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The Economics of Maps

Abhishek Nagaraj and Scott Stern

For centuries, human beings have codified their geographic knowledge in maps. Mapmaking was a large and economically significant activity during the Middle Ages, and new maps were a central tool leveraged by explorations undertaken during the Age of Discovery. More recently, digital maps of the world, such as Google Maps, have been among the important applications of digital technology. Digital maps have not only enabled access to real-time transportation and traffic information, but have also supported location-based innovations such as ridesharing apps, real estate portals, and local search engines—and are a core input into the $340–400 billion dollar geospatial technology and location intelligence industry.

Consider how mapmakers influenced the choices and explanations of explorers via the example of one of the most famous maps ever produced. The *Martellus Map* was a Mappa Mundi (a medieval European world map) by Henrich Martellus, a geographer and cartographer from Nuremberg, who lived and worked in Florence from 1480 to 1496. While the Martellus Map was relatively accurate, it deviated to some extent from other maps of its day. The southern tip of Africa was extended to 45 degrees south latitude (even though it is actually at 34 degrees). It also extended the entire east-west length of the Eurasian landmass (from 180 degrees to 240 degrees). These miscalculations supported a theory that Cipangu

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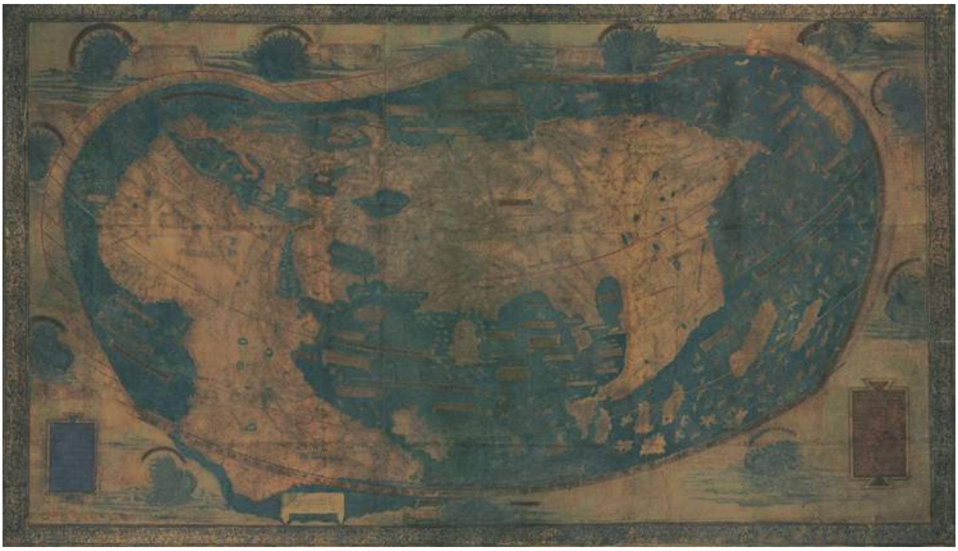
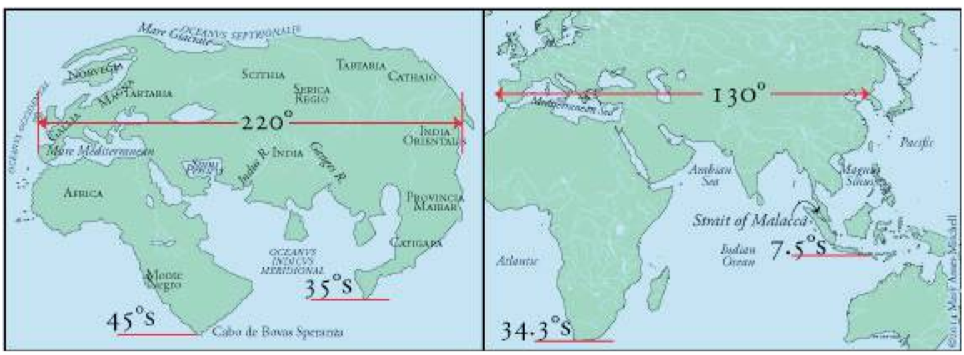
Figure 1
Martellus Map of the World (circa 1489) and Its Distortions

A: The Martellus Map



B: Stylized representation



Source: Panel A: Henricus Martellus. "Maretllus' World Maps." 1489–1490. Last updated August 15, 2019. http://www.myoldmaps.com/late-medieval-maps-1300/256-henricus-martellus/. Panel B: Mary Ames Mitchell. "Columbus' New Proposal." Last updated 2015. http://www.crossingtheoceansea.com/OceanSeaPages/OS-62-ColumbusNewProposal.html.

(Japan) was significantly closer to the west of Europe than it actually is (Davies 1977). While "ground truth" would indicate that a route going to Japan via Africa was considerably shorter, the Martellus Map made a westward voyage to Japan seem attractive, as illustrated in Figure 1. The Martellus Map described a view of the world that may have shaped the course of history through the unanticipated discoveries of the North American continent by European explorers. Critically, it is believed to have been referenced by Christopher Columbus in planning his voyages, was used to support the financing of his expedition, and was ultimately the basis for his mistaken belief that he had discovered India when in fact he was in the Bahamas (Vietor 1963).

In modern empirical work in economics, maps play an important role as data sources (Glaeser et al. 1992; Moretti 2012; Naik, Raskar, and Hidalgo 2016; Chetty et al. 2014; Dell 2010), but economists have rarely undertaken the systematic study of the production of maps as a knowledge good and their consequences for economic and social outcomes. However, a recent flurry of work across disparate subfields has begun to remedy this gap and includes work that looks at the impact of satellite mapping (Casaburi and Troiano 2016; in this journal, Donaldson and Storeygard 2016; Katona et al. 2018; Nagaraj 2018), local business maps (Luca, Nagaraj, and Subramani 2019), subway maps (Larcom, Rauch, and Willems 2017), redlining maps (Aaronson, Hartley, and Mazumder 2017), and flood insurance maps (Michel-Kerjan 2010). In addition to these systematic studies, maps potentially play a role in urban economics; industrial organization through locations of firms and customers; public finance via topographical, census, tax, insurance, and weather maps; political economy (via policies on gerrymandering and property rights); and housing and financial markets. The connections between maps and these topics remain largely uncharted territory.

The present essay seeks to provide a theoretical lens to unify recent work on the role that geographic information plays in economic geography. We review and unify a variety of studies in different literatures that serve to establish the causal role that maps play in shaping economic outcomes. As context, we also provide a brief overview of the multi-billion dollar mapping and geospatial sector of the economy. Building on insights from cartography, we then argue that maps are composed of data and designs, serving as a novel type of information good with unique and specific properties. We then outline the economic properties of maps in terms of fixed costs, rivalry, and excludability and trace out implications for the social versus private returns to mapmaking. This exercise helps clarify possible market failures in mapping supply and the role of the public sector in this area.

We then explore the economic implications of a central insight from cartography that “a map is not the territory” (Korzybski 1933, 750). Maps are fundamentally a representation of physical space different from ground truth. We argue that representations appearing on a map are not an objectively “best” way to represent a geography, but instead reflect the goals, incentives, constraints, and choices of map producers, which themselves depend on particular economic and strategic environments. We endogenize the process of cartographic representation and clarify key economic dimensions which influence representational choices. In particular, we examine: (1) the costs of mapmaking, (2) the nature of demand for maps, (3) intellectual property and the competitive environment, (4) the role of innovation in mapmaking technology, and (5) incentives of mapmaking organizations or individuals. We offer predictions about how these factors shape the ways in which maps may differ from ground truth, and the economic and social consequences of these choices. We also clarify that mapmaking is a dynamic, endogenous process subject to path dependence, and that these five dimensions provide sources of exogenous variation to this path-dependent trajectory. We conclude with an overview of the open theoretical and empirical research questions in this area.

The Economic and Social Consequences of Maps

Why study maps? Even before their present-day relevance, maps have played an important—albeit unintended—role in shaping history. These changes have occurred not only because maps provide useful information, but also because they distort and represent such information in consequential ways. During the US Civil War, General George McClellan's reliance on a distorted map, one which failed to show the Warwick River as a significant obstacle to an invasion of Richmond, resulted in the war being unnecessarily prolonged, producing a hefty loss of lives on both sides (Shulten 2012; Monmonier and de Blij 1996). Other consequences of inaccurate maps were more deliberate. British colonialists justified their ownership of some territories by employing colors and symbols that represented regions of India as British possessions, even though their control on the ground was tenuous and far from complete. Such maps helped to encourage further investments by the British government in securing India for the British Empire, providing significant rewards for the colonialists (Barrow 2004).

