on building an industrial base allowed Singapore to free itself from its dependence on its hinterland, evident in its role as an exporter of rubber and tin produced in Malaysia and Indonesia. The unbroken rule of the People's Action Party (PAP) was established on 'its ability to use the economy as a vehicle to gain a much higher level of control over the state and society' (Trocki, 2005:162). By making an alliance with international capital, the PAP boosted direct foreign investment and eliminated the need to share power with local capitalists. It also influenced how foreign capital was invested, directing funds towards manufacturing in the first instance and then towards oil industries in the 1970s. A focus on the technology sector emerged in the mid-1980s. The Intelligent Island plan of 1992 fast tracked the building of a high-speed fibre optic network on which future technology and data industries could rest. Liberalisation of the financial and telecommunications sectors followed, reaching a peak after the 1997 Asian financial crisis. However, Singapore's government-linked corporations (GLCs) remained an important part of the economy, reinforcing the tight relations between the country's business elites and the ruling party.

Current efforts aim to create a regional industry hub focused on extracting value from the creation, processing, movement and storage of data. Singapore has advanced data infrastructure, attractive tax rates, flexible labour laws (for skilled migrants), start-up and lucrative R and D incentives have allowed the data industries to flourish. There are 70 to 75 very large data centres in the country: these are estimated to constitute about 50% of South East Asia's data centre capacity (BroadGroup, 2016). Inside these data centres the world's largest cloud service operators keep and run their servers including Amazon Web Services (AWS), Alibaba, Microsoft Azure, Digital Ocean, Google, GoDaddy and Linode. Many of the world's largest global technology companies and platforms have a regional headquarters in Singapore including Twitter, Microsoft, LinkedIn, Microsoft, Apple and Hewlett Packard, as do regional leaders like

1 This information derives from the following map created by Singtel in 2015: http://info.singtel.com/coverage/googlemaps/. Accessed 19 January 2019. Since this time, Singtel has become co-owner of at least two additional cables (Indigogo and Se-Me-WE-5). We can thus conclude that Singtel is currently part owner of 35 cables, including 13 of the 20 that land in Singapore.

Garena, Grab, Lazada and Razer. In 2018, Facebook, which at this time had its regional headquarters and 1,000 employees located in Singapore, announced it would build its first data centre in the country: an eleven-storey 170,000-square-meter building (Cheok, 2018). Terence Lee (2016) argues that these global tech companies threaten to displace Singapore's GLCs as they can offer services in areas such as retail, transport and logistics where the GLCs have traditionally dominated. But the government also has a stake in assuring the efficiency and competitiveness of the data industries. Temasek Holdings, the government's investment arm, has close to one quarter (23%) of its total investment in the telecommunications, media and technology sector. In the future, it plans to move into artificial intelligence and biotechnology (Temasek, 2017): two fronts of technological expansion that require storage and processing of large amounts of data.

Ironically, the proliferation of data centres in Singapore has produced geographical and socio-economic combinations similar to those that gave birth to its nineteenth-century economy. While the country has always been a logistical switch point and has since the 1980s tried to position itself as an intermediary with expanding businesses in China, the initial approach of the post-independence era emphasised the establishment of an industrial base that would allow the fledging nation to stand free from regional trading networks based on the production and export of goods such as rubber. But the fact that data centres in Singapore serve clients and labour forces across South East Asia means that the island remains a point of regional commodity and labour exchange. What is transacted these days is not only physical goods or bodies but also data that travel at fast speed across national borders. Data farming, to recall an industry term that describes the production, collection and manipulation of data to generate valuable information, has replaced revenue farming as Singapore's main front of extractive capitalism, although the government still 'farms out' business by exercising considerable control over tenders and setting the rules of play for corporate activities. Yet, to understand the relevance of the contemporary data industries from a logistical point of view, it is necessary to stress the discontinuities as well as the continuities with the extractive activities of the colonial past.

