Mapping and Modeling Illicit and Clandestine Drivers of Land Use Change:

Urban Expansion in Mexico City and Deforestation in Central America

by

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ABSTRACT

Anthropogenic land use has irrevocably transformed the natural systems on which humankind relies. Understanding where, why, and how social and economic processes drive globally-important land-use changes, from deforestation to urbanization, has advanced substantially. Illicit and clandestine activities--behavior that is intentionally secret because it breaks formal laws or violates informal norms--are poorly understood, however, despite the recognition of their significant role in land change. This dissertation fills this lacuna by studying illicit and clandestine activity and quantifying its influence on land-use patterns through examining informal urbanization in Mexico City and deforestation Central America. The first chapter introduces the topic, presenting a framework to examine illicit transactions in land systems. The second chapter uses data from interviews with actors involved with land development in Mexico City, demonstrating how economic and political payoffs explain the persistence of four types of informal urban expansion. The third chapter examines how electoral politics influence informal urban expansion and land titling in Mexico City using panel regression. Results show land title distribution increases just before elections, and more titles are extended to loyal voters of the dominant party in power. Urban expansion increases with electoral competition in local elections for borough chiefs and legislators. The fourth chapter tests and confirms the hypothesis that narcotrafficking has a causal effect on forest loss in Central America from 2001-2016 using two proxies of narcoactivity: drug seizures and events from media reports. The fifth chapter explores the spatial signature and pattern of informal urban development. It uses a typology of urban informality identified in chapter two to hypothesize and demonstrate distinct urban expansion patterns from satellite imagery. The sixth and final chapter summarizes the role of illicit and clandestine activity in shaping deforestation and urban expansion through illegal economies, electoral politics, and other informal transactions. Measures of illicit and clandestine activity should--and could--be incorporated into land change models to account for a wider range of relevant causes. This dissertation shines a new light on the previously hidden processes behind ever-easier to detect land-use patterns as earth observing satellites increase spatial and temporal resolution.

DEDICATION

This dissertation is dedicated to the community leaders and journalists in Mexico City and Central America who put their lives on the line to fight for social and environmental justice for their families and communities. Thank you for opening up your communities, homes, realities, and stories to me. Thanks to Zara Muñoz and Galdino Flores (rest in power), who helped me understand the politics of informal settlement growth in Xochimilco. Zara, your dedication to improve your community and fight for human rights inspires me. Thanks to Galdino for giving me tours of the chinampas for my engagement photo session and Billie's visit. To El Salvador for teaching me about life and death. To Norma Vaquero, who taught me how to listen in communities, enter the world of children, humbly recognize my place, fill the world with color, and remember that *por el amor no muere lo nuestro*. To countless others- Mario, Guadalupe, Ricardo, Mateo, Jorge, Karla- who brought me places in Mexico City I never could have accessed.

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CHAPTER 1

INTRODUCTION

The paucity of formal study of illicit activities in land system science

Land, the terrestrial component of the biosphere, is a part of nearly every biophysical process that sustains life. It is now widely recognized that anthropogenic land uses have transformed the structure and function of carbon, water, nitrogen, and phosphorus cycles at an unprecedented rate (Falkowski et al., 2000; Vitousek et al., 1997), assisting in the conditions that give rise to the Anthropocene (Crutzen, 2002). These changes influence the dynamics of species distributions, water availability, temperature, net primary production, ocean chemistry, fish stocks, and a host of other components of the biosphere essential to human well-being (Steffen et al., 2015). Understanding where, why, and how land-use changes occur is essential to address global sustainability.

Land systems science (LSS) is an interdisciplinary research field dedicated to understanding these land-use changes (Turner II et al., 2007; Verburg et al., 2015). Linking earth observations via remote sensing to social-environmental system assessments has led to significant advances in causally linking land changes to their generating processes (Chowdhury and Turner II, 2019; Lambin and Meyfroidt, 2011; Verburg et al., 2015). Special attention has been given to the processes of land-use change, examining the human dynamics in question (Lambin et al., 2001; Liverman et al., 1998; Rindfuss et al., 2004). Despite this progress, a significant blind spot remains in the assessments of land change causes (or drivers) and consequences, those following from illicit activities involving land transactions.

Illicit activities are those not allowed or permitted by formal or informal rules of governance (i.e., institutions) and occurring across a spectrum of formal to informal institutional settings. Illicit transactions (exchanges) may be given other normative labels including illegal, corrupt, criminal, illegitimate or fraudulent. Illicit transactions are often clandestine activities, invariably hidden from prevailing institutions, because the actors involved wish to avoid detection and the potential for sanction or shame. The label "illicit" is also normative, because it identifies a transaction in the eye of the beholder (or researcher) as violating a social norm or formal law. Some behaviors that are non-public in character but are common, such as small bribe from a citizen to a government official to expedite paperwork, may not be considered illicit in a society normalizing such behavior. Some illegal activity may also be licit if authorities commonly permit it. For example, the Dutch term *gedeogen* refers to toleration of offenses, such as the government permitting the use of small amounts of cannabis. The category of illicit is fluid and subjective, making it difficult to provide a typology with clear boundaries of what is licit versus illicit. Furthermore, categorizing illicit versus licit transactions may obfuscate from the functional role clandestine behavior plays in land systems. The intent of this dissertation is to examine the mechanism of clandestine exchange, most of which is illicit, and unpack its influence on land systems.