Emerging empirical literature in economics and related fields also points towards the causal role that mapping and geographic information has played in shaping social and economic outcomes. Given the endogenous nature of maps and the variety of factors that systematically shape them, economists have tended to exploit shocks to the quality of maps (coming from innovations in mapmaking or spatial variation in their accuracy) to identify empirically their causal role. We provide a brief overview of these studies in a variety of different fields.

Consider the case of the 2014 London Underground strike. Service stoppages prompted regular riders to consider alternative commuting routes, at which point they discovered that their previous choices had been suboptimal (Larcom, Rauch, and Willems 2017). While they primarily focus on how agents learn about optimal routing, a key finding shows a larger proportion of passengers found they were engaged in suboptimal routing in areas where the Tube map was more distorted. For example, as shown in Figure 2, a traveler going from Paddington to Bond Street stations had a choice of transferring via either Baker Street or Notting Hill Gate. Though the Notting Hill Gate route was in fact 15 percent slower on average, more than 30 percent of passengers used this route simply because the London Tube map displayed the Notting Hill Gate station as south rather than west of Paddington, causing the total length of the two routes to falsely appear equal (Guo 2011). It was only because real-world experimentation was induced that commuters learned about the mistaken inferences from the canonical yet inaccurate London Tube map.

Beyond effects on individual decision-making, mapmaking distortions affect a broad range of areas, including public finance. Property taxes have traditionally depended on the codification of property rights through parcel maps. Incomplete

Figure 2
An Example of How the London Tube Map Distorts Distances

A: Schematic Tube map B: Geographical map

Source: Adapted from Guo (2011). Panel A: London Underground. Panel B: Simon Clarke.

or inaccurate parcel maps may result in misspecification of property lines, offering the potential for tax avoidance. Casaburi and Troiano (2016) assess how the use of satellite imagery in Italy allowed for improved parcel maps, resulting in the identification of more than 2 million "ghost buildings," facilitating a crackdown on tax evasion and ultimately enhancing tax revenues by €472 million over a four-year period. Similarly, during the Greek debt crisis, the Greek government leveraged satellite imagery from Google Maps to detect undeclared property improvements such as swimming pools. In the suburbs of Athens alone, the government's count of swimming pools rose from 324 to 16,974 after maps were deployed for this use (Daley 2010).

Similarly, the pricing and demand for flood insurance both depend on the information presented in flood risk maps (Michel-Kerjan 2010). The National Flood Insurance Program's (NFIP) reliance on outdated maps resulted in Colorado policyholders paying 15 times more in premiums compared to claims, while Mississippi policyholders received five times more in claims than they paid in premiums. Inaccurate flood maps also affect the choices homeowners make about their levels of insurance coverage. Families in New Orleans underestimated their levels of flood risk and therefore underinvested in insurance protection, a choice that proved costly in the wake of Hurricane Katrina.

Other recent work highlights the potential influence of maps on investments in regional natural resources, which in many analyses are assumed to be exogenous and known. But as highlighted by Wright (1990), US leadership in energy and mineral resources is not simply a product of natural endowments, but also relies on systematic investments in the topographic and geological mapping of regions through organizations like the US Geological Survey. The effect of investments in mapping is clearly demonstrated by the history of gold exploration and discovery. The introduction of satellite imagery by the NASA Landsat program during the 1970s facilitated the identification of geographical lineaments that strongly predict the presence of gold deposits. Nagaraj (2018) takes advantage of random variations in the timing and quality of these images (like whether the image was cloud-free) to demonstrate that new maps resulted in nearly doubling the likelihood of discovery of new gold deposits when compared to unmapped regions, an effect disproportionately associated with finds from smaller and younger exploration firms.

In some cases, maps can illuminate the spatial distribution of economic activity, such as research using data on nighttime lights from the US Air Force Defense Meteorological Satellite Program's Operational Linescan System (DMSP OLS) (Croft 1978; Henderson, Storeygard, and Weil 2012; Donaldson and Storeygard 2016; Baragwanath et al. 2019). In other cases, maps can affect economic outcomes in the region they aim to describe. The Home Owners' Loan Corporation, founded during the Great Depression to regulate the housing market, created residential security maps to assess the risk of lending in a specific location. Districts deemed to have lower residential security were "redlined," resulting in higher racial segregation and lower homeownership rates, credit scores, and house values in subsequent decades (Aaronson, Hartley, and Mazumder 2017). These maps not only reflected the existing reality of segregation but served as a tool for the state to exacerbate discriminatory practices (Scott 1999).

Finally, there are a number of consequences when maps establish political boundaries. Many of these consequences are unintended, especially because the mapmakers themselves have different reasons for the ways in which they define borders or label areas. For example, when the 49th parallel was chosen as the dividing line between the United States and Canada and ratified in the Oregon Treaty in 1846, the vague language regarding the channel around Vancouver Island led to an armed standoff between 1859 and 1872 when arbitration awarded the San Juan Islands to the United States (Kershner 2013). Some international disputes are not so easily resolved. The Sykes-Picot Agreement drafted during World War I divided the Ottoman Empire into new states using a ruler, resulting in imprecise and arbitrary boundaries that have arguably been at the heart of the instability of that region for the last century (Wright 2016). Maps seem to have an outsized role in shaping outcomes of interest to economists and other social scientists.

The Geospatial Industry

A first step to uncovering the economics of maps is to understand the industrial organization of the geospatial industry consisting of organizations that gather, store, process, analyze, and distribute geospatial information. Consumer-facing mapping services include digital mapping technologies such as Google Maps, which by itself has over 1 billion active monthly users globally and over 150 million active users in the United States (Popper 2017; Clement 2018). Digital mapping services are highly valued by these consumers; for example, Brynjolfsson, Collis, and Eggers (2019) use choice experiments to estimate that the median US consumer would have to be paid at least $3,648 in order to forego digital maps for a year (exceeding the value associated with digital video, social media, or messaging). In addition to end users, the mapping industry serves diverse organizations and stakeholders across a wide variety of industries (mining, agriculture, insurance, and real estate, to name a few) and public sector organizations (from local to national governments). The broad reach of the geospatial industry is associated with significant economic output. The size of the global geospatial industry is estimated to be between $339–400 billion (Geospatial Media and Communications 2019; AlphaBeta 2017), with a somewhat older estimate just for the United States of about $75 billion (Boston Consulting Group 2012). Even if one focuses more narrowly on the "surveying and mapping" sector (NAICS code 54137), geospatial data collection involves 16,800 businesses with total revenue of $7.8 billion in 2018 in the United States (O'Connor 2018).

Figure 3 divides the industry into four broad groups: geospatial technology providers (hardware, earth observation, software), data providers (surveying and mapping companies, government), delivery platforms (business-to-business and business-to-consumer) and analytics (business-to-business, consulting and design agencies). While some sectors such as geospatial technology are relatively fragmented (for example, there is no single dominant surveying company), several key areas are highly oligopolistic (location-based mapping services) and others feature a single dominant firm (such as ESRI in the area of geographic information system software). There are also a wide range of business strategies across and within these sectors. While some firms such as Rand McNally historically sold maps of their own design directly to consumers, other companies such as Mapbox license mapping data and software to customers to build maps of their own design (and for their own purposes). Also, some leading companies such as Google employ a platform strategy in which maps are provided for free to consumers whose use is then monetized through location-sensitive and context-sensitive advertising. Google Maps, for example, is expected to generate revenue to the tune of $11 billion by 2023 primarily through advertising (Schaal 2019). The demand for mapping products seems to be growing rapidly due to the growth in automation, artificial intelligence, and advanced analytics increasing the adoption of geospatial technologies in organizations (BCG 2012; Geospatial Media and Communications 2019).

