The Urban Stack
A Topology for Urban Data Infrastructures

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Abstract: In this article, I develop the concept of the "urban stack" to elucidate how urban data infrastructures gain legitimacy and produce value in capitalist cities. Using two case studies, I study how the stack can incorporate both digital and non-digital components into its hierarchical topology. Heterogeneous components are strung together not only through technological means, as might be inferred from the emphasis on digitality in smart city literature, but also through the 'soft infrastructures' of legal designations, franchise agreements, privacy policies, and info-graphics. A topological comparison between the case studies yields three novel insights: first, urban data infrastructures exploit extant infrastructural conditions; second, technical and protocological operations at the control layer can be used to legitimate ontological claims; and third, technology producers employ a selective and asymmetrical display of information at the level of the interface in order to manage mobile urban populations in real-time. From these insights, it is possible to reach a more abstract conclusion: value production for urban data infrastructures hinges on their producers' ability to enroll heterogeneous elements into their stacked configuration and to then use this configuration to control the flow of information.

Keywords: interface; infrastructure; on-demand economy; stack; urban data.

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1. Introduction: Beyond the Urban Interface

Our representational lexicon of the smart city is populated by all sorts of digital, touchscreen interfaces. As a nominal resource to citizens, these interfaces offer visitors "personalized streams of city data are rendered into 'actionable' information" (Mattern 2014). More often than not, however, the information on offer is pre-processed and presented to users as colourful info-visualizations that boast of the efficiency of city services but offer "little understanding of how and where the mediation of urban systems takes place within the city itself" (ibid). As Shannon Mattern argues in her critique of the smart city, if we truly want to learn about the politics of urban data and actually existing smart cities (Shelton et al. 2015), we need first to see these interfaces as the mere surface of vast, digital-material infrastructures that work by rendering the city as data.

Getting at these infrastructures means studying the composition of the operating systems and material supports that lay hidden, beneath and behind the interface: the vertical formation of interdependent layers of hardware and software that are stacked together, materially and protocologically, to produce the digital-material assemblage of the city (McFarlane 2011; Galloway 2004). This is what Mattern terms the "urban stack". Its hardware includes switches, wires, and cables; pipes, telephone poles, and gas lines; the transmitters and receivers of mass communication broadcasts, as well as wi-fi internet connections and 4G cell networks; the dirt, concrete, plastics, rubber, metal, and flesh that are the city's core materials. Its software involves elements of the digital interface – "all those zoomable maps and apps that translate urban data into something useful" (Mattern 2014) – but also other kinds of interfaces that need be neither public nor digital: the paperwork of the police officer, the ticket punch of the train conductor, the analogue clock atop city hall, the route of the postman/woman; the inscription devices that enable or constrain mobility (Peters 2013; Rose-Redwood 2006; Valverde 2011). Taken together, these assemblages of humans and their social practices, objects and their materials, infrastructured technologies and their interfaces, are what make the city an urban space, "not simply a context for the support or appropriation of specific lives," but "the provisionally stitched together, jigged up intersections of bodies and materials upon which things are both moved and caught" (Simone 2011, 356).

This article develops and extends Mattern's concept of the urban stack in order to advance our understanding of how and why the composition of digital urban formations matters. It focuses on two case studies of urban data infrastructures and the composition of their stacked assemblages: a public wi-fi infrastructure currently under construction in New York City, and the worker-facing apps employed in the "on-demand economy". I conclude by arguing that value production in the urban stack hinges on urban technology producers' ability to enrol heterogeneous elements into a hierarchical flow of information and, through this enrolment (Law and Mol 2001), to effect forms of control.

2. The Urban Stack

The concept of "the stack" is borrowed from software production, where it refers to a specific, hierarchical assemblage of hardware, network protocol, and software (Solomon 2013). Theorists of software and power have applied the stack as topology for mapping how digital media relate to and affect the material, cultural, legal, and political worlds in which they are embedded (Bratton 2016; 2014; Solomon 2013; Straube 2016). The stack itself, however, is a somewhat ambiguous analytic object. As Solomon (2013) writes, the stack topology conflates the "operative structure that exists materially within the program code of software systems" with the "class of diagrams used to explain both these operative structures and software systems more generally". Without being able to fully disentangle these two dimensions, the slippage between material structuring and diagrammatics is nonetheless productive; it reflects both the ways in which practitioners conceptualize the integration of software and hardware as well as the topological relationships within their integration. These analyses suggest that, while the stack is a specific type of assemblage, its specificity is revealing for data infrastructures that bridge material-digital divides – exactly what is at stake in the urban stack.