Numerous observations indicate that illicit transactions influence land changes worldwide, and in some cases, may be more prevalent than licit transactions. For example, 40% of deforestation globally is estimated to be illegal (e.g., Forest Watch Indonesia et al., 2002; Ravenel et al., 2005), a figure reaching 80% in Indonesia and Brazil (Lawson et al., 2014). Local politicians with agency over land use permits may abuse this power to grant land access to their supporters to maintain political power. In election years, deforestation increases dramatically (by over 40%) in Indonesia (Burgess et al., 2012), and by 8-10% in the Brazilian Amazon when an incumbent runs for mayor (Pailler, 2018). Other examples include urbanization and infrastructure development via kickbacks (Baskaran et al., 2015; Weinstein, 2008), revenue generation through agriculture by terrorist groups (Jaafar and Woertz, 2016), narco-deforestation in Central America (Mcsweeney et al., 2014) , illegal charcoal production and deforestation (Cavanagh et al., 2015), and informal urban settlement (Aguilar, 2008).[1]

In these and other examples, illicit activities are typically unrecorded (i.e., missing in official state or municipal records), even if their land use is openly observable and known, (e.g., much informal urbanization in the Global South) and may result in land changes that would not likely take place otherwise (e.g., narco-deforestation [below]). For these reasons, illicit activities have, for the most part, been absent in theories and models of land systems and their change (Meyfroidt et al., 2018), despite the recognition of the prominent role that they maintain on land uses and systems.

Examining these activities is difficult in part because knowledge about their operation are rarely available (i.e., officially undocumented) nor linked to pixel data, hindering the corroboration of illicit transactions and land-use change, especially through the analytics marking LSS research. Given this impediment, do approaches exist that would enable us to make inferences about the location, extent, pattern, and consequences of illicit activities? We suggest that they do. In the following section, we insert illicit activities within a conceptual framework of land-use transactions, and provide two "pixel-based" approaches that can be used synergistically to identify land uses associated with illicit activities. We also identify new or unused data and analytical methods that facilitate the operation of the approaches.

[1] In addition, much land change globally involves clandestine transactions, regardless of their illicit or licit nature. For example, an estimated 42 to 100 million ha of land in sub-Saharan Africa, Latin America, and Asia have been purchased or leased to private companies since 2000, a rate of acquisition 20 times above historical averages (Wolford et al., 2013), leading to concerns about "land grabs" (Ruilli et al., 2012), some of which involve questions about clandestine activities. Other examples includes the use of tax havens, many that offer secrecy of transactions, to invest in land resources such as the 68% or more of financial capital for the major soy and beef companies deforesting the Amazon (Galaz et al., 2018).

Inserting illicit activities into land system research

Despite the importance of these processes worldwide (Peluso and Lund, 2011), it is difficult to demonstrate the causal role of illicit and clandestine activities in land changes. Both a paucity of data and research risks may preclude researchers from formally modeling this phenomenon. Failure to account for these kinds of drivers, however, may miss the identification of significant dynamics in land change.

LSS has yet to engage fully with the range and nuances of institutional contexts that shape illicit transactions that may result in unique landscape signatures. Their identification and operation will likely improve the understanding of land change and the accuracy of land system models. This improvement requires insights gained in political science and political economy about clientelism, corruption, and illicit economies.

This dissertation seeks to begin to fill this lacuna. It examines two types of clandestine transactions in Latin America, one urban and one rural, which have corollaries in Latin America and throughout other parts of the world (DeFries et al., 2010; Redo et al., 2012). The effects of clientelism, or exchanging votes for improvements in informal settlements to make them formal, has been and remains common in Mexico City. Informal settlements have resulted in the loss of substantial conservation land while providing shelter for an enlarging portion of the Basin's population (Aguilar and Santos, 2011; de Alba and Hernández Gamboa, 2014; Hagene, 2015). In contrast to Mexico City's clandestine land operations, narco-related ranch and palm oil plantation expansion in Central America are illicit transactions, undertaken, in part, to launder drug monies. Illicit narco-trafficking in Central America has thus been identified as potentially precipitating deforestation (Mcsweeney et al., 2014).

This dissertation aims to both understand the institutional conditions that promote clandestine activity and quantify the influence of these activities on land conversion at a landscape scale. It asks:

1. Can illicit and clandestine drivers of land-use intensity be identified either by unique spatial patterns of change or through correlations with proxies of illicit activity?
2. What is the role of these activities in urbanization in Mexico City and deforestation in Central America?