The Production of Maps

We now turn to describing the essential elements of mapmaking, as a first step to uncovering the economics of mapping information. At its core, a map takes selected attributes attached to a specific positional indicator (spatial data) and pairs it with a graphical illustration or visualization (design) (DiBiase 2008). The canonical political "world map" visualizes spatial data about country names and political boundaries, while a tourist map might visualize data on the location of historical monuments along with walking trails and bus routes. While the scope of mapmaking is quite broad (ranging from weather forecasts to the identification of historical battlefield locations), mapmaking is but a subset of the broader realm of knowledge production (for example, it excludes scientific discoveries such as electromagnetism as well as creative work such as novels). Maps are meaningful because they are associated with a specific terrain, but they are not intended to provide a full or comprehensive description of the underlying reality. Instead, it is well understood that even the most "complete" maps are only abstractions

Figure 3
An Overview of the Geospatial Industry

Category	*Type*	*Leading organizations*	*Selected size estimates*	*Competitive*	*Public/ private*
Geospatial technology providers	Hardware	Airbus, Boeing, Lockheed Martin, Raytheon	€42B estimated worldwide revenues in 2015 (European GNSS Agency 2017).	Concentrated with diverse periphery	Mixed
	Remote sensing satellites	Maxar/ DigitalGlobe, Planet Labs, governments	MDA purchased satellite imaging company DigitalGlobe for $2.4B in 2017 (MDA Corporation 2017).	Concentrated	Mixed
	Software	Esri, Pitney Bowes, QGIS	Esri's revenue was $1.1B in 2014 (Helft 2016).	Concentrated	Private and open source
Data providers	Organizations	NAVTEQ/ HERE, TomTom/ TeleAtlas, OpenStreetMap, USGS/NASA, UK Ordnance Survey	Location-based data generated an estimated $230B in worldwide revenue in 2016 (AlphaBeta 2017). In FY 2019, the US government spent $1.4B on defense GPS and $96M on civil GPS augmentation (GPS.gov 2019).	Concentrated	Mixed
	Surveying and mapping companies	No major national/ international players	$7.8B from 16,800 firms in the US in 2018 (O'Connor 2018).	Competitive	Private
Delivery platforms (B2C/B2B)	Apps/ location-based services	Google Maps, OpenStreetMap, Mapbox	Google purchased social navigation app Waze for $1.1B in 2013 (Lunden 2013).	Concentrated but diversifying	Private
Analytics (B2B)	Consulting and design agencies	BCG's GeoAnalytics group, terraPulse, Farmers Edge	Global market size estimated at $78.6B in 2019 (Geospatial Media and Communications 2019).	Competitive	Private

Source: Authors.

or incomplete descriptions of the underlying reality (Robinson et al. 1995; Monmonier and de Blij 1996).

Maps are not made at random but by mapmakers who exercise significant discretion and agency, whose choices are shaped by the economic, strategic, and institutional environment in which a particular map is produced. Two key elements of mapmaking are worthwhile to distinguish: the gathering and organizing geospatial information (data) and, conditional on that data, the use of geospatial tools and visualizations to create a particular map (design).

The first step in any cartographic production is finding a data source that includes both the geographic locations of interest and the associated attributes of interest to a mapmaker (DiBiase 2008). For example, a cartographer interested in making a map of restaurants near a tourist attraction must first acquire the latitude and longitude locations of the hotels of interest, associated attributes (for example, three-, four-, or five-star status) as well as some information for the "base map," which refers to the location of key highways, towns, political boundaries, and other key background. Base-mapping data can come from different places, including free and public sources (like the US Geological Survey) as well as private sources (such as Google Maps). Data on the object of interest can sometimes be obtained through an open-source or public initiative, but might need to be licensed or even directly collected at significant cost. The eventual map and its informativeness is inherently constrained by the choice of data provider. For example, Yelp maps rely on external data aggregators for data on local business listings and such providers often miss listings for businesses that are in more remote locations or smaller in size. In fact, when compared with administrative data from tax records, Yelp coverage is found to be in the range of about 60 percent (Luca, Nagaraj, and Subramani 2019), although such gaps in coverage can improve almost overnight when data providers add missing listings to their database. Incomplete or selective data can be consequential; in the case of Yelp listings, the exclusion of a restaurant is estimated to reduce restaurant revenue to the tune of 5–12 percent.

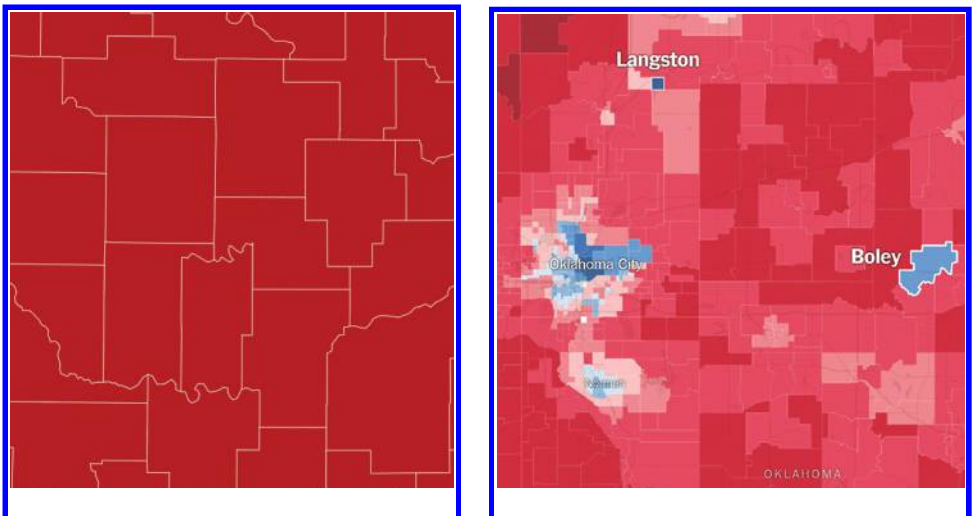
Having chosen data sources and selected key locations and attributes, the mapmaker must then pick a design that visualizes the underlying information. This process is based around a wide variety of choices, including those around simplifying certain features and exaggerating others, using symbols and classifying attributes into groups, and so on. A prominent example of a design choice is aggregation, which involves deciding the geographical unit at which information is displayed. Consider alternate maps for the 2016 presidential election in a predominantly Republican area, such as the areas of Oklahoma shown in Figure 4. A cartographer might group electoral results by county, depicting a state where all regions appear to be staunchly Republican, or the cartographer might group them by precinct, which might reveal certain pockets (like parts of Oklahoma City, Langston, or Boley) that voted for the Democratic candidate. Similarly, another consequential design choice is around mathematical projections used to represent a three-dimensional earth on a two-dimensional surface. The standard choice to adopt the Mercator projection (invented in the 16th century to aid navigation) increases the relative size of areas far from the equator, thereby increasing the perceived importance of areas such as Western Europe at the expense of large land masses at the equator, most notably Africa.

Private versus Social Returns to Mapmaking

Conceptualizing maps as a design representing data has important implications for the economic properties of maps. To a first approximation, both data and designs are types of knowledge goods and so can be characterized as "non-rival" (use by one person does not preclude use by others) and partially "excludable" (it

Figure 4
Vote Patterns for 2016 US Presidential Election around Oklahoma City, OK

A: County level B: Precinct level



Source: Panel A: Politico 2016. Panel B: Upshot Staff 2018.
Note: The darker shades of red denote majority Republican vote share, and darker shades of blue denote majority Democratic vote share.

is possible to limit use for those without explicit permission). This characterization allows us to consider the likely distortions that arise in terms of the private incentives to produce and disseminate data and designs, respectively.

First, mapping data is in many respects a classical public good. Almost by definition, mapping data is non-rival insofar as the use of data for a map by any one person does not preclude its use by others; moreover, the information underlying a given database is non-excludable because copyright law does not protect the copying of factual information. While the precise expression included within a database can be protected through copyright, the underlying geographical facts reflected in the database cannot be protected. As such, there is no means by which a data producer can preclude others from undertaking independent verification and use of a given body of geographical information (often at much lower cost than the initial sunk cost of the initial gathering and organizing of geospatial data). The combination of non-rivalry and non-excludability of mapping data makes its production prone to private underinvestment, providing a rationale for government support. Indeed, many of the most widely used maps rely on publicly funded geospatial data, including US Geological Survey topographical maps, Census demographic information, and local land-use and zoning maps. Further, even when private sector data is available in a given domain, it often relies heavily on public databases, as is the case with weather forecasting data (Lewis 2018).

Although significant bodies of mapping data are non-excludable (at which point public provision is common), there are important cases where mapping data is in fact excludable, either through secrecy or contract. For example, the use of high-definition maps for autonomous vehicles comes with significant restrictions on the copying of the underlying data, and image maps (such as satellite or aerial maps) are themselves protected by copyright (even though the factual information contained in these images is not subject to copyright). Mapping data that allows for excludability exhibits properties more akin to a club good than a traditional public good. Specifically, the significant fixed costs of data collection combined with relatively cheap reproducibility creates entry barriers that supports natural monopolies or oligopolistic competition. It may be efficient for only a single firm to engage in data collection and for the industry to simply license these data (under agreed-upon contractual terms) from this monopoly provider. For example, DigitalGlobe is the leading provider of high-resolution, copyrighted satellite imagery, charging significant prices for access to data (whose marginal cost of reproduction is near zero) to a variety of downstream sectors, including insurance, energy, and mining. The private market for access to raw global street-mapping data is controlled by TomTom/TeleAtlas and NAVTEQ/HERE, who engage in oligopolistic competition through licensing contracts with downstream users.