The fungibility of territory

The server–client relationship underlies the network architectures established between data centres and their remote users. In a server–client architecture, all computers connected to a network are either servers or clients. The former runs programs or applications that share their resources with clients. The latter do not share resources but request content or service functions from servers. Because data centres concentrate servers under one roof, and allow the establishment of peering connections between servers, they become powerful sites of content storage and service delivery. Clients are distributed around these facilities, although not necessarily in spatial proximity. Data centres store, process and transmit data from clients spread across diverse spaces and scales and this enables them (or in the case of multi-user installations, the companies that place servers in them) to engage in economies of extraction that aggregate, analyse and sell such data. In the case of data centres quartered in Singapore, clients are predominantly interested in the location of Singapore as an efficient and secure

'gateway' to data sources and digital services operating within the South East Asian region (BroadGroup, 2016). The presence of a company like Telin (Telkom Indonesia), which runs three data centres in Singapore under a local subsidiary, means that much of the data generated by the firm's clients is stored and routed through facilities in Singapore. Not only do Telin's Singapore data centres offer a launch pad for companies seeking to market digital products and services to the expanding ranks of Internet users in Indonesia but they also provide service capacities for Indonesian companies and institutions that connect to Telin's national ICT networks. In this way, data centres generate a client footprint, or territory, which follows patterns of networked distribution and cuts across the exclusivity and contiguity of state territories. Yet because data centres obscure relations between clients and can only pass information through the mediation of servers, such patterns of territorial networking remain invisible to all but the logistical gaze.

Data centres clearly market their territorial reach to prospective clients, giving territory a fungible quality – by which we mean that the conceptualisation of territory by data centre operators and users is characterised as much by openness and receptivity to patterns of economic exchange as it is to the political sovereignty of any particular state. Telin Singapore (2017), for instance, seeks to attract business by highlighting its extensive network across the Indonesian archipelago. Yet, given the centrality of digital networking to contemporary forms of governance and rule, the commercial imperative of providing territorial reach to data centre clients also has wider political implications. To understand the client footprint of data centres as a form of territory is to treat these facilities not only as digital infrastructures but also as political institutions that influence how power is wielded across wide geographical vistas. This approach is consistent with critical work that argues that infrastructures 'exist as forms separate from their purely technical functioning' and show 'how the political can be constituted by different means' (Larkin, 2013:329). Keller Easterling (2014) introduces the term 'extrastatecraft' to describe the making of polity through infrastructural and technical systems that operate in parallel, rivalry or partnership with the state. Saskia Sassen (2018:7) discusses how 'operational spaces' that 'include networked digital structures' integrate 'only parts of national spaces' and 'cross multiple interstate borders with great ease'. Noting how such networked structures cannot 'survive without some very material infrastructures, and, often massive conglomerations of buildings', she describes them as '*situated* territorial spaces' or 'new cross-border geographies of centrality'. Although Sassen does not deal directly with data centres, her understanding of these 'largely extractive and infrastructural spaces' (8) registers the way in which data centres produce 'bordering dynamics' that are 'partly formalised, partly emergent, and partly not necessarily meant to be formalised nor to be particularly visible' (7). The capacity of data centres to generate operational spaces that function within but also partly beyond existing law and jurisdictional relations is an important territorial feature of their client footprints.

These complex territorial dynamics do not mean that data centres are generic spaces whose geographical location is inconsequential. Although they may have weak social, as opposed to infrastructural, ties to the urban or national contexts in which they exist, these facilities tend to cluster in formally constituted territories that offer a safe harbour for data storage and favourable business environments. Singapore attracts

data centres not only because of its advanced digital infrastructures but also because of its geographical location, skilled workforces, access to reliable supplies of electricity and water, regulatory environment and the political stability offered by the continuous PAP rule. But this pre-eminence is under threat as the industry grows in neighbouring countries such as Thailand, Vietnam and Malaysia. In the case of the latter, an explicit attempt is being made to piggyback on Singapore's industry position by establishing a data centre park at Sedenak in the country's southern Iskandar province (Sedenak Iskandar Data Hub, 2018). Able to offer cheaper prices for labour, electricity, land and water with very little attenuation in network speed in comparison to Singapore, such initiatives could potentially unsettle Singapore's market dominance. Nation-states also legislate data sovereignty measures that require certain types of data, for example, citizens' health data, to be stored on national territory. Arguably as much of a trade as a security measure (Selby, 2017), given that security in cloud computing involves mirroring and distribution of information, such 'data nationalism' (Chander & Le, 2015) limits the tendency for companies and institutions based in surrounding countries to store data in hubs like Singapore. The relation of data centres to territory is thus complex and crosshatched: on one hand, they establish their own discontinuous and distributed territories; on the other, they remain subject to standard geopolitical, trade and territorial arrangements.