Here I follow Mattern's (2014) more liberal and heuristic use of the stack in order to conceptualize the relationship between data and materiality in the smart city. When applied to urban systems, the stack as a heuristic allows seemingly disparate data infrastructures to be juxtaposed in a meaningful way. More precisely, it can illuminate how data infrastructures enrol and assemble various objects, materials, human practices, technologies, and infrastructures into a looping structure of data flow (Kitchin and Lauriault 2014). Its implicit topological orientation reflects topological spatial thinking, "that some spatial problems depend not on the exact shapes of the objects involved but on the ways that they are put together, on their continuities, and cuts" (Secor 2013, 431). As I argue here, urban data infrastructures gather together digital and non-digital infrastructural components that, in their topological ordering, effect a privatization of material and infrastructural public goods. The protocological control that they perform works to enact a proprietary claim to that data (Thatcher et al. 2016).

Figure 1 shows how smart city practitioners adapt a stack topology from software development and apply it to the smart city imaginary. At the bottom of this diagram are various devices used to collect data about urban populations, spaces, and processes. In the smart city imaginary (Söderström et al. 2014), data collection is accomplished through the use of ubiquitous digital sensing and urban informatics – devices that are imperceptibly embedded within the urban landscape (Shepard 2011). In practice, however, much data collection involves both digital and analog data, as well as a combination of automated and manual collection processes[1].

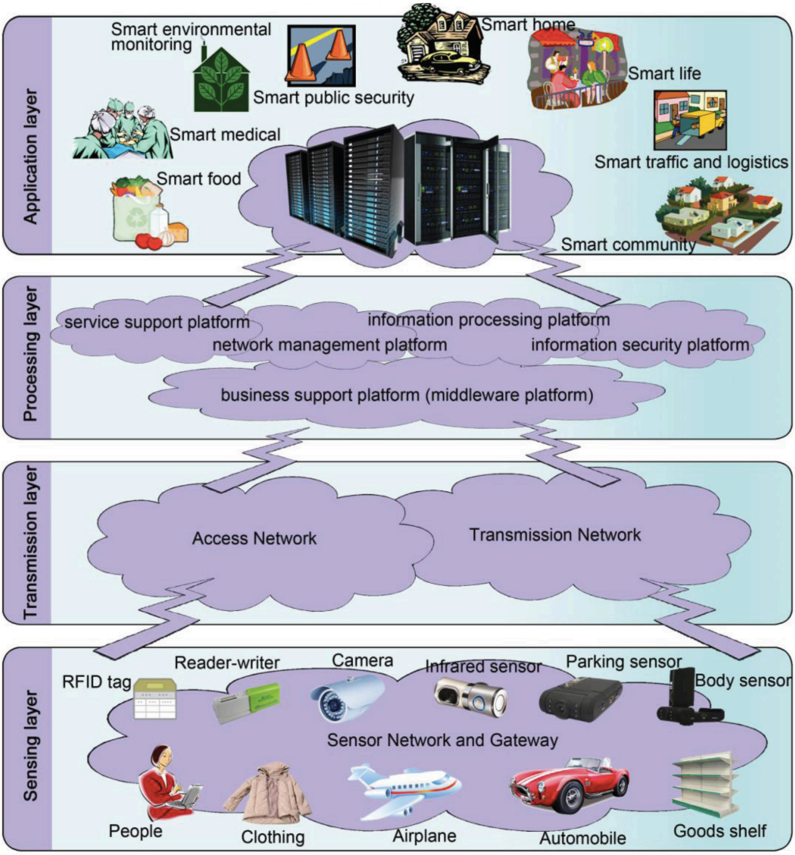

Figure 1 – The urban stack. Source: Liu and Peng 2014.

We can imagine this base layer as a *distributed infrastructure*, tethered together into a coherent program through its stacking. Urban data infrastructures rely on already-existing infrastructural conditions. Data collection and aggregation is highly opportunistic in this sense (Thatcher 2014).

[1] Data about bicycle ridership in New York City, for example, utilize traffic cameras with algorithmic sorting systems to automatically tag bike riders, but for sites where data collection is deemed valuable and such technologies don't yet exist, the Department of Transportation still places a staffer on the corner, manually counting cyclists by hand (cfr. NYC DOT 2016).