Even when excludability allows for the "private provision of a public good" (Milgrom, North, and Weingast 1990), efficiency is far from guaranteed. First, in the absence of perfect price discrimination, private entities may only provide mapping data at a high price (relative to near-zero marginal cost), reducing efficient access. Beyond pricing, the private provision of mapping data may additionally be concentrated in locations with high demand (such as urban areas) to the exclusion of less concentrated regions. For example, commercial providers of satellite imagery have vastly greater amounts of data for high-density regions (such as cities) than rural areas that might be equally interesting from an environmental point of view, and even then, cities in the developed world have much greater coverage than cities in the developing world. While such prioritized data gathering might be optimal for the monopoly provider of mapping information, exclusion from mapping databases induces social distortions among downstream users and consumers.

Conditional on the production and availability of a given body of geospatial data, maps involve a second type of knowledge good through the production of a particular map design. Like data, designs are also a knowledge good in that multiple individuals can use a particular map design (and so a design is non-rival) and the degree of excludability for a given design may vary with the institutional and intellectual property environment. With that said, a striking feature of a map design is that, almost by construction, a map is created for the purpose of visual inspection, and it is much easier to copy than a database (which might be protected by secrecy or contract). One consequence of this is that there may be underinvestment in high-quality and distinct designs for a given body of geospatial data. For example, of the 200,000 top websites using a map, 180,000 utilize the now-standard visual design of Google Maps, rather than a design of their own making (BuiltWith 2019).

A potential consequence of the non-excludability of mapping data and designs is inefficient *overproduction* of mapping products that compete with each other. Once a given map is produced for a particular location and application (say, a city-level tourist map), copycat maps can be produced at a lower sunk cost; because demand for maps of a given quality and granularity is largely fixed, free entry based on a given map involves significant business-stealing (Mankiw and Whinston 1986). In other words, conditional on the data and the design, and in the absence of excludability, there is likely to be a commons problem where there is an oversupply of relatively homogeneous map design varieties. Perhaps the most extreme version of the commons problem for maps is the case of a "treasure map," whereby a valuable object can be located through the use of a specialized map. While a single copy of such a map might lead to efficient exploration, competitive supply of such a map will result in a (socially inefficient) race to be the first to find the buried treasure!

Map data and map design, then, are similar in that they are both subject to potential underinvestment. But, whereas map data can be combined or represented in an almost limitless number of ways (that is, there is not likely to be "overuse" of mapping data), map designs may be subject to low incentives for production of a map design of a given quality, but then be subject to overproduction due to imitative copycats.

As well, though not the primary focus of our analysis, both mapping data and design choices depend on the availability of cartographic tools (from measurement instruments to design tools such as ESRI's ArcGIS software), and the availability and quality of these tools themselves depend on the institutional and intellectual property environment. Finally, it is useful to note that, beyond their functional value, maps are not only knowledge goods but also creative consumption goods, and there is an active market (and value placed) on maps with distinctive designs due to their artistry or historical significance. For example, the only known copy of the famous Waldseemuller map produced in 1507 was sold for $10 million to the Library of Congress in 2003 because this was the first map to use the name "America" and is often referred to as America's birth certificate.

How Economic and Institutional Context Affects Mapmaking

Beyond the question of possible market failures and potential remedies via the public sector in the supply of maps, the economics of mapmaking as a distinct knowledge good raises a broader question. Not only is the map *not* the territory (Korzybski 1933, 750) or a "mirror of nature" (Harley 1989), but it is also a potentially biased representation shaped by social, political, and economic forces. In other words, the choices of data and design that underly the making of a map are endogenously shaped by economic forces. The central question then becomes: how do the economic, technical, and institutional environments in which those choices are made affect the types of maps that are produced?

Consider the contrast shown in Figure 5 between the two leading mobile phone maps, Google Maps and Apple Maps. A detailed comparison of these two interactive maps for San Francisco, New York, and London by the cartographer Justin O'Beirne (2016) shows striking differences. While both Google and Apple Maps offer a similar number of features at a given level of resolution, Google Maps labels

Figure 5
A Comparison between Apple and Google Maps

Source: Adapted from O'Beirne (2016).

relatively more roadways and transit, while Apple Maps favors landmarks and shops. The differences are not small; with a given level of zoom, the average incidence of label overlap is only 10 percent. Moreover, these differences do not seem to be random. Apple's mapping priorities reflect its focus on a relatively affluent end user seeking a particular place, like the Empire State Building. Google Maps prioritizes its role as a platform for connecting map-using businesses to users, particularly through transportation applications such as Uber and Lyft. Though differences between maps are likely not noticed by most of the public, users nonetheless are presented with very different representations of an underlying territory depending on which application they use.

How might differences in the microeconomic and institutional environment affect the production of maps? We focus on the impact of variation in five critical dimensions: the costs of mapmaking, the demand for maps, competition, and intellectual property provisions, innovation, and organizational incentives. While mapmaking is a dynamic and path-dependent process, with old maps shaping newer ones, we discuss these five dimensions as key forces that shape the quality and nature of maps in important ways.

Costs of Mapmaking

Perhaps the most important source of variation influencing mapmaking arises from dramatic variations in the costs of producing a map. Cartographic firms such as TomTom produce global maps through original surveying, and those relying on TomTom basemaps can usually use them only at significant cost. For example, in 2012, in order to launch their Maps product, Apple contracted with TomTom to license cartographic data at scale. Although Apple is only one of their clients, TomTom registers nearly $1 billion in revenue primarily from the licensing of their proprietary data (TomTom 2019). By contrast, map-based applications can also use Google Maps, usually at a lower cost but with much less flexibility in terms of selecting underlying data and choosing a custom representation. For example, while Uber has made significant investment in original mapping efforts (it planned to spend $500 million on a global mapping project as of 2016, according to Hook 2016), their consumer application largely uses a relatively generic Google Maps representation at a cost of $58 million for three years of mapping services (S-1, Uber 2019). Finally, there are also a number of open-source and relatively cheap mapmaking initiatives such as OpenStreetMap that offer a high degree of customization, but are also relatively uneven in terms of their data quality (Barrington-Leigh and Millard-Ball 2017). Tesla shifted over the 2010s towards open-source mapping technology for its in-car navigation system (Lambert 2017) and reportedly spent about $5 million for a two-year licensing deal with Mapbox in December 2015 (Bloomberg 2018). In addition to cost considerations around base maps, mapmakers also face similar choices in terms of the technology and software used to create maps as well as the cost of human capital to develop such maps. For example, an annual license per user for ESRI's ArcGIS product can cost up to $3,462 (ESRI 2016) while other tools are free.

This variation in the cost of access to mapping data as well as the cost of map design can have a significant effect of the nature of the finished map. A striking example of such cost variation comes from the Landsat program. Despite (or perhaps because of) the early success of the Landsat satellite imagery program, the US government privatized the initiative in 1984, resulting in a dramatic increase in the price of satellite data from 1984 through 1995 at which time the data was brought back into the public domain. For example, the cost to purchase one complete set of Landsat TM data covering the coterminous United States went from about $250,000 in 1982 to over $1.9 million in 1991. Nagaraj, Shears, and de Vaan (2018) explore the impacts of these cost variations on the production of scientific maps used for environmental and climate change analyses. During the high-cost privatization era, there was a much lower rate of production of high-quality environmental maps covering wide areas, particularly in the developing world. Maps based on Landsat imagery were not only less common, but they often tended to focus on narrow geographic areas rather than area-wide or country-wide surveys, in order to reduce the cost of mapping studies. However, the relative paucity of high-quality large-scale maps documenting environmental change (such as the deforestation of the Amazon or continent-wide glacial melt) may well have delayed key scientific research and reduced the salience of some important topics in policy circles.

Cost variations can also arise from private sector mapping firms (such as Planet Labs or DigitalGlobe/Maxar in the area of satellite imagery). These firms charge significant fees and tend to serve commercial industries such as those in mining and energy, largely excluding noncommercial sectors such as academia or nonprofits who are also interested in these data. Although fees paid by the private market are not public, the US National Geospatial-Intelligence Agency signed a $44 million annual contract starting in 2019 to access Maxar (DigitalGlobe) commercial imagery (Maxar Technologies 2019). However, these firms do occasionally license their data at relatively low cost for broader social purpose. After the Haiti earthquake in January 2010, two private companies, DigitalGlobe (now Maxar) and GeoEye (acquired by DigitalGlobe in 2013), provided free, high-resolution, pre- and post-disaster satellite imagery within three days so that volunteers and experts working with the World Bank could make Building Damage Assessment maps, which are the central tools in guiding disaster relief (World Bank 2010). The availability of low-cost post-disaster imagery from private firms in the last 10 years has led to more timely and comprehensive disaster maps (which were previously based on costly aerial and on-the-ground surveys), transformed disaster mapping, and improved disaster response (Singh 2018). More generally, dramatic variation across time and space in the costs paid by mapmakers for mapping data (and complementary technology to produce maps such as software or mapping instruments) provides economists with an opportunity to trace out the supply of maps of a given type and determine the downstream consequences for economic outcomes.