These questions are addressed in the following four chapters—stand-alone research papers—and summarized in the sixth. The research is based on synthesis of socio-environmental data, including interviews with key actors, remote sensing of urban and forest change over a 15-year period, and ancillary data regarding voting and zone change in Mexico and cocaine transport in Central America. This first chapter introduces the paucity of work on illicit and clandestine transactions in land systems and how to address them. It argues that new data and methods could quantitatively assess the role of these activities, which is empirically demonstrated in subsequent chapters. The second chapter analyzes qualitative interview data with actors who purchase, sell, or regulate urban land in Mexico City. The third chapter examines how electoral politics influence informal urban expansion and land titling of informal settlements in Mexico City, using panel regression. The fourth chapter tests the hypothesis that narcotrafficking has a causal effect on loss in Central America from 2001-2016, using two proxies of narcoactivity. The fifth chapter explores the spatial signature and pattern of informal urban development in Mexico City with satellite imagery. The sixth and final chapter summarizes how illicit and clandestine activity through illegal economies, electoral politics, and other informal transactions plays a significant role in shaping deforestation and urban expansion. It identifies how measures of illicit activity could be incorporated into land change models to identify a wider range of relevant causes to bridge methodological and conceptual divides in Political Ecology and Land System Science (Turner and Robbins, 2008). This dissertation shines a new light on the previously hidden processes behind ever easier to detect land-use patterns as earth observing satellites increase spatial and temporal resolution, improving our understanding of illicit and clandestine activity in the earth system.

A conceptual framework to study land patterns and illicit transactions[2]

The challenges and knowledge gaps described above point to the need to better understand illicit and clandestine activities in the context of land systems. Illicit activities are undertaken in formal and informal institutional settings. They can be illegal as defined by rules of governance of the state or a lower order administrative unit, or subvert informal norms and ethics (e.g., sanctions, taboos, customs, traditions, and codes of conduct) (North, 1990). Illicit activities are those that are not formally legal, or normatively disapproved and not permitted by group norms or ethics. Illicit transactions in either institutional setting may be accepted business as usual (and perhaps, licit) among the actors or organization (henceforth, actors) at play. In addition, the appearance of licit transactions (e.g., formal land holdings) may follow from illicit processes, such as bribery among state officials or threats of violence on marginalized landholders, or serve to maintain an illicit activity, such as land uses for money laundering. Significant to these activities are their clandestine quality, which pose large problems for land change analyses.

[2] This chapter, largely taken from my proposal, was recrafted into a perspective with three co-authors, Nicholas Magliocca, B. L. Turner II, and Peter Verburg. It is currently under revision for publication submission.

All institutions, formal and informal, are given the legitimacy which allows their persistence via trust, norms, power, and other repeated interactions and exchanges among actors. Importantly, the structure of actors and interactions in illicit land transactions differs from that of formal land transactions in two ways (Fig. 1). First, in illicit transactions the differential power (i.e., social, political, economic, or informational capital) between the actors with needs and the actors with authority and influence tends to be large (e.g., Bebbington et al., 2004; Vandergeest and Peluso, 2015). This distinction facilitates the tendency for illicit activities to co-opt and blend in with existing economic and social structures to avoid detection (Basu, 2014; Cavanagh et al., 2015; Duffy, 2006). Second, licit transactions and contracts are typically enforced by a third party, either a formal institution such as a court of law, or an informal institution such as a community board. These transactions share the non-codified and non-written characteristics of informal institutions, but unlike them are invariably clandestine and adjudicated without a third party, often based on trust between the two actors involved to keep the exchange secret. Illicit transactions may also be enforced by threats or intimidation, including extortion and violent action (Lambsdorff et al., 2005a).

Following Ostrom's (2011) Institutional Analysis and Development framework, the actors with land-based or monetary needs and those with the authority and influence (or power) to fulfill them make exchanges in the "action arena", the space where actors weigh the costs and benefits of potential transactions and outcomes (Fig. 1). These outcomes may include land entitlements and improvements, resource output, monetary funds, or externalities (e.g., environmental disservices, such as loss of biotic diversity) for actors with needs and political, economic, or social gains and losses for actors with authority and influence. The degree of authority or control of each actor, the perceived benefits each expects from the outcome, and formal and informal institutions (e.g., rules of governance) shape conditions of exchange and the adjudicating authority in the action arena. The social and environmental land system co-evolves, producing the landscape uses and patterns observed.