Infrastructures erected for one purpose are coopted for another. The same goes for networks and protocols, digital and otherwise. A company doesn't have to reinvent GPS, traffic systems, census tracts, or government bureaucracies in order to implement a new urban technology. But of course, such opportunistic cooptation of existing infrastructures is hardly acknowledged by smart city boosters.

In the middle is the *control layer*[2]. This is the level at which analogue and native-digital data are aggregated together, processed, standardized, and analyzed. It is also at this layer that most proprietary software systems take hold (Kanngieser 2013; Rossiter 2014). Regardless of whether the source is public or private, data at the control level becomes privatized through its analysis. Machine learning techniques employ data to train algorithms for improved accuracy, or to discover non-obvious relationships between disparate phenomena. As the cloud icons at both the Transmission and Processing layers in Figure 1 suggest, control is opaque to non-experts and outsiders. It involves code and interfaces that are not oriented toward end users, making them difficult to represent iconically (Chun 2011; Galloway 2012). Cloud icons stand in for the proprietary analytics that are so central to how value is imagined to be produced in capitalist systems (e.g., Mayer-Schonberger and Kukier 2012) – to how citizens are dispossessed of their data (Thatcher et al. 2016).

At the *interface*, processed data are presented to end-users through platforms that are both informational and informatic[3]. Interfaces are doubly communicative in this sense: they both gather and display information (Halpern et al. 2013). Notable is the highly selective and asymmetrical way that information is presented to different types of users, and the effects that such asymmetries can have. As Galloway (2012, vii) writes, "Interfaces are not simply objects or boundary points" but "autonomous zones of activity […] processes that effect a result of whatever kind". The selectivity by which information is communicated to different users is derived from a set of decisions made by technology producers to achieve desired effects from users' interactions. Such decisions are thus an important source of control in urban space and a key objective amongst urban technology producers who utilize urban data. The uneven distribution of information, which hails different user-types as subjectivities (see Dalton et al. 2016) and augments patterns in urban mobility, is similarly an oft-neglected component of digital urbanism.

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[2] The term "control layer" is borrowed from early descriptions of how GPS technologies work (Kaplan, cited in Kanngieser 2013, 604).

[3] The present discussion is limited to the types of urban interfaces that Mattern (2014) considers as the "points of engagement" through which smart city practitioners imagine citizens will interact with smart city operating systems – screens, dashboards, displays, graphical user interfaces, etc.

3. The City of the Future: Two Case Studies

The hierarchical topology of the urban stack helps to elucidate how value is produced and control exercised through urban data infrastructures. How technology producers construct new stacks, or take advantage of stacked assemblages already in use, affords control over the flow of data and the production of new data ontologies (Kitchin and Lauriault 2014). Through a consideration of two case studies of urban data infrastructures, I illustrate how value is produced and legitimacy ensured by controlling the flow of information. These case studies share a number of similarities in how heterogeneous elements are assembled together to effect a stacked topology: each relies on the affordances of externalized infrastructures; each utilizes technical and protocological operations at the control layer, not only to extract value but also as a form of technological legitimation; and each employs a selective display of information on the urban interface as a way to manage mobile urban populations in real-time (Kanngieser 2013; Levy 2015; Rossiter 2014).

3.1 The Future of Public Spaces

In 2014, New York City Mayor Bill De Blasio announced that a consortium of private companies had won a Request for Proposal (RFP) to implement a vision of what the future of public spaces would look like (NYC.gov 2014b). This vision came in the form of an infrastructure for free public wi-fi called LinkNYC, slated to become the world's fastest municipal wi-fi infrastructure and largest outdoor advertising network (ScreenMedia 2014). Intersection, the for-profit conglomeration of two existing companies – Titan and Control Group, an out-of-home advertising firm and technology design company, respectively, along with consulting by technology giants Qualcomm and Comark (NYC.gov 2014a) – was now licensed to implement, operate, and maintain the LinkNYC infrastructure. The potential advertising revenue generated by LinkNYC, to be split with the City of New York, makes the infrastructure an attractive model for other cities. Much larger players, including Google's Sidewalk Labs, quickly garnered interest in the project (Ingraham 2015), and there is already talk of replicating LinkNYC in other cities (Kinney 2016; Tadena 2016).