Demand for Maps

Beyond cost, the nature of demand for particular types of maps will affect what maps are produced. If potential users of maps in a given territory are largely homogeneous in terms of the locations and features of interest, then different maps will likely include similar information and little differentiation in terms of design (as in the case of tourist maps). For example, the vast majority of visitors to an art museum are interested in a representation of the overall layout of the museum, key attractions (such as the Mona Lisa), and information on amenities such as bathrooms and the cafeteria. Though there are in principle an infinite number of potential representations of the Louvre, the majority of Louvre maps—including those in independently produced guidebooks—look remarkably similar given the relatively homogenous demand for information in this context.

In other contexts, demand can be quite heterogeneous across space and affect the type of maps in use. Consider the stark differences between the leading street maps of New York City versus those of Los Angeles in the pre-digital era. In New York City, the leading mapping agencies provided a relatively compact map, featuring a general overview of the territory (for example, the New York-New Jersey metropolitan region) and a small number of detailed cutouts of specific geographies like downtown Manhattan, adjacent Brooklyn locations and a separate map for midtown Manhattan listing theaters, and so on. In Los Angeles, the dominant map was the iconic Thomas Guide, which provided a comprehensive set of detailed street-by-street maps included in an atlas-style publication weighing more than two pounds and with over 3,000 pages and was designed to be used while en route in an automobile (Daum 2015). Despite hosting populations of a similar size, heterogeneity in the nature of demand for geographic information across these two markets explains a large portion of this difference. In New York City, the most common historical use for maps was largely to navigate towards a small number of locations in Manhattan. Los Angeles, by contrast, has historically been more spread out in terms of its population and attractions, and so different users are starting from and going to a more diverse set of locations. Mapmakers responding to this variation in the heterogeneity in demand for spatial information produced a large compendium of equally detailed maps for the different regions of Los Angeles, while in New York, the standard maps had significantly greater representation and detail for certain central locations, while ignoring other regions.

Assessing the effects of heterogeneous demands on map production and use is in principle testable using methods similar to the industrial organization studies of media production and use (for example, Berry and Waldfogel 1999). A wide range of map collections have been catalogued, and the inclusion or exclusion of particular features within particular territories for a given map is potentially measurable. Finding the relationship between these differences in map production and their impacts may prove an interesting trajectory for future research.

Competition and Intellectual Property

By their nature, maps have a high fixed cost of initial development and a lower marginal cost of replication and are therefore quite sensitive to the strength of intellectual property laws protecting mapping data and representations. In fact, US copyright law from the outset offered copyright protection to "maps, charts and books," which was consistent with the idea that geographical maps were valuable forms of intellectual property that required incentives for their production and dissemination (Landes and Posner 1989). Absent perfect intellectual property rights, the production of a map encourages entry by imitative mapmakers, which reduces the incentive to produce original maps. Indeed, the explicit inclusion of charts and maps in the US Copyright Act of 1790 was motivated by the arguments of mapmakers such as Jedidiah Morse (the so-called "father of American Geography"), who argued to Congress that failure to defend his rights would result in a reduced investment in map design and production (Maher 2002).

In addition to employing copyright, firms often invest in additional strategies to protect their intellectual property. In particular, mapmakers have devised the idea of inserting fictional "paper towns" or "trap streets" in maps (Jacobs 2014). This strategy allows them to detect rivals who might copy their data (rather than collecting similar data through an original survey) and thereby protect costly investment in original data collection. Such strategies are commonly deployed by mapmakers to this day for factual data (Bridle 2012).

Our earlier discussion on non-excludability highlighted the central tension regarding the impact of intellectual property. On the one hand, an absence of

Figure 6
Competing Street-Level Imagery Maps for 639 17th Street NW, Washington, DC

A: Microsoft StreetSide B: Google StreetView

Source: Panel A: https://binged.it/2YGYTcB. Panel B: https://goo.gl/maps/XbqqhTqSXRNY3GiW8.

formal intellectual property protection leads to underinvestment in mapping data and high-quality map design, but inefficient entry by copycat mapmakers. On the other hand, a high level of formal intellectual property protection can shift the basis of competition away from imitation and towards duplicative investment. For example, over the past two decades, no less than four different organizations—including Google Street View, Microsoft StreetSide, OpenStreetCam project, and TomTom—have undertaken comprehensive and qualitatively similar initiatives to gather street-level imagery and mapping coordinates for the entire US surface road system. While an absence of intellectual property protection might lead to under-provision, the provision of property rights for maps may instead be associated with overinvestment, as illustrated by the two very similar street-level images in Figure 6.

Finally, it is interesting to consider the nature of maps when mapmakers that do not enforce copyright, such as nonprofits or crowdsourcing communities, face competition from commercial providers who do. Nagaraj and Piezunka (2018) study crowdsourced, open maps on the OpenStreetMap platform and find that such maps are likely to look different in the presence of commercial competition as compared to cases when they are the only such platform in town. By examining how OpenStreetMap contributors respond to the entry of Google Maps in different countries around the world, they show that commercial competition causes casual mapmakers to stop contributing, while already established volunteers increase contributions. In other words, voluntary efforts to create maps may result in maps that are of high value to a small group of "superusers" but may be less aligned with overall market demand.

Innovation

Exogenous shocks from technological innovations both enable and constrain mapmakers and the mapping representations they choose. Consider the adoption of astronomical tools for navigational purposes that profoundly shaped nautical cartography in the second half of the 15th century (Ash 2007). Navigators, venturing outside of established trade routes, incorporated tools such as the quadrant and the astrolabe (used to calculate altitudes of celestial bodies) to calculate their north-south position on the earth's surface. Before this innovation, navigators relied on portolan charts, which are maps with straight distance lines marked between points such as ports or landmarks and were designed to aid navigation by "dead reckoning" techniques (which involve navigating using distance and direction from the origin). The use of astronomical tools and mathematical navigation techniques gave birth to projected maps that use latitudes and longitudes, a system that is used to this day.

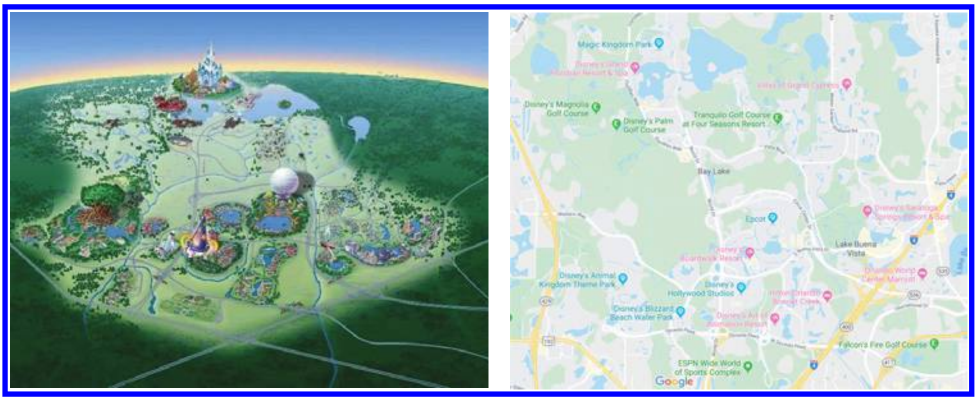
The development and adoption of new technologies continues to shape the nature of maps in the modern era. Consider the case of satellite technology discussed before. Though aerial imagery became available for significant portions of the Earth over the course of the first half of the twentieth century, systematic satellite mapping of the globe only began in 1972 with the launch of the Landsat program by the United States Geological Survey and NASA. Despite the high costs of producing these maps, the US government initially chose to distribute the underlying data (in the form of satellite photographs) at a nominal cost. Remote sensing data, such as data from satellites, allows for easier access to information and provides higher spatial resolutions and a wider geographic coverage, leading to higher quality maps in many domains, increased use by industry and, increasingly, economists (as discussed in this journal by Donaldson and Storeygard 2016).