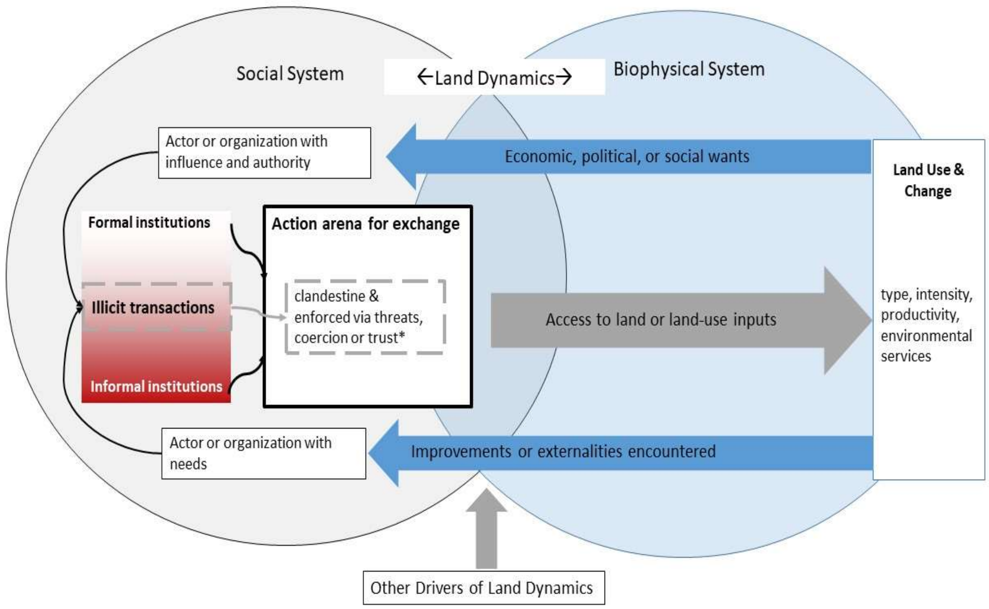

Figure 1 Adding illicit transaction into an action arena for land use. (Following Ostrom 2011; Turner et al. 2007; small arrows link actors to institutional mechanism of illicit transactions, occurring across a spectrum of formal to informal institutional constraints). *denotes a specific type of trust between the two actors to deliver on the exchange and keep it clandestine. Trust in general underlies legitimacy of all institutions, formal and informal.

To these we add illicit activities. Examples of illicit land transactions include: bribes to officials to not prosecute illegal land sales, common to deforestation and cattle ranching expansion in the Petén, Guatemala (Grandia 2013); local government officials bribed to clear slums for shopping mall development Mumbai (Weinstein, 2008); selective enforcement of urban land zoning regulations and land eviction to gain political support of votes in informal settlements, known as “forbearance” in Bogota and Lima (Holland, 2016), and anonymous elite “big men” who help foreigners navigate and expedite the process to obtain gold mining concession permits in forested areas of Ghana

(Hausermann et al., 2018). In addition, access to land, either licit or illicit in kind, may be a screen for a more central illicit activity, such as access for cattle ranching to launder drug monies in Central American (below; Devine et al., 2018; McSweeney et al., 2017).

Accounting for the illicit transactions is challenging because they are intentionally hidden. Official data attempting to track "the hidden" are commonly not available for public use and when available prove to be incomplete. Primary data collection is often only possible once the researcher builds long-term, trusted relationships in the field that allow the topic to be broached, and even then broaching the topic may be dangerous. As a result, observations of illicit activities are incomplete, fragmented, and/or unreliable, often based on anecdotes or side comments made in formal surveys, and tend to be specific to one location or community. In addition, mismatches occur in the spatio-temporal scales between the level at which illicit-clandestine activities are perpetrated (e.g., social interactions, local contexts) and the landscape scale analysis.

The context under which illicit or clandestine activities occur has been studied by various disciplines including new institutional economics (della Porta and Vannucci, 2005), urban sociology (de Alba and Hernández Gamboa, 2014; Roy, 2005), and political science (Hicken, 2011; Scott, 1969). These insights have been applied to quantitative modeling and hypothesis testing to explain clandestine behavior at the individual level (Armantier and Boly, 2011; Barr and Serra, 2009), or agent-based modeling at a city scale (Patel et al., 2012). The insights from these studies are rarely integrated into studies of land systems, however.

Discipline-specific methods employed to analyze illicit activities include ethnographic field research, statistical analysis, and simulation modeling, which produce diverse types of data (e.g., ethnographies, material or capital flows, social/organized criminal organization network structures) are difficult to reconcile in space and time. Observations may also be unreliable because, in some cases, a highly sensationalized activity causes biases in reporting (i.e., known as the "spotlight" effect for crime data), such that lower or moderate levels of the same activity are missed elsewhere. Even more problematic is political manipulation of data regarding illicit activities by governments and authorities, which may be incentivized to hide activities in which they are formally charged to control or eager to tout the success of their efforts to do so. Overall, the clandestine character of illicit transactions, by definition, makes them difficult to detect and study, and creates a paucity of data and knowledge that challenges formal investigation of these phenomena.

"Socializing the pixel/pixelizing the social" to understanding clandestine activity

Despite the importance of clandestine and illicit processes worldwide (Peluso and Lund, 2011), it is difficult to demonstrate the causal role of these activities in land changes through the quantitative and modeling approaches common to LSS and articulated in such work as *People and Pixels* (Liverman et al., 1998) and *Land Change Science: Observing, Monitoring and Understanding the Trajectories of Change on the Earth's Surface* (Gutman et al. 2004). This connection and cause has proven difficult because of the dual challenges of "pixelizing the social" and "socializing the pixel" as a means to dig deeper into the processes operating on land change (Geoghegan, 1998). "Socializing the pixel" refers to the use of remote sensing data to analyze pixelated patterns of land-use changes that are "mined" to indicate which societal processes are responsible for the patterns. "Pixelizing the social", in contrast, refers to linking social data (e.g., social surveys and census data) to "pixelized" units of land to glean their associations, providing inferences about the social, political, and economic forces at play.