LinkNYC utilizes the city's extant payphone infrastructure to create a network of kiosks, called "Links," that provide free wi-fi access with a radius of at least 150 feet (and up to 500), free telephone calls to anywhere in the United States, and, through the touch-screen interface, free access to information about city services. One of LinkNYC's key features is that users receive a unique token that allows them to move within and across network nodes without having to log back into the network each time their device is "handed off," meaning that this meshed coverage has the potential to be extensive in certain areas (I Quant NY 2014). One estimate suggests that LinkNYC's overall coverage will include more than a third of New York City's land area[4]. Construction of the Links began in late December, 2015 in a rush to meet the stipulations of the service agreement (Brandom 2015). Several hundred Links now dot Manhattan, the Bronx, and Queens, with between 7.500 and 10.000 planned for implementation across the five boroughs. Each Link comes equipped with two 55-inch digital, LCD signage displays dedicated to advertising (ScreenMedia 2014). The expected windfall of advertising revenue is slated to pay for the infrastructural overhaul and to yield an approximate $500 million for both the public and private entities involved over the next decade (Department of Information Technology and Telecommunications [DoITT] 2014).

LinkNYC's potential for generating urban data has been celebrated as invaluable for urban planning purposes (Fung 2016; Hotz 2015; NYC.gov 2014b). Despite repeated concerns about privacy infractions on the network (e.g. NYCLU 2016), the promise that LinkNYC will provide real-time data about mobile urban populations to institutional actors – including real estate developers, city planners, app developers, advertisers, metropolitan police, transit authorities, etc. – is an important mechanism for establishing the infrastructure's legitimacy (cfr. Gustin 2016). In the words of Intersection's Chief Strategist Dave Etherington:

> When you think about LinkNYC and the 7.500 or so fairly evenly distributed nodes across the five boroughs, then that does represent a really interesting opportunity to learn about the city, the behaviours of the city, that could lead directly to health benefits, more efficient use of traffic – being able to sense, are trucks idling near these things illegally? Is there congestion? Is there a traffic jam? Is there noise pollution, air pollution? All of these things, by microlocation, could really empower some really interesting insights about the city that will make it a kind of more enjoyable place to live (Behind the Numbers 2016).

To quell lingering privacy concerns, Intersection developed a concise (if still vague) privacy code (NYC.gov 2016) outlining the technical protections in place. Data shared over the networked will be encrypted and automatically anonymized by unique, randomized keys for each MAC address that logs onto the wi-fi network. LinkNYC also promises not to track web browsing histories on devices connected through the wi-fi. However, even if these technological solutions and protections for privacy prove effective, data generation will continue apace. This is because LinkNYC's most valuable data-infrastructural affordance is its ability to simply count people: "We do not collect information about your precise location. However, we know where we provide Wi-fi services, so when you use the Services we can determine your general location" (NYC.gov 2016). By virtue

[4] Manhattan's coverage may be as high as 50% while other areas could be as low as 16% (I Quant NY 2014).

of logging into the LinkNYC wi-fi, users will be counted, in place, in real-time. The system may "combine Technical Information or non-Personally Identifiable Information about your use of the Services with similar information about other users in an aggregate or anonymous manner" in order to "measure or understand the effectiveness of advertising we serve to you and other customers like you, and to deliver relevant advertising to you" (ibid).

There is also the potential for LinkNYC to count people who are not logged onto its wi-fi (cf. Musa and Eriksson 2012). Evidence of this can be gleaned in documentation of the LinkNYC technical capabilities as well as by considering how companies in the Intersection consortium have behaved historically. In 2014, Titan, Intersection's advertising arm, installed Bluetooth low energy (BLE) beacons on New York's payphones, which are capable of counting all devices with wi-fi and Bluetooth connection capabilities within its range. When it was made public that Titan had installed these devices without notifying citizens, the New York City Department of Information Technology and Telecommunications (DoITT) required Titan to remove the beacons (Bernstein and Ryley 2014). This same technology is built into the Link system (Intersection 2016), although representatives from Intersection claim that they have not yet been turned on (Gustin 2016).