How are we to understand the importance of these territorial networks for work organisation and globalisation? A first step means expanding our understanding of work beyond paid labour, although this certainly remains a consideration when firms outsource their information technology needs to external data centre providers that promise to provide secure data storage and processing on terms more economically favourable than can be organised locally. In this case, workforces that use digital equipment, whether under direct employment arrangements or under various kinds of indirect, labour hire or piecework arrangements, occupy the client end of network architectures that provide infrastructures, platforms or software as a service. Under these conditions, workforces in different nation-states or under different labour regimes might share resources provided from the same data centre or even the same server, as much as the latter is possible to identify in a computing environment where all machines have been virtualised. For instance, a directly employed but precarious data entry workforce in Indonesia might upload data to be stored in the same Singapore data centre that serves a ride share platform for gig economy workers in the Philippines. This is a hypothetical example, as the server–client architecture that pertains in data centres does not reveal such connections in an evidentiary way. But the plausibility of such arrangements raises the question of how relations between such workforces are to be understood and theorised.

To this, we must add another question about the role of unpaid workforces. Consider the new ranks of Internet users in Indonesia that digital service providers attempt to reach by placing their servers in Telin's Singapore data centres. Like their counterparts in other parts of the world, many of these users sign up to digital services that generate value by aggregating, analysing and selling on data produced by users, whether from Internet searches, social media use or other activities such as news browsing and online shopping. Data centres are essential to this extractive economy

because they provide the infrastructural base that allows aggregation, analysis and selling on of data to take place. That user activity creates data that enable extraction and value generation suggests that this activity should be conceptualised as labour. This does not mean that the extraction implicit in contemporary data economies is equivalent to the extraction performed on the colonial revenue farm or the 'extraction of surplus labour' inherent in classical wage exploitation as conceived by Marx (1977:141). What distinguishes the labour of the data generation from that accomplished on the revenue farm or under the wage contract is the way it mobilises social cooperation as a productive force.

In the case of the revenue farm, relations of debt and addiction tie workers to syndicates that become important vehicles for commodity production and capital accumulation. As in the relation of 'formal subsumption' described by Marx (1977:1019), previously existing productive processes are appropriated by capital and synchronised with dynamics of valorisation from an external position. Under the wage contract, by contrast, capital directly organises social cooperation within the spatial and temporal parameters of the working day. Marx (1024) characterises this situation as 'real subsumption', by which he means that the 'entire development of the productive forces of *socialised labour* . . . takes the form of the *productive power of capital*'. The extraction of value from data generated by users' digital activity extends this logic at the same time as it explodes its spatial and temporal continuity. Social cooperation performed and organised through online participation produces data that are then aggregated, analysed and sold to create value. The moment of extraction applies to neither residual productive activities, such as the cultivation of pepper and gambier that took place on Singapore's revenue farms, nor those organised directly by capital, such as those that occur in the industrial factory. Instead, capital draws externally upon emergent forms of digital sociality, with which users engage for purposes such as consumption, work, play and communication. To understand this engagement as labour is to emphasise the subjective element of this sociality. From this flows a raft of questions, including the critical issues of how subjects who perform such labour make a living or fit into patterns of class identification and struggle (Huws, 2014:173–81). For now, we want to emphasise how the labour of data generation extends across and increasingly defines the contours and qualities of social life rather than being confined to the workplace or tethered by relations of dependence and indenture. Recognition of this subjective condition is no longer confined to advocates of the 'social factory' thesis (Tronti, 1966; Terranova, 2000). An understanding of data as labour has also gained traction among proponents of so-called radical markets (Posner & Weyl, 2018) who argue that payment of subjects who produce data would contribute to technological development and economic growth.