LSS has made much progress in pixelizing the social: greater spatial and temporal resolutions of pixel-based biogeophysical data commensurate with social data (e.g., household surveys, census blocks); new satellite sensor capabilities; increased data availability through open access data; development of tool kits for analysis; and significant amounts of funding to encourage data use. This progress has resulted in the ability to monitor decades of land-use changes at high resolution for forest, water, and agricultural systems (Cooley et al., 2017; Hansen et al., 2013; Jain et al., 2016; Pekel et al., 2016). Higher resolution spatial-temporal time series facilitate impact evaluation of land use policies (Blackman et al., 2017; Heilmayr and Lambin, 2016) and support causal inference to better understand which socioeconomic process drive landscape outcomes.

Socializing the pixel—informing socio-politico-economic processes and theory from land change patterns—has evolved less. Perhaps the most well-known linkage of pattern to process is that of the "fishbone pattern of deforestation" in Amazonia, in which road and farm parcels placements generate a specific pattern visible in the aerial image (De Oliveira Filho and Metzger, 2006). Proximate causes, such as the roads and parcel allotments in Amazonia, have been identified via specific patterns they generate to better understand global deforestation (Curtis et al., 2018). Examining land-use patterns to provide insights about social problems or theory, however, confront the age-old axiom that the same process can give rise to the different spatial patterns and vice versa (Skole et al., 2004) (equifinality). Not surprisingly, this difficulty has led to a research bias focused on drivers or causes of land change that can be correlated with existing "pixelizable" socio-economic data.

This research bias has hampered the ability of LSS to consider the role of illicit and clandestine activities in land system changes. Studying these activities is difficult in part because pixel-linked data and knowledge about their operation are rarely available.

Linking land change patterns to illicit or clandestine socio-economic processes to corroborate these linkages has thus been a challenge. Yet, pixelizing approaches that omit illicit activities as causal factors in analysis may fail to identify or even misinterpret the reality involved. As such, subsequent land governance policy informed by this approach may be ineffective.

In the absence of data facilitating pixelizing approaches, can the "socializing" approach support inference about where and how illicit activities are occurring? Do clandestine activities create distinctive patterns of land change (e.g., illegal deforestation or grassland grazing) that are anomalous relative to those created by legal socio-economic activities within the same social-environmental system?

While directly observing illicit and clandestine activity is challenging, 'pixelizing' and 'socializing' approaches can be used in different but complementary ways to study the influence of these activities on land systems. Pixelizing approaches can leverage new data to observe and map land change patterns and attempt to attribute some portion of observed land change to suspected illicit and clandestine activities. Socializing approaches begin with land change patterns or other socio-economic outcomes with known links to illicit and clandestine activities and attempt to explain the processes through which those outcomes are produced. Increasing the temporal and spatial resolution of and improved access to remote sensing may allow for direct measurement or proxies for illicit and clandestine activities, adding them to the array of land change drivers examined by LSS and related research fields. In many cases, the data may exist but have not been processed in land-change studies. In others, methods used in other research fields and LSS could be better leveraged in the effort.

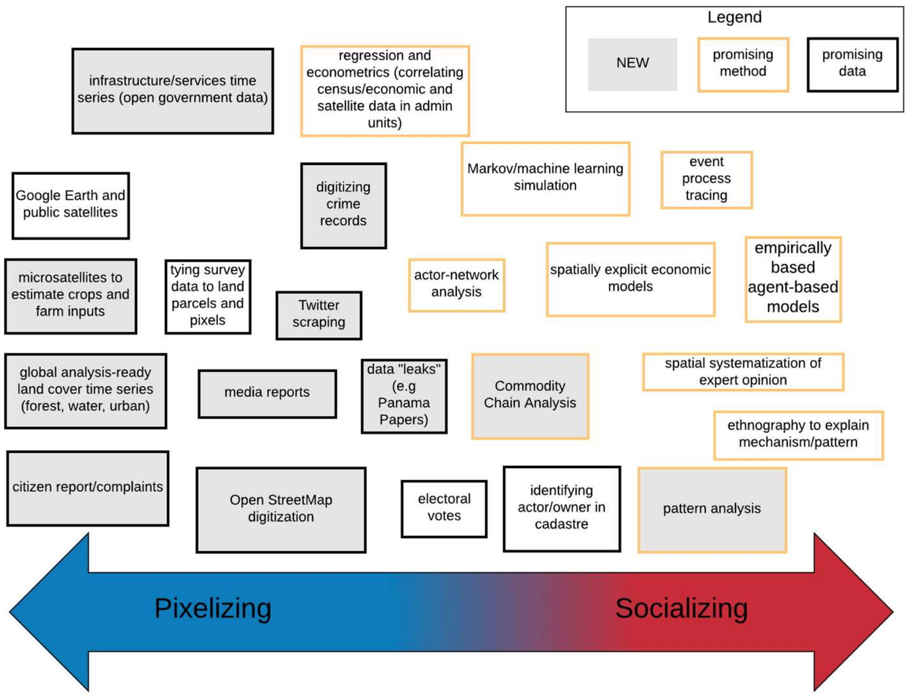

Figure 2. Extant and promising data and methods applicable for pixelizing/socializing land systems research.