The technological capacity to silently count readable devices is not new, nor is it limited to LinkNYC[5]. What is new about the LinkNYC's potential data collection is the granularity and penetration that it achieves. With smart phone penetration reaching 80% of New Yorkers in 2015 and still growing (NYC Dept. of Consumer Affairs 2015), LinkNYC is poised to generate real-time locational and mobility data on a majority of New York's population. The uses towards which this data might be put are, at present, limited to the twinned domains of advertising and urban planning. Where the urban planning uses of data legitimates LinkNYC's silent locational data collection, the advertising revenue generated for the City likewise legitimates the public-private partnership between Google-backed Intersection and the City of New York. The normalized dwindling of public service provision in neoliberal or entrepreneurial cities (Harvey 1989) opens a market-space for private companies to capitalize on infrastructure and to label it "innovation". In Intersection's Chief Strategist Etherington's words:

> The advertising concessions related to this infrastructure are seen as vehicles for innovation and that's really where we're at in our focus from the media side – that,

[5] In 2013, an IT worker discovered that the New York Department of Transportation had been silently scanning drivers' EZ-Pass tags (RFID cards for automatic toll collection), in order "to monitor the flow of New York City traffic [...] scrambl[ing] the serial numbers to anonymize vehicles and their owners." See http://www.popsci.com/article/diy/ezpass-hack-covert-scanning (retrieved April 30, 2016).

with these advertising contracts, we're able to introduce not just increased advertising revenue for cities, but we can bring in new technologies and new innovation (Behind the Numbers 2016).

The desired outcome of LinkNYC is to transform public spaces into sites of real-time data generation that can be capitalized on through advertising sales. The release of this data to urban planning agencies legitimates not only the City's involvement, but also the private company's right to silently collect and analyse urban data without even tacit consent.

3.2 The Future of Work

Recent discussions about the future of work have emphasized the role that app-based platforms will play in making labour economies more flexible (e.g., Hanrahan 2015). This debate is especially important for cities, given the growth and concentration of the service sector as a major local economic industry in urban areas in the U.S. and elsewhere (Lopez-Cermeño 2015), as well as the impact that work platforms have already had on cities (Zumbrun 2016). Prominent examples include informal taxi services Uber and Lyft, and courier services like Caviar and Postmates. These companies profit from the algorithmic management of fleets of independent contractors who, through worker-facing apps loaded onto their mobile smartphones, connect with customers seeking delivery or taxi services. Fleet management apps work as semi-automated systems for labour assignment and oversight (Rosenblat and Stark 2016, 2). They use closely-guarded algorithmic calculations to set prices for both customers and payouts for workers. If described at all, explanations of these algorithmic calculations are cloaked with vague terminology about the distance of a delivery or a taxi fare, or even shifting levels of demand. Neither the customer nor the worker has access to the full information (Kirchner and Mattu 2015).

The term "on-demand economy" describes the experiences of both customers and workers for these platforms. What these companies deliver is quasi-luxury, hyperlocal mobility – the movement of goods (as in the food courier platforms Caviar and PostMates) or people (as in the taxi and black car services Uber and Lyft): door-to-door service, ordered with the push of a button, just-in-time and on-demand (Ruckelshaus 2016). Workers for these companies, designated as independent contractors rather than employees (Scheiber 2015), are enticed with the promise of flexibility – working whenever they choose, deciding whether to accept or deny any job in the form of delivery or ride request. Work, like the service, is available on-demand: workers log on whenever they want and choose which jobs to accept or reject. But labour is also on-demand: workers are not paid without completing an order or a fare, and order allocation is dictated by the same opaque algorithmic calculations that determine the payment for a given job (Rosenblat and Stark 2016)[6].

Despite the promise of flexibility, in practice, on-demand platforms employ numerous disciplining techniques (such as ratings systems and accountability indices) to cajole workers into adhering to some sort of scheduling system or acceptance rate – the same rigid components from which flexible working was meant to depart (cfr. Graboyes 2016). For instance, Caviar, an upscale food delivery service available in fifteen of the country's largest metro areas, sends an automated weekly email to its workers with a breakdown of completed orders and payments[7]. The company recently introduced a new component to this email, an index of workers' scheduling reliability, which calculates the ratio of time spent logged into the app during a scheduled shift. Workers are contractually not obliged to commit to scheduled shifts, but for management, having a schedule helps plan for predicted ebbs and flows in demand. The index impresses upon the worker his or her standing as reliable, despite its contractual irrelevance. Several indicators are excluded from this index that could just as easily reflect a worker's reliability. For example, when understaffed, the company sends out a notice to encourage couriers to sign on; the scheduling reliability index does not account for how often a courier responds to these emergency requests[8]. Nor is there a calculation of what percentage of time a worker sat idle during his or her scheduled shift – logged on, but not receiving orders and thus not getting paid.