Finally, technological shocks also provide opportunities to determine causal effects of maps. In the case of Landsat, there were significant variations in the timing of the availability of "clear" satellite maps of a given region due to differences in weather (for example, some regions were originally photographed on a cloudy rather than clear day) and luck (for example, some images were poor due to random technical errors). It was later discovered that high-quality satellite maps can be used to identify gold deposits that form at fault line locations on the surface of the earth. Nagaraj (2018) brings together these two phenomena to demonstrate that otherwise random variation in the baseline availability of satellite maps resulted in upstream exploration-oriented firms taking advantage of sizeable differences in the timing of new gold deposits around the world (relative to integrated mining companies). Thus, variation in satellite image quality constrains mapmakers when the quality is low or images are unavailable and enables mapmakers when the quality exceeds a certain threshold.

Organizations and Incentives

In contrast to a traditional product or service, mapmaking often involves more than maximizing the profitability of selling a given map. Instead, it serves broader purposes of the organizations that fund the production and the cartographers that design that map. As information goods that involve the selective inclusion and exclusion of particular pieces of data, maps are often produced as a means to an end. For example, maps produced by Disney are given out for free, but are meant to stimulate demand for Disney-owned properties and attractions. In fact, as shown in Figure 7, the official Disney World map showing hotels in the area simply excludes a major state highway abutting its western edge, and represents the mixed residential

Figure 7
Maps of the Disney World Area in Orlando, FL, by Disney (Left) and Google Maps (Right)



Source: Disney map: https://www.wdwinfo.com/resortmaps/propertymap.htm. Google map: https://www.google.com/maps/@28.3855756,-81.5768293,13z.

areas adjoining the property (including non-Disney resort properties) as pristine wilderness even when alternate maps (such as Google) provide a more unbiased look. This map provides a very specific view of the Orlando area, aiming to maximize the engagement that Disney visitors have with theme park properties. The commercial goals of the sponsoring organization therefore have an important role to play in shaping the nature of maps.

A similar logic applies even when the mapmaking organization has noncommercial goals. A particularly striking example of the impact of commercial and nonprofit orientations of mapping can be seen in the mapping of refugee camps in areas such as Jordan, Nigeria, or the Gaza Strip produced over the past decade. In most areas of the world, and certainly in most locations with high levels of commercial activity, the for-profit Google Maps offers more or equally granular and detailed maps than open-source projects such as OpenStreetMap. However, as shown in Figure 8, the advantage turns to the nonprofit OpenStreetMap when one examines the establishment of high-quality maps and their dynamic updating for refugee camps (Palen et al. 2015). The prosocial motivations of OpenStreetMap volunteers have important implications for the maps that they produce.

Even for organizations with broadly similar objectives, differences in how they hope to achieve those objectives can result in significant alterations in map design. During the Cold War, Russian mapmakers made thousands of highly detailed 1:50,000 scale maps of many regions around the world, while the US military rarely made maps more detailed than 1:250,000, and those only covered areas of high strategic interest (Davies, Kent, and Risen 2017). These differences in mapping reflected differences in Cold War military strategies. Whereas the Soviet Union was focused on tank power and therefore required highly detailed cartographic maps

Figure 8
Maps for the Zaatari Refugee Camp, Jordan, on Google Maps (Left) Compared to OpenStreetMap (Right)

Source: Panel A: https://goo.gl/maps/pSwb8obFLTJTD2sM8. Panel B: https://www.openstreetmap.org/#map=15/32.2925/36.3215.

at a high level of resolution, the United States emphasized the importance of air power and required maps that covered a greater degree of terrain at a lower level of resolution.

It is important to emphasize that while our discussion has primarily focused on economic and prosocial incentives, maps are cultural and artistic products, and cartographers have long valued their artistic independence, demonstrating originality through design and aesthetics. One particularly salient example comes from the justly (in)famous New York subway map designed by Massimo Vignelli. Designed along modernist principles, this map prioritized a simple and clean look over accuracy; all routes ran at 45- or 90-degree angles, and Central Park was reconfigured as a square rather than a rectangle (Vignelli, Charysyn, and Noorda 1972). The uproar over its introduction ultimately led to a more traditional and informational representation, but this map has remained a favorite of modernist design critics to this day (Rawsthorn 2012). This simple but extreme example shows us that while map producers design maps according to their own idiosyncratic incentives, map users often need to rely on the information in the map without reference to how the underlying terrain has been distorted by those incentives.

Finally, while the factors of cost, demand, technology, competition, intellectual property, and organizations provide key shifters to the nature of maps, it is important to note that mapmaking is an endogenous and complex knowledge accumulation process. New maps build on preexisting ones, which are themselves shaped by these factors. The central feature that old maps influence newer ones creates path dependence in mapmaking that can lead to new information disseminating quickly across maps, but which could also cause large errors and inaccuracies to propagate

Figure 9
A French Map Depicting Baja California as an Island c. 1677

Source: Pierre Duval. "Carte Vniverselle du Monde Avec de nouvelles Observations: Amerique Septemtrionale." 1677. https://exhibits.stanford.edu/california-as-an-island/catalog/cb303zr7917.

for decades. The canonical example of this problem comes from the well-known case of California being depicted as an island on European maps throughout the seventeenth and into the eighteenth century. A Spanish expedition as early as 1539 (including many others) indicated that Baja California was a peninsula, and European maps initially represented it as such. However, starting in the early 1600s, most European maps depicted California as an island, as seen in Figure 9. Historians suggest that incorrect stories of Sir Francis Drake's travels in the Pacific in 1578 led to mapmakers across the European continent to make this error that was ultimately propagated across European maps for over 250 years (Polk 1995). Such path dependence creates strong linkages between newer and preexisting maps, and the five factors we highlight (cost, demand, innovation, competition, and organizations) can strengthen or weaken this link in important ways. While a full discussion of path dependence is beyond the purview of this essay, competition likely plays an important role. For example, there is likely to be a lower diversity in mapping representations when government or open maps are available to copy as opposed to more competitive settings where each provider must make maps from scratch, which would limit path dependence.

Concluding Thoughts

Our analysis has focused on the distinctive economic properties of maps. The features of territories that are mapped and those that are not are endogenously shaped by the incentives and preferences of mapmakers. This area of inquiry is quite nascent and several theoretical, empirical, and policy challenges remain open.

First, on a theoretical level, we understand little about the equilibrium properties of maps. Why do maps that ostensibly have similar goals look different from one another in different settings and contexts (say, subway maps versus automobile maps)? Which mapping representations are more likely to succeed or fail? How do the factors that shape mapmaking interact and produce the maps that we see and use? While our framework is focused squarely on the agency of the mapmaker in shaping maps, how do users, data-providers, and policymakers shape the incentives of mapmakers through their own strategic interventions? Addressing such questions would help us clarify the relationship between social and private returns to mapmaking and identify industries and contexts where the two are likely to diverge.

Second, there are empirical challenges to consider when measuring the effects of different maps and mapmaking regimes on economic outcomes. In order to measure what was and was not included on a given map, we need a measure of ground truth distinct from the mapmaking project under study. For example, in order to examine which restaurants were not included on Yelp maps, Luca, Nagaraj and Subramani (2019) compared Yelp listings with administrative data from tax records. In many cases, a clean comparison is hard to achieve, especially when a mapping program includes features of the terrain that are uniquely captured in that map but not elsewhere. We need more empirical strategies to help provide a general methodology for work that tries to uncover the economic implications of endogenous variations in mapping.

Third, there are several open policy questions in this area. How can we systematically incorporate the idea that maps and geographic information not only describe geographies but also provide unique and (in our opinion) underutilized tools to shape geography? For example, consider the recently released Startup Cartography Project (Andrews et al. 2017) that provides highly granular maps of high-potential entrepreneurial activity in the United States. These maps not only describe the state of American entrepreneurship (Guzman and Stern 2016), but also provide policy guidance to startups on where they should locate and to policymakers on where they should focus their efforts. Similarly, intergenerational mobility maps provided by Chetty et al. (2014) are being used by policymakers to guide the allocation of resources across geographies. How should such maps be designed to maximize social returns? How can maps be incorporated into a policy toolkit, and what are some general processes of map design that maximize social welfare?

Finally, while we focused our attention on geographic maps in this essay, our work has broader implications for maps of non-geographic spaces as well. For example, some work in economics has studied the development of the human genome map (Williams 2013; Jayaraj and Gittelman 2018; Kao 2019) and its role in shaping the direction of pharmaceutical innovation. Similarly, planetary and space maps of various kinds are important in the development of astronomical and astrophysical models. Industry maps and the idea of "mental mapping" are also commonly used metaphors in business (Puranam and Swamy 2016). Our basic framework that separates mapping representations from the terrain and focuses on the mapmaker's endogenous selection process could be equally applicable in these scenarios.

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References

Aaronson, Daniel, Daniel A. Hartley, and Bhashkar Mazumder. 2017. "The Effects of the 1930s Holc 'Redlining' Maps." FRB of Chicago Working Paper WP-2017-12. https://ssrn.com/abstract=3038733.