In any case, an understanding of data supply as labour thickens and complicates arguments about the relevance of the territorial networks generated by data centres for work organisation. As compared to a view that accounts only for directly or indirectly employed workers, this perspective integrates an awareness of the business models of digital providers that generate profit by extracting data from users and selling them or using information derived from their analysis to design services that can then be sold or rented. Such an analysis needs to account for the likelihood that tech firms like

Google and Facebook will move away from advertising-based revenue models towards the marketing of services that deploy artificial intelligence and machine learning (Morosov, 2018). But the point remains the same. Data centres mobilise server–client architectures to disperse and draw in the labour of many diverse and heterogeneously located subjects, spanning different kinds and experiences of labour. Although these subjects may work in different sectors, enterprises or occupations, be paid or unpaid, employed or unemployed, or occupy positions in discrete supply chains, they are placed in infrastructural relation to each other by virtue of their connections, known or unknown, to data centres. How are we to conceive of this relation and the diagram of power it establishes in the context of network topologies, jurisdictional boundaries and existing means of conceptualising the relation between different kinds of working subjects and industrial units? The next section of this article takes up this question by assessing the logistical organisation of labour accomplished by data centres in the light of current conceptions of supply chains and production networks.

Production topologies

In Singapore, revenue farms provided the financial and logistical backbone to the economic system of colonial extraction for more than 100 years. Since the free movement of goods through the ports were so critical to the global success of the colonial administration, duties could not be imposed as a key way to extract value and revenue. Thus, the colonial administration developed and relied on revenue farms to finance its operations. By benefiting from revenue farms, at a distance and without direct involvement, the colonial administration was able to benefit from labour, industries and practices that they otherwise could not have accessed, whether because of a limited physical presence, a lack of other infrastructure in place or because doing so would have been questionable legally or morally. As Lisa Lowe (2015:74) explains, 'ideas of "free trade"' were intrinsic *both* to liberal political and economic freedom in England, *and* to the improvisation of new forms of sovereignty in the empire, as Britain moved away from strict mercantilism to expanded worldwide trade, and from colonial practices of slavery and territorial conquest to new forms of governance linked to the production of value through the movement of goods and people'.

We point to resonances between the way revenue farming established Singapore as a switch point for regional networks of labour and commodity trade and the current role of the country's data centres in organising labour relations and data flows across regional borders. Exploring these affinities does not mean we draw an easy parallel between colonial forms of administration and the governance strategies of Singapore's current ruling party. Nor do we seek to update the trite and misleading media analogy 'data is the new oil' by suggesting that 'data is the new opium'. We recognise the historical, legal and economic differences surrounding the production, circulation and consumption of these two commodities. We also acknowledge that the post-independence governance approach of the PAP has had very different implications for land holding and state monitoring of the Singaporean economy than those that pertained in the colonial era. Under PAP rule, state land ownership increased from around 30% in 1960 (Chan & Shanmugaratnam, 2015) to around 90% in 2017, while the size of the country increased by almost a quarter by filling-in swamps and

expanding the coastline (Subramanian, 2017), At the same time the PAP focused on growing Singapore's two sovereign wealth funds – both of which now consistently rank in the world's 10 wealthiest (Sovereign Wealth Fund Institute, 2018). These changes provided the pre-conditions for the state to orchestrate the shift from manufacturing to oil and then data industries that has characterised Singapore's economic trajectory. Yet, just as Trocki (2008) argues that revenue farms were crucial to establishing national borders and territories in South East Asia, we suggest that data centres play a prominent role in shaping territorial arrangements that influence the current traffic of labour, goods and information in the region and beyond. To understand more fully this intersection between data centres, labour and territory, we need to situate our argument with respect to recent theoretical and empirical accounts of transforming patterns of global production and work organisation.