Pixelizing approaches

Figure 2 outlines extant and new data and methods arranged along a spectrum according to the degree to which they contribute to pixelizing versus socializing efforts. Digital data representing aspects of human behavior at increasingly high spatial temporal resolution over the last few decades have become available owing to advances in satellite monitoring, initiatives that "open", "leak," or digitize data from governments and companies (e.g., The Panama Papers), crowdsourcing, and records of human activity online from twitter and the media. Pixelizing these data is expected to improve understanding of the causes of land change created by human behavior or societal structures. For example, common causal inference approaches include fixed effects econometrics regression, difference-in-differences- or matching approaches already used to study land systems (Arriagada et al., 2012; Blackman et al., 2017; Wright et al., 2016).

Methods that link survey data with parcel level land change is another way to understand land systems from a pixelizing perspective (Chowdhury and Turner, 2006).

A few pixel-based approaches have been undertaken. These include the effects of the eradication of illicit coca plantations on forest regrowth (Sánchez-Cuervo et al., 2012) and the relationship of coca production on deforestation (Dávalos et al., 2011). Official government reports on coca eradication have been linked to areas of forest change (2012) and aerial photographs of coca production have been employed in supervised classification algorithms to asses where growth in the crop was correlated to deforestation in multi-level regression models (Dávalos et al., 2011).

Socializing approaches

At the other end of the spectrum, socializing the pixel involves leveraging process-based insights informed by theory, ethnography, and expert knowledge to explain observed patterns, or model them with dynamic, process-based approaches (e.g., agent-based models). Socializing approaches are especially useful when there is not enough spatial or temporal data on human behavior to pixelize. A variety of methods exist to render ethnographic or expert knowledge systematically and spatially (Magliocca et al., 2018). These process-based understandings can inform extant methods of pattern analysis (Nagendra et al., 2004) or agent-based land model simulations. Limitations of agent-based models notwithstanding (Groeneveld et al., 2017), they can simulate the decisions of actors made in the "arena" (from Fig. 1), yielding spatial-temporal patterns that can be tested in regard to their robustness and compared with observed patterns of land change (Brown et al., 2014).

Methods from other disciplines that could be leveraged include event process tracing from political science, commodity chain analysis from economic geography, and investigative journalism. Event process tracing traces chains of records of official transactions searching for anomalies (Holland, 2016). Commodity chain analysis is used to understand how, why, and where illicit economic activity is captured in spaces where goods are produced, transported, and consumed (McSweeney et al., 2018). McSweeney and colleagues (2018) used ethnographic data from fieldwork and the media to estimate prices paid for various types of labor required to transport cocaine and multiplied these unit amounts by government estimates of volume of product moving through the region. Investigative journalism has also documented the process of illicit activity for specific land parcels. For example, journalists have used names on cadastral records of land ownership and land-use permits to known criminals or politicians with documented corruption cases case studies from both narcotrafficking (InSight-Crime, 2011) and palm oil (Chain Reaction Research, 2018; The Gecko Project and Mongabay, 2018). Cadastral data are useful because land or permits are often held legally by a third party who is a family relative, or a shell company registered off-shore, rather than by a narcotrafficker directly. Ancillary data from crime records, media, business databases, or ethnography may be required to develop the indirect links between the legal landowner or shadow business and illicit actor. These examples are limited spatially (one region of Honduras, or specific cases in Indonesia), limiting generalizability to study landscapes systematically. They explain, however, the mechanisms of illegal activity and its relation to the environment compared to pixelizing approaches.

Many other methods fall between the pixelizing and socializing approaches, including analyses of flows and networks between actors, goods, and land uses and machine learning/prediction algorithms. Models vary from extrapolation of trends and patterns towards simulating the land-use consequences of assumed theory or rule sets (see Brown et al., 2014 for full descriptions and examples). These models can be used to simulate land change patterns based on historical data *before* the illicit activity occurs compared to simulated patterns during the time the phenomenon influences the land system. The challenge involved here is the differences between legal and illicit activities that may require different representations of land use decision making and deviations from trends and observed historic patterns. Some data sets are also relevant to both approaches, such as voting data that identify patterns of political exchanges, including patronage or clientelism (the contingent exchange of citizens' votes for access to a public good or services (Hicken, 2011)) and relationships to land use titles or changes.

Pixelizing and socializing approaches alone are insufficient to advance understanding of illicit-clandestine activities beyond the descriptive stage of assessment. The challenge is finding the right integration or pairing of pixel/social approaches given the state of the data. We provide a framework for integrating these approaches that elucidates how illicit transactions operate in land systems, providing a roadmap for studying any land system process or phenomenon that suffers from incomplete, fragmented, and/or unreliable data.

Integrating illicit activities and remote sensing approaches

Mixed methods (e.g., quantitative-qualitative) approaches for studying complex, multi-scalar land system phenomena are problematic in the illicit-clandestine context because data and knowledge gaps are so ubiquitous that compounding or cascading uncertainties can overwhelm attempts at causal inference. Consequently, analyses tend to focus on particular parts of an illicit or clandestine phenomenon, typically determined by data availability, which minimizes attributional errors but necessarily produces only partial explanations. As such, triangulating methods are proposed to leverage synergies between partial but complementary evidence (Fig. 3).