What is most striking is the opacity around whether or not this ratio affects one's rankings in the algorithmically-defined queue of couriers used for dispatching orders. As one Caviar courier explained during an interview:

> When I first started working for Caviar, I was told that we weren't obligated to accept orders. It's completely at our discretion when we want to work and what orders we want to accept. That was a big selling point for them looking for couriers […]. Now, they're doing this [scheduling] reliability system […]. It feels like Caviar is trying to guilt trip us for not showing up for our shifts, which are not obligatory, and whether or not we're being penalized for showing up for our shifts is kind of unclear. But whether or not they're penalizing us, it seems like they're asking us to penalize ourselves[9].

Another example is Uber's policies for deactivating drivers. Prior to the

[6] Contrary to this model, some have argued that since Uber and other companies do profit off of drivers even when they are not delivering a passenger, workers should be paid for their time.

[7] My methods for this research include working as a Caviar courier for 12 months; I received these emails while working for Caviar.

[8] A typical notice, which is called "the bat signal" by management, reads "Lunch is busy NOW and we are understaffed! Go online NOW to take full advantage of this lunch bizness, Philly!" (received 5/3/2016).

[9] Interview conducted March 7, 2016.

settlement of a class action lawsuit (Isaac and Scheiber 2016), Uber was opaque about its deactivation policy. Rationales ranged from inactivity (not working for 90 days) to low acceptance rates (the ratio of how many rides a driver accepts to how many requests he or she receives) (Dough 2016). These disciplinary techniques are automated and incorporated into the technological fabric of workers' day-to-day labor practices.

In addition to mechanisms that belie the flexibility of on-demand work, on-demand platforms are also characterized by their highly selective and asymmetrical display of information within the worker interfaces (see also Rosenblat and Stark 2016). Lyft drivers see maps that show them areas where surge pricing (or Prime Time) is in effect. In these areas, passengers are subjected to higher rates due to local distributions of demand (or algorithmically-predicted distributions of demand) at a given time interval (Chen and Sheldon 2015; Kirchner and Mattu 2015; Rosenblat and Stark 2016). Workers argue that dynamic pricing is a fleet management technique used to incentivize drivers to go to busier areas. But since the algorithmic calculations that determine surge pricing are opaque to drivers, as are the number and whereabouts of other drivers on the road at the same time, there is no guarantee that going to a surge zone will mean getting a well-paying job. In another example, the courier apps often obscure the address of a delivery drop-off when the worker is prompted to accept or reject an order. High rise apartments or office buildings can be unattractive to couriers, since payment is calculated based on the ground-distance between the restaurant and the delivery address and not on how much time is spent getting to an apartment or office. Knowing that a drop-off location is on the 25th floor might thus be a disincentive for a courier to accept the job; the company's interest is thus to omit this information until a courier has already accepted the order. Such informational asymmetries give workers just enough information to complete a task, but obscure enough information that the company's interests appear to be in the workers' as well.

4. Topologizing Urban Data Infrastructures

The case studies presented here differ in interesting ways. LinkNYC is a large infrastructural overhaul managed by private firms and marketed as a public good in the form of free wi-fi; apps in the on-demand economy are much more distributed and explicitly focused on extracting value from workers. Despite their differences, the two cases share much in common, and their similarities can be fruitfully highlighted by employing the topology of the urban stack. Using the stack as a heuristic, these cases can be *bent* and *stretched* to facilitate comparison (Secor 2013), which, in turn, can help to expand our understanding of how "actually existing smart city" interventions (Shelton et al. 2015) are legitimized, and how controlling the flow of information can produce capitalist value.

4.1 Distributed Infrastructures

Both case studies rely on a distributed infrastructural base upon which other elements are stacked to create small monopolies of data collection, storage, and analysis. This distributed base externalizes costs and mitigates risk by taking advantage of extant infrastructural conditions. With LinkNYC, there are two ways that extant infrastructure is enrolled into the network. First, LinkNYC exploits the sunk cost telecommunications infrastructure already in place in New York City, constructing its hardwired connections between the Links within the conduits built beneath the surfaces of New York's most densely packed pockets (PlaNYC 2013). Fiber optic connections can be strung through conduits, which can be accessed simply by opening a manhole cover. LinkNYC is being built without having to break ground. Second, LinkNYC relies on the growing penetration of smartphones amongst New Yorkers. Smartphones and other readable devices, such as tablets or laptops, even if not actively connected to the LinkNYC wi-fi networks, serve as de facto sensors for LinkNYC's production of real-time data about urban populations. This data collection is integral to its legitimacy.