AlphaBeta. 2017. "The Economic Impact of Geospatial Services: How Consumers, Businesses, and Society Benefit from Location-based Information." https://www.alphabeta.com/wp-content/uploads/2017/09/GeoSpatial-Report_Sept-2017.pdf.

Andrews, Raymond J., Catherine Fazio, Jorge Guzman, and Scott Stern. 2017. "The Startup Cartography Project: A Map of Entrepreneurial Quality and Quantity in the United States across Time and Location." https://static1.squarespace.com/static/5963ccedebbd1a0ffdb5ae00/t/596624123e00be701a3737d3/1499867278836/Andrews+Fazio+Guzman+Stern+%E2%80%94+Startup+Cartography+Project+%E2%80%94+EARLY+DRAFT.pdf.

Ash, Eric H. 2007. "Navigation Techniques and Practice in the Renaissance." In *The History of Cartography*, Vol. 3, edited by David Woodward, 509–27. Chicago: The University of Chicago Press.

Baragwanath, Kathryn, Ran Goldblatt, Gordon Hanson, and Amit K. Khandelwal. 2019. "Detecting Urban Markets with Satellite Imagery: An Application to India." *Journal of Urban Economics*.

Barrington-Leigh, Christopher, and Adam Millard-Ball. 2017. "The World's User-Generated Road Map is More than 80% Complete." *PLoS ONE* 12 (8): e0180698. https://doi.org/10.1371/journal.pone.0180698.

Barrow, Ian J. 2004. *Making History, Drawing Territory: British Mapping in India, c. 1756–1905*. New Delhi: Oxford University Press.

Berry, Steven T., and Joel Waldfogel. 1999. "Public Radio in the United States: Does It Correct Market Failure or Cannibalize Commercial Stations?" *Journal of Public Economics* 71 (2): 189–211.

Bloomberg. 2018. "Nobody Wants to Let Google Win the War for Maps All Over Again." *Fortune*, February 21. https://fortune.com/2018/02/21/google-waymo-mapping-software/.

Boston Consulting Group (BCG). 2012. *Putting the U.S. Geospatial Services Industry on the Map*. https://media.nationalgeographic.org/assets/file/BostonConsultingGroup_US_FullReport.pdf.

Bridle, James. 2012. "Trap Streets: The Road Not Taken." *Cabinet Magazine*, Fall. http://www.cabinetmagazine.org/issues/47/bridle.php.

Brynjolfsson, Erik, Avinash Collis, and Felix Eggers. 2019. "Using Massive Online Choice Experiments to Measure Changes in Well-Being." *Proceedings of the National Academy of Science* 116 (15): 7250–55.

BuiltWith. 2019. "Mapping Usage Distribution in the Top 1 Million Sites." Sydney, Australia: BuiltWith. https://trends.builtwith.com/mapping.

Casaburi, Lorenzo, and Ugo Troiano. 2016. "Ghost-House Busters: The Electoral Response to a Large Anti-tax Evasion Program." *Quarterly Journal of Economics* 131 (1): 273–314.

Chetty, Raj, Nathaniel Hendren, Patrick Kline, and Emmanuel Saez. 2014. "Where Is the Land of

Opportunity? The Geography of Intergenerational Mobility in the United States." *Quarterly Journal of Economics* 129 (4): 1553–1623.

Clement, J. 2018. "Most Popular Mapping Apps in the United States as of April 2018, by Monthly Users." *Statista*, May 29. https://www.statista.com/statistics/865413/most-popular-us-mapping-apps-ranked-by-audience/.

Croft, Thomas A. 1978. "Nighttime Images of the Earth from Space." *Scientific American* 239 (1): 86–101.

Daley, Suzanne. 2010. "Greek Wealth is Everywhere but Tax Forms." *New York Times*, May 1. https://www.nytimes.com/2010/05/02/world/europe/02evasion.html.

Daum, Meghan. 2015. "Letter of Recommendation: The Thomas Guide to Los Angeles." *New York Times*, April 3. https://www.nytimes.com/2015/04/05/magazine/letter-of-recommendation-the-thomas-guide-to-los-angeles.html.

Davies, Arthur. 1977. "Behaim, Martellus and Columbus." *Geographical Journal* 143 (3): 451–59. https://www.jstor.org/stable/634713?seq=1.

Davies, John, Alexander J. Kent, and James Risen. 2017. *The Red Atlas: How the Soviet Union Secretly Mapped the World*. Chicago: University of Chicago Press.

Dell, Melissa. 2010. "The Persistent Effects of Peru's Mining Mita." *Econometrica* 78 (6): 1863–1903. http://www.econometricsociety.org/tocs.asp.

DiBiase, David. 2008. *Nature of Geographic Information: An Open Geospatial Textbook*. State College, PA: Pennsylvania State University. https://opentextbc.ca/natureofgeographicinformation/.

Donaldson, Dave, and Adam Storeygard. 2016. "The View from Above: Applications of Satellite Data in Economics." *Journal of Economic Perspectives* 30 (4): 171–98.

ESRI. 2016. "State of North Carolina MPA Price List E412F-1Q2017." April 11. https://files.nc.gov/ncdit/documents/files/E412F-1Q2017-Price-list-Time-Material-Costs.pdf.

European Global Navigation Satellite Systems Agency. 2017. *GNSS Market Report*. Issue 5. https://www.gsa.europa.eu/system/files/reports/gnss_mr_2017.pdf.

Geospatial Media and Communications. 2019. *GeoBuiz 2019 Report: Geospatial Industry Outlook and Readiness Index*. https://geobuiz.com/geobuiz-report-2019.

Glaeser, Edward L., Hedi D. Kallal, José A. Scheinkman, and Andrei Shleifer. 1992. "Growth in Cities." *Journal of Political Economy* 100 (6): 1126–152.

GPS.gov. 2019. "Fiscal Year 2019 Program Funding." https://www.gps.gov/policy/funding/2019/.

Guo, Zhan. 2011. "Mind the Map! The Impact of Transit Maps on Path Choice in Public Transit." *Transportation Research Part A: Policy and Practice* 45 (7): 625–39.

Guzman, Jorge, and Scott Stern. 2016. "The State of American Entrepreneurship: New Estimates of the Quantity and Quality of Entrepreneurship for 15 US States, 1988–2014." NBER Working Paper 22095.

Harley, John Brian. 1989. "Deconstructing the Map." *Cartographica: The International Journal for Geographic Information and Geovisualization* 26 (2): 1–20.

Helft, Miguel. 2016. "The Godfather of Digital Maps." *Forbes*, February 10. https://www.forbes.com/sites/miguelhelft/2016/02/10/the-godfather-of-digital-maps/#357afcdf4da9.

Henderson, J. Vernon, Adam Storeygard, and David N. Weil. 2012. "Measuring Economic Growth from Outer Space." *American Economic Review* 102 (2): 994–1028.

Hook, Leslie. 2016. "Uber to Pour $500m into Global Mapping Project." *Financial Times*, July 31. https://www.ft.com/content/e0dfa45e-5522-11e6-befd-2fc0c26b3c60.

Jacobs, Frank. 2014. "Agloe: How a Completely Made Up New York Town Became Real." *Big Think*, February 12. https://bigthink.com/strange-maps/643-agloe-the-paper-town-stronger-than-fiction.

Jayaraj, Sebastian, and Michelle Gittelman. 2018. "Scientific Maps and Innovation: Impact of the Human Genome Map on Drug Discovery." http://docplayer.net/129325399-Scientific-maps-and-innovation-impact-of-the-human-genome-map-on-drug-discovery-sebastian-jayaraj-a-dissertation-submitted-to-the.html.

Kao, Jennifer. 2019. "Charted Territory: Evidence from Mapping the Cancer Genome and R&D Decisions in the Pharmaceutical Industry." https://scholar.harvard.edu/files/kao/files/kao_jmp_cancer_pharma.pdf.

Katona, Zsolt, Marcus O. Painter, Panos N. Patatoukas, and Jieyin Zeng. 2018. "On the Capital Market Consequences of Alternative Data: Evidence from Outer Space." 9th Miami Behavioral Finance Conference 2018.

Kershner, Jim. 2013. "Britain and the United States Agree on the 49th Parallel as the Main Pacific Northwest Boundary in the Treaty of Oregon on June 15, 1846." *HistoryLink*, July 31. https://historylink.org/File/5247.

Korzybski, Alfred. 1933. *Science and Sanity: An Introduction to Non-Aristotelian Systems and General Semantics*.