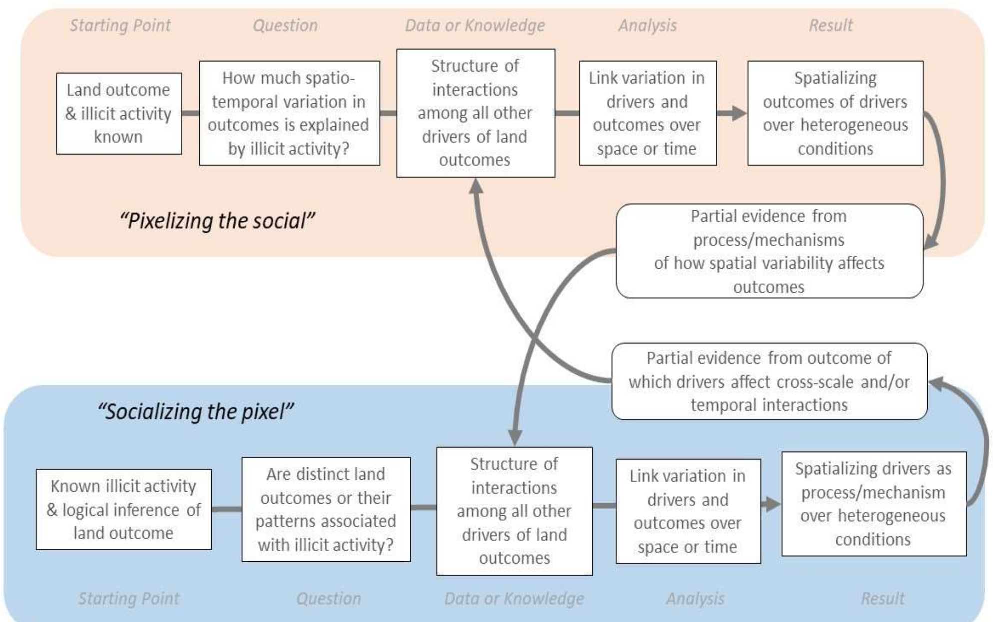

Figure 3. Approaches to address illicit activities involving remote sensing data.

When a known or hypothesized *process* is the starting point, pixelizing the social is at play. The motivating research question is: how much spatial and temporal variation in the land-use outcome is explained by socio-economic variables of interest? Given initial knowledge of key variables, alternative hypotheses or explanations are formed about how the process will manifest the outcome of interest differently under varying contextual conditions. Data are needed to describe where and/or when the effects of those variables on the outcome of interest might differ. Methods for causal inference and correlation, which account for co-variation over space and time (most commonly, regression), link variation in contextual and causal factors to observed outcomes. The result is partial inference into how outcomes vary over space or time as the consequence of a process operating in heterogeneous conditions. This approach relies on developing or pixelizing proxy variables of illicit or clandestine behavior (i.e., the known or hypothesized process), advanced via new data sources identified in Fig. 2. Well established causal inference approaches (e.g., fixed effects models) can be used to identify how authorities preferentially distribute public goods, such as electricity, at opportune times and places to influence electoral outcomes (Baskaran et al., 2015). Similar techniques can be employed to develop proxy data on the political or economic capital exchanged in the action arena, be they votes, water access, or lax enforcement. These data can then be leveraged in regression models to relate the change in space and time of the proxy to the observed landscape change. It is critical in this approach that the model include the accompanying "licit" or conventional drivers of change for comparison to the influence of the illicit transaction.

When a known or hypothesized *outcome* is the starting point, socializing the pixel is at play. The motivating research question is: how are variations in the known outcome over space or time produced by candidate socio-economic processes? Given initial assumptions about the structure of variable or factor interactions, alternative hypotheses or explanations are formed about which processes are important and how they interact over space or time to generate the outcome(s) of interest. Data are assembled to describe the varying outcomes produced by the process of interest. Deductive methods for causal inference then test how well alternative process-level explanations reproduce the empirical outcomes of interest. The result is a process-based explanation linking empirical outcomes across multiple system levels or over time. Advances in the socializing frontier are largely driven by new methods using existing data (Fig. 2). Cases in which suspicious activities are taking place but the evidence is minimal (i.e., the known or hypothesized outcome), analysis of landscape patterns (e.g., analyzing remote sensing data with pattern analysis software) may reveal unusual or anomalous land changes. These changes can be associated with various possible causes, seeking to establish which is the most likely via field observations, surveys, the media, and so forth. If the mechanisms in the action area (Fig. 1) and interaction between actors are relatively well understood, simulation modelling, such as an ABM, can codify the understood rules to determine the efficacy of the observed patterns found in the first approach. This approach has been used in other land use studies (Manson and Evans, 2007), but has only just gained traction in the context of illicit and clandestine land transactions (Magliocca et al., 2019).

In rare cases, various documents and cadasters may exist that allow a direct link between actors engaging in illicit or clandestine activities and third parties who register land titles. Examples include published actor network analysis with cadastral records, which have been used to link lesser known members of a cartel to specific parcels in the Petén (InSight-Crime, 2011), and investigative journalism at Mongabay to link illegal palm oil permits and shell companies with electoral dynamics in Indonesia (Chain Reaction Research, 2018; The Gecko Project and Mongabay, 2018). Researchers could make better use of investigative journalism efforts and systematize these reports at landscape scales.