In the on-demand economy, the most profound way that companies take advantage of distributed infrastructures hinges on the legal designation of workers as independent contractors rather than workers. The questionability of this designation was recently deferred by the settlement of a class action suit involving Uber workers in Massachusetts and California (Isaac and Scheiber 2016). For on-demand services like Uber, Lyft, or Caviar, this deferment is a boon: not only do the companies remain free from being required to cover employee expenses such as Social Security and workers' compensation, they can continue requiring workers to provide their own means of communication and transportation – typically a smartphone and a bicycle or car. Employees are left to cover the costs of data bills and fuel, as well as for any upkeep and repair to vehicles due to wear and tear incurred while working on the road. Further, companies are legally prohibited from providing tax education to workers, as this would breach the legal distinction between independent contractor and employer (Mishel 2016). On-demand economy companies have proved successful at enrolling workers who are willing to supply their own means of transportation and communication – costs that employees typically do not cover. The infrastructural conditions that facilitate that rapid, on-demand movement of people and things in this sector is thus outsourced to the workers themselves, both in terms of their own bodies and labor (including risk of injury, healthcare coverage, fatigue, etc.) and in terms of their privately owned consumer technologies, which serve as networked infrastructural components[10].

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[10] The outsourcing of labor in the on-demand economy is reminiscent of 19th century telegraph messenger boys, who, as Downey (2003, 134) argues, were both

4.2 Control

Control is exercised in both the LinkNYC and on-demand economy examples through the effects of black-boxed regimes of calculation. In the case of LinkNYC, two functions at the control layer will be key to its success. The first is the hidden protocological activity that randomizes or anonymizes user identification in order to ensure privacy. These protocols transform aggregated user data into a format that can become informationally meaningful while simultaneously providing a technological solution to concerns over privacy. The second function at the control layer involves the dynamic, algorithmic calculation of pricing for advertising that will be based on this information (Behind the Numbers 2016). Once a real-time count of devices is in place, algorithms will not only "allow advertisers to deliver highly targeted content to passers-by, [which] works similarly to ad-targeting algorithms users encounter while surfing the Web" (Campbell 2016), but also to create a dynamic pricing model such that ad space costs more when more people are around to view them (Shpanya 2014). As one online advertising trade magazine explains, the Links' "strategically placed, networked digital signage displays" are situated within "a larger multiscreen ecosystem that effectively amplifies brand messages to create a deeper level of engagement with active consumers […] with highly targeted messages" (ScreenMedia 2014). LinkNYC's real-time data on the ebbs and flows of urban populations will be able to make already-valuable out-of-home advertising space even more profitable by charging advertisers more during periods of high traffic.

With on-demand economy smartphone apps, the control layer is largely hidden from workers, effecting an informational asymmetry that can be leveraged to manage large fleets of workers in real-time (Rosenblat and Stark 2016). Control is manifest in the proprietary algorithms that determine which couriers or drivers should be matched with which deliveries or riders, where, when, and at what price (Chen and Sheldon 2015). The proprietary nature of these algorithms is central to the profitability of companies in the on-demand economy. But it is also important in legitimizing claims that on-demand companies are not service providers, but rather technological platforms that serve merely to connect supply and demand. Such claims are important, since they legitimate the designation of workers as independent contractors, who supply their own modes of transport, communication, health insurance, etc. As one Uber engineer wrote in a widely read forum about Uber on Quora:

> A taxi company contracts drivers, deals with vehicles, pre book rides [sic], etc. Uber deals with building data centres, running real time software services, facilitat-

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"active components" of telegraphy as a technological system and "laboring agents within produced urban spaces".

ing payment and conducting research into the economics of real time transportation automation, among solving all sorts of other interesting technological problems – all things that are not done by a taxi service. It's a totally different operation from what a taxi company or a transportation service does […] Uber is not a taxi company, but a technology company that provides solutions for people's transportation needs [just like] eBay is not a shopping mall, but a technological platform that enable [sic] private sellers to find buyers for what they have to offer (Tal 2015).