Over the past decades, there has been a proliferation of chain and network metaphors in studies of globalisation, international political economy, development, business management and labour processes. Ursula Huws (2014:88–89) provides a schematic typology of the three main ways of thinking about relations between firms and workforces in these fields. The chain paradigm focuses on relations between firms involved in the production and distribution of a given product. Developed mainly for understanding the globalisation of manufacturing industries, this approach enables us 'to understand not only the spatial distribution of the tasks that contribute to producing the final product and the value contributed in each step but also the power relationships between the different actors along the chain' (88). The *filière* approach allows visualisation of 'how a product like electricity or water is distributed across a single economy' (89). Less useful for understanding international flows or power relationships, it provides a means for tracking flows within discrete economies and a way of modelling inputs and outputs between sectors. The network paradigm offers the potential to map interactions between actors both within and between economies. According to Huws, it is less effective in accounting for the direction of flows or the drivers of change. Huws suggests that a model that understands economies as composed of modular 'business functions' composed of interchangeable tasks can overcome the weaknesses and strengths of these approaches. Other important recent contributions stress the mobilisation of labour within the constitutive diversity of 'supply chain capitalism', focusing on factors of gender, ethnicity, nationality, religion and citizenship status (Tsing, 2009). The literature on 'global production networks' also points to the role of diversity in production processes, moving beyond state-centric approaches by investigating the 'nexus of interconnected functions and operations through which goods and services are produced, distributed and consumed' (Henderson et al., 2002:445).

All of these approaches have something to contribute to an analysis of how data centres contribute to contemporary extractive economies by linking firms and workforces across diverse territories. But because the concepts of chain, flow and network are metaphors that seek to describe complex material relations, they have limited applicability in studying the different kinds of connectivity enabled by data centres and related infrastructures. Interrogating the global production network paradigm, for instance, Christopher Foster and Mark Graham (2017:76) note that 'the

digital is rarely problematised as a changing, dynamic and active element' but instead 'either treated as a background element or ignored'. Foster and Graham call for an analysis that examines which actors gain from the digital, explore the processes by which digital networks come into being, and emphasise how the digital operates in 'constant interplay between networks and territories' (85). Such an approach clearly needs empirical inputs, for instance as regards the codes, standards and algorithms that mediate action within digitally enabled production networks. For the current study, the question of how data centres create their own territorial networks is paramount. Research on this issue cannot be content with the mobilisation of standard chain, flow or network metaphors. The chain metaphor, for instance, does not register how relations of peering between firms in data centres create new forms of comparative advantage. The flow metaphor cannot account for packet switching technologies that transmit data in bursts (Sprenger, 2015:73–104). And the network metaphor cannot explain how the physical wiring of data centres generates distinct topologies that determine how different clients, users and labour forces interact (or don't) in digitalised production environments.

In this regard, it is important to note that not all data centres (or indeed digital networks) are alike. We have already pointed to the difference between data centres run by single firms for their own operations and multi-user data centres that bring servers utilised by different firms, users and workforces under a single roof. But data centres also have different network configurations, depending on their purposes. With names such as closed-tree, Clos, fat-tree, Dcell, BCube, c-Through, Helois, PortLand and Hedera, these network topologies determine how physical machines are materially connected to each other (directly or via switches) in data centres. Different topologies imply different trade-offs between network qualities such as speed, redundancy, path diversity, energy conservation and scalability. A data centre that attracts business from high-frequency financial traders, for instance, is likely to have a Clos topology, since this architecture reduces buffering and favours low latency transmission that provides information from stock markets with minimal delay. By contrast, a large commercial multi-user centre might prefer a fat-tree topology that modularises the servers used by different firms and connects them to each other via electronic switches that lead to a 'meet-me' (peering) room. When such a centre supplies software, platforms or infrastructure as a service, however, a more flexible architecture that utilises optical switches to reconfigure during runtime is an attractive option (Liu et al., 2013).

The design of network topologies is now a crucial part of the data centre business. Different topologies can be combined in a single data centre, for instance, creating hybrid networks that seek to balance and optimise operations. On top of the physical infrastructure of network topology, a software layer controls the viritualisation process by distributing load and virtual machines across physical machines. With names like Sunbird, Nlyte and Tuangru, data centre infrastructure management software packages bridge information across organisational domains to configure workflows, power use and the like. Technically this means the operations of any single client might be distributed across different physical machines or even across physical machines in different data centres. The possibilities are multiple and, due to processing speeds, highly variable in time. It is also true that network topologies extend outside data

centres into cabling systems and that the various architectures available have their own infrastructural histories; for instance, the widely used Clos topology has its origins in 1950s telephone exchanges. But because virtualisation means that east–west traffic (between servers in the same facility) increasingly outweighs north–south traffic (between servers and clients located outside of data centres), it is important to understand the relevance of data centre topologies for production processes. We need to account for these network architectures if we are to supplement political economic analyses that rest on chain, flow and network metaphors with relevant knowledge concerning the infrastructural conditions that shape relations between firms, workforces and users in digital economies.