New York: The International Non-Aristotelian Library Publishing Company.
Lambert, Fred. 2017. "Tesla is Updating its Maps and Navigation with Open Source Mapping Platforms." *Electrek*, July 3. https://electrek.co/2017/07/03/tesla-map-navigation-open-source-platforms/.
Landes, William M., and Richard A. Posner. 1989. "An Economic Analysis of Copyright Law." *Journal of Legal Studies* 18 (2): 325–63.
Larcom, Shaun, Ferdinand Rauch, and Tim Willems. 2017. "The Benefits of Forced Experimentation: Striking Evidence from the London Underground Network." *Quarterly Journal of Economics* 132 (4): 2019–55.
Lewis, Michael. 2018. *The Coming Storm.* Audible Audio: Audible Original.
Luca, Michael, Abhishek Nagaraj, and Gauri Subramani. 2019. "Getting on the Map: The Impact of Online Listings on Business Performance." Unpublished.
Lunden, Ingrid. 2013. "Google Bought Waze for $1.1B, Giving a Social Data Boost to its Mapping Business." *TechCrunch*, June 11. https://techcrunch.com/2013/06/11/its-official-google-buys-waze-giving-a-social-data-boost-to-its-location-and-mapping-business/.
Maher, William J. 2002. "Copyright Term, Retrospective Extension, and the Copyright Law of 1790 in Historical Context." *Journal of the Copyright Society of the USA* 49 (4): 1021–39.
Mankiw, N. Gregory, and Michael D. Whinston. 1986. "Free Entry and Social Inefficiency." *RAND Journal of Economics* 17 (1): 48–58.
Maxar Technologies. 2019. "Maxar Technologies Awarded Four-Year Global EGD Contract by the U.S. Government for On-Demand Access to Mission-Ready Satellite Imagery." *Sensor and Systems*, August 28. https://sensorsandsystems.com/maxar-technologies-awarded-four-year-global-egd-contract-by-the-u-s-government-for-on-demand-access-to-mission-ready-satellite-imagery/.
MDA Corporation. 2017. "MDA to Acquire DigitalGlobe, Creating Industry Leader in End-to-End Space Systems, Earth Imagery, and Geospatial Solutions." February 24. https://mdacorporation.com/news/pr/pr2017022402.html.
Michel-Kerjan, Erwann O. 2010. "Catastrophe Economics: The National Flood Insurance Program." *Journal of Economic Perspectives* 24 (4): 165–86.
Milgrom, Paul R., Douglass C. North, and Barry R. Weingast. 1990. "The Role of Institutions in the Revival of Trade: The Law Merchant, Private Judges, and the Champagne Fairs." *Economics and Politics* 2 (1): 1–23.
Monmonier, Mark, and H.J. de Blij. 1996. *How to Lie with Maps.* 2nd ed. Chicago: University of Chicago Press.
Moretti, Enrico. 2012. *The New Geography of Jobs.* Boston: Houghton Mifflin Harcourt.
Nagaraj, Abhishek. 2018. "The Private Impact of Public Information—Landsat Satellite Maps and Gold Exploration." http://abhishekn.com/files/nagaraj_landsat_oct2018.pdf.
Nagaraj, Abhishek, and Henning Piezunka. 2018. "Deterring the New, Motivating the Established—The Divergent Effect of Platform Competition on Member Contributions in Digital Mapping Communities." http://abhishekn.com/files/nagaraj_piezunka_competition.pdf.
Nagaraj, Abhishek, Esther Shears, and Mathijs de Vaan. 2018. "Does Data Access Democratize Science?" Unpublished.
Naik, Nikhil, Ramesh Raskar, and César A. Hidalgo. 2016. "Cities Are Physical Too: Using Computer Vision to Measure the Quality and Impact of Urban Appearance." *American Economic Review* 106 (5): 128–32.
O'Bierne Justin. 2016. "Cartography Comparison." https://www.justinobeirne.com/cartography-comparison (accessed December 1, 2019).
O'Connor, Claire. 2018. *IBISWorld Industry Report 54137: Surveying and Mapping Services in the US.* Los Angeles: IBISWorld.
Palen, Leysia, Robert Soden, T. Jennings Anderson, and Mario Barrenechea. 2015. "Success and Scale in a Data-Producing Organization: The Socio-Technical Evolution of OpenStreetMap in Response to Humanitarian Events." In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 4113–22. Association for Computing Machinery.
Politico. 2016. "2016 Oklahoma Presidential Election Results." December 13. https://www.politico.com/2016-election/results/map/president/oklahoma/.
Polk, Dora Beale. 1995. *The Island of California: A History of the Myth.* Lincoln, NE: University of Nebraska Press.
Popper, Ben. 2017. "Google Announces Over 2 Billion Monthly Active Devices on Android." *The Verge*, May 17. https://www.theverge.com/2017/5/17/15654454/android-reaches-2-billion-monthly-active-users.

Puranam, Phanish, and Murali Swamy. 2016. "How Initial Representations Shape Coupled Learning Processes." *Organization Science* 27 (2): 323–35.

Rawsthorn, Alice. 2012. "The Subway Map That Rattled New Yorkers" *New York Times*, August 5. https://www.nytimes.com/2012/08/06/arts/design/the-subway-map-that-rattled-new-yorkers.html.

Robinson, Arthur H., Joel L. Morrison, Phillip C. Muehrcke, A. Jon Kimerling, and Stephen C. Guptill. 1995. *Elements of Cartography*. 6th ed. New York: Wiley.

Schaal, Dennis. 2019. "Google Maps Poised to Be an $11 Billion Business in 4 Years." *Skift*, August 30. https://skift.com/2019/08/30/google-maps-poised-to-be-an-11-billion-business-in-4-years/.

Schulten, Susan. 2012. "Mismapping the Peninsula." *New York Times*, April 20. https://opinionator.blogs.nytimes.com/2012/04/20/mismapping-the-peninsula/.

Scott, James C. 1999. *Seeing like a State: How Certain Schemes to Improve the Human Condition have Failed*. New Haven: Yale University Press.

Singh, Bajinder Pal. 2018. "When Disasters Strike, Satellites Come Calling." *ReliefWeb*, October 22. https://reliefweb.int/report/indonesia/when-disasters-strike-satellites-come-calling.

TomTom. 2019. "Q4 and FY 2018 Results." TomTom Investor Relations, February 6. https://corporate.tomtom.com/static-files/65db0677-d017-4c06-9b0b-54c0bc4329b0.

Uber. 2019. "Form S-1 Registration Statement." Securities and Exchange Commission. Filed on April 11. https://www.sec.gov/Archives/edgar/data/1543151/000119312519103850/d647752ds1.htm.

Upshot Staff. 2018. "Political Bubbles and Hidden Diversity: Highlights from a Very Detailed Map of the 2016 Election." *New York Times*, July 25. https://www.nytimes.com/interactive/2018/07/25/upshot/precinct-map-highlights.html.

V1 Media. 2019. "Maxar Technologies Awarded Four-Year Global EGD Contract by the U.S. Government for On-Demand Access to Mission-Ready Satellite Imagery." *Sensor and Systems*, August 28. https://sensorsandsystems.com/maxar-technologies-awarded-four-year-global-egd-contract-by-the-u-s-government-for-on-demand-access-to-mission-ready-satellite-imagery/.

Vietor, Alexander O. 1963. "A Pre-Columbian Map of the World, Circa 1489." *Imago Mundi* 17: 95–96.

Vignelli, Massimo, Joan Charysyn, and Bob Noorda. 1972. "New York Subway Map." *MoMA*. https://www.moma.org/collection/works/89300.

Wang, Jules. 2019. "Google Maps Revenue Expected to Increase, Following API Price Hikes and Planned Ads." *Android Police*, April 11. https://www.androidpolice.com/2019/04/11/google-maps-revenue-expected-to-increase-following-api-price-hikes-and-planned-ads/.

Williams, Heidi L. 2013. "Intellectual Property Rights and Innovation: Evidence from the Human Genome." *Journal of Political Economy* 121 (1): 1–27.

Wood, Mark. 2014. "The Island of California." *Pomona College Magazine*, March 11. http://magazine.pomona.edu/2014/spring/the-island-of-california/.

World Bank. 2010. *2010 Haiti Earthquake Final Report*. https://www.gfdrr.org/sites/default/files/publication/2010haitiearthquakepost-disasterbuildingdamageassessment.pdf.

Wright, Gavin. 1990. "The Origins of American Industrial Success, 1879–1940." *American Economic Review* 80 (4): 651–68.

Wright, Robin. 2016. "How the Curse of Sykes-Picot Still Haunts the Middle East." *The New Yorker*, April 30. https://www.newyorker.com/news/news-desk/how-the-curse-of-sykes-picot-still-haunts-the-middle-east.