Activity at the control layer allows for dynamic pricing models that exploit surges in demand, allocates orders to the lowest-costing courier or driver based on the distance to the customer, and, ultimately, serves as a justification for the companies' designation as technology producers rather than urban transportation or logistics services, which would be regulated more stringently.

4.3 Interface

Finally, the selective display of information at the interface level is key to the functioning of both LinkNYC and on-demand economy companies. On the one hand, the omission of information can be used tactically to realize certain effects. This is clear in the on-demand economy's worker-facing apps. For example, the Caviar Courier app has a sequence through which couriers must step through when accepting, picking up, and delivering an order. Throughout this sequence, certain bits of information are given while others remain omitted. The need-to-know basis of information here is productive: it gives workers just enough information to complete the task at hand, but not enough for them to gain a full understanding of how the system works and thus optimize their output in the form of payments. The same could be said of LinkNYC's interfaces and the "larger multiscreen ecosystem" (ScreenMedia 2014) into which they fit. This ecosystem is both informational and informatic: usage generates data. But these data are systematically excluded and consciously hidden from interface displays (Chun 2011). The doubly-communicative interfaces are designed such that individual users can never access the full scope of information relevant to the landscape in which they're operating, but are expected nonetheless to use the information that they do have to maximize private gain. This reflects Mattern's (2014) point about the trade-offs implicit in the smart city interface; they "suggest that we've traded in our environmental wisdom, political agency and social responsibility for corporately-managed situational *information*, instrumental rationality and personal consumption and convenience. We seem ready to translate *our* messy city into *my* efficient city" (original emphasis).

But if certain information is selectively omitted or excluded, other information is strategically included in order to achieve certain effects. In the on-demand economy's worker-facing apps, information about worker reliability and productivity is tactically deployed in an effort to discipline workers into conforming to the rigid elements of supposedly flexible work.

Indices and info-graphics about the worker's performance are described by workers as "mind games" or "guilt trips". These techniques are common to the integration of digital surveillance mechanisms within the workplace (Kanngieser 2013; Levy 2015; Rossiter 2015). With LinkNYC, the potential for advertising displays to direct the attention of passers-by to local consumer points of interest is a subtler form of managing mobility. Hyperlocal, modular ad displays can be designed to steer potential customers to local restaurants, cafes, shopping centres, department stores, with the promise of discounts or coupons: "You can expect the [LinkNYC] kiosks to start telling you there's a table for two open at the French bistro down the street, for instance. Or that the subway station nearest you is offering limited service due to repairs" (Fung 2016). This kind of hyperlocal notification allows those with access to the network's counting capabilities to produce market value through the targeted modulation and steering of mobile urban populations.

5. Conclusion

The urban stack is a productive heuristic with which we might better understand how urban data can be made a valuable commodity. Using the two case studies of LinkNYC as a data-generative municipal wi-fi infrastructure and the worker-facing apps of the on-demand economy, I showed how the stack can incorporate both digital and non-digital components into its hierarchical topology, including telecommunications conduits located beneath the streets in Manhattan and other parts of New York City, as well as mobile fleets of drivers and bikers, as infrastructures for facilitating or steering the movement of goods and people. I have also illustrated that heterogeneous components are strung together not only through technological means, as might be inferred from the emphasis on digitality in smart city literature, but also through the "soft infrastructures" of legal designations, franchise agreements, privacy policies, and info-graphics, as well as the dispersed infrastructure of transportation and communications maintenance.

Using the urban stack to construct comparisons across urban data infrastructures yields novel insights. Here I have shown how urban data infrastructures rely on the affordances of externalized infrastructures by exploiting extant infrastructural conditions. Further, both LinkNYC and companies in the on-demand economy utilize technical and protocological operations at the control layer to extract value from digitally-mediated interactions. LinkNYC legitimates its data collection practices through technological means to secure privacy and the promise of sharing this data with urban planning actors, while for companies in the on-demand economy, control layer activity legitimates claims about the status of workers as independent contractors rather than employees. Finally, in both cases, technology producers employ a selective display of information at the level of the urban interface to manage and capitalize on the movements of urban populations in real-time. From these insights, it is possible to reach a more abstract conclusion: value production for urban data infrastructures hinges on their producers' ability to enrol heterogeneous elements into their stacked configuration, and then use this configuration to control the flow of data and information.

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