We are well aware that the physical production of material commodities continues to expand at the global scale and that digital labour cannot be considered in separation from a wider analysis of changing divisions of labour. However, as we noted earlier in writing about the production of data, information networks have been crucial to the social expansion of labour beyond the factory walls. Informatisation also reorients other modes of production, from peasant economies altered by the introduction of genetically modified crops to manufacturing industries challenged by new fronts of automation based in artificial intelligence and machine learning. Indeed, as a recent International Labour Organization report (Chang, Rynhart & Hunyh, 2016) details, these latter developments are putting manufacturing jobs in South East Asia at risk, marking an end to the trend that moved these jobs to this region across past decades. Artificial intelligence and machine learning also contribute to the service economies that are beginning to eclipse the advertising-based business models of large tech firms. Significantly, these technologies require the storage and processing of large amounts of data in data centres, confirming the centrality of these facilities to contemporary operations of capital. If we understand data supply as labour, however, what this situation confirms is that the real engine of these developments is living knowledge, intelligence and subjectivity. Even though data centres are highly automated environments that employ few workers (usually male managers, technicians and security staff), the flashing lights and buzzing fans inside these installations materially register the presence of distant labour forces, which are connected and organised into patterns of social cooperation by the network topologies we have discussed.

To speak of production topologies is to augment the discussion of production networks with knowledge of the network architectures that structure operations within and between data centres. Celia Lury, Luciana Parisi and Tiziana Terranova (2012:5) have discussed how topology provides a way of describing how 'a distributed, dynamic configuration of practices is organising the forms of social life'. In their conception, topology is 'emergent in the practices of ordering, modelling, networking, and mapping that co-constitute culture, technology and science'. We seek to extend this perspective by bringing a discussion of how data centre networks open to a high degree of variability contribute to relations between firms, users and workforces in contemporary production networks. While the existing literature on global production networks stresses the '*social processes* involved in producing goods and services and reproducing knowledge, capital and labour power' (Henderson et al., 2002:444), it places emphasis on the '"architecture", durability and stability' (453) of network relations as opposed to their variance.

Knowledge of data centre topologies and processes of virtualisation places these relations in a more dynamic context. Doubtless, production still sometimes occurs through linear chains and fixed networks; but without an appreciation of the more complex and distributed production relations introduced by data centre topologies, it will be difficult to identify critical points in production processes where workers might effectively apply their agency. This is because data centres provide an infrastructural fix for capitalist actors to skirt traditional labour actions, by designing logistical routes around which to redirect production processes, for instance, or by furnishing technologies of fault tolerance and mirroring that absorb such disturbances in ways that minimise their effects. Assisting workers to see and understand how data centre production topologies connect them across different countries, employment statuses, and occupational and social identities is a first step to imagining new forms of organisation and solidarity adequate to challenge the extractive operations of contemporary capital.

In terms of the debate on logistics and the forms of power it generates, a focus on data centres and their topologies allows us to intervene in discussions about how logistical power interacts with other forms of power. In particular, the question of how data centres generate networked territories that discontinuously cross state spaces is crucial for assessing how logistical power meets sovereign power and the governmentalisation of power in and beyond the state. We reserve fuller discussion of this matter for another occasion (although see Neilson, 2012; 2018). For now, it is sufficient to note that the position of Singapore as a data centre hub with regional network capabilities provides a strategic focus for research seeking to understand transformations in labour relations and processes at the regional scale. This article has made preparatory steps in that direction. Unpacking the historical, territorial and topological relations that position labour forces in relation to data centres may seem a complicated task, but it remains one worth completing if we are to devise new means of collective action to forge a life beyond capitalism.

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