Pixelizing and socializing approaches should inform one another to build understanding. The outcomes of pixel-based approaches can be used to calibrate behavioral decisions in an ABM. Likewise, ethnographic observations and pattern analysis may structure causal factors in a regression or other causal inference method. Leveraging both approaches is essential in the context of incomplete, fragmented, and/or unreliable data when studying illicit activity. Given the difficulty of obtaining pixel-based data about illicit or clandestine activities, however, greater understanding of such phenomena is more likely to come from synthesizing many socializing approaches, and leveraging that understanding to identify proxies of illicit activities for which pixel-based data can be obtained.

Next to the methods derived from the people and pixels efforts, other steps are needed to better address illicit-clandestine processes affecting land systems. Explicitly examining how the agency of illicit and clandestine actors shape the land systems requires bridging large and small divides between research orientations, such as political ecology and LSS (Turner and Robbins, 2008), as well as closer collaboration with political scientists. The mechanisms by which actors with power differentially enforce or implement land-use policies to key groups in order to maintain their electoral allegiance have been identified in political science (Albertus et al., 2016; de Janvry et al., 2014; Holland, 2016). This work, however, tends to lack a spatial component such that the land systems impacts of the transactions are insufficient for LSS. The framework presented here encourages the use of new data, old methods, and new interdisciplinary connections to take various approaches to understand the processes behind ever easier to detect land-use patterns. Beyond just people and pixels, power and politics constitutes a lacuna that, incorporated correctly, should improve LSS models for various types of social-environmental systems. This dissertation aims to begin to fill this gap through empirical analysis of the clientelism in informal urban development in Mexico City and narcotrafficking in Central America.

Socializing and Pixelizing urban expansion in Mexico City and forest loss in Central America

This dissertation focuses on empirical cases that exemplify contemporary, highly salient, urban and rural dynamics, critical at the interface of global efforts to conserve ecosystem services. Both cases require qualitative analysis to understand the action situation surrounding illicit transactions (orange circle, Fig. 1) as well as quantitative analysis to understand the extent and significance of these transactions on land conversion (blue circle, Fig. 1). While each case is distinct, under a unique set of institutional arrangements and ecological dynamics that define land-use outcomes, they were chosen in concert for this dissertation to empirically demonstrate that utility of the proposed conceptual framework in providing new insights to understand drivers of land change in diverse locations.

Case I: Informal Urban Land Transactions in in Mexico City (Chapters 2, 3, 5)

Underlying the influence of informal settlements in Mexico City is the severe housing deficit. Despite investment in public housing projects, the paucity of access to credit for the poor to purchase land makes the formal housing market inaccessible for a significant portion of the city's population. The majority (60%) of new housing construction is informal and unregulated (Connolly, 2009), comprising 65% of total urban housing and land use, the highest in Latin America. Formal programs designed to reduce urban expansion in order to mitigate floods and increase water supply, especially in the southern fringe of the city, include the District's "Zero-Growth" plan that forbids urbanization on conservation land, and support for farmers in the Basin to retain 17,000 ha of conservation land forested (Perevochtchikova and Vasquez Beltran, 2010). These formal programs are juxtaposed against the irregular and informal settlements that are driving urbanization patterns in the south of the city on conservation land (Aguilar and Santos, 2011; Tortajada and Castelán, 2003). The 847 irregular settlements along the city's southern fringe exist on four distinct property regimes: federal land, such as a National Protected Areas; *ejidos* (communally owned properties designated for agriculture in 1917); community land (communally owned indigenous properties dating to the 1600s); and private lands not yet designated as formally urban.

Regularization, the city's effort to accommodate irregular settlements into formal urban planning, has been a problematic solution to the crisis. This process increases land values by guaranteeing access to urban services and the ability to sell and rent land legally once tenancy is established (Cruz Rodriguez, 2000).The public sector cannot legally supply the physical infrastructure for water, sanitation, electricity, and drainage to informal settlements until their lands are "regularized." Paradoxically, some urban scholars find the increase in land value can force the original settlers who cannot afford formal market prices onto the next informal settlement (Legorreta, 1994); others, however, contest the generality of these empirical findings (Duhau, 1998). Regularization is a complex, multi-institutional process, which is dependent on land tenure type (Schteingart and Salazar, 2010).

Initial expert interviews confirmed politics permeates informal settlements and the regularization process at all stages. Politicians at every level—local borough, local representatives in the city legislative assembly, federal level senators, mayors, and even the President—can formally or informally influence regularization or access to urban services. Borough level politicians are informally incentivized to regularize settlements and/or provide public services as a way to gain votes for themselves in local elections or for their party in national elections, which facilitates their own upward political mobility. At the national level, Presidents have used their power to enact massive regularization programs, especially of informal settlements in *ejidos*, near election times (Herrera, 2005; C. E. Salazar, 2012). Commonly, politicians assist residents to obtain voting credentials; to avoid eviction; residents may need to provide proof of their vote in the form of photos of ballots or other indications of compliance. While the eviction process is spurred at the local level by boroughs in collaboration with the City's Ministry of Environment Department (SEDEMA), it can be stopped by the higher-level mayor's office, which must approve and finance the army personnel required for the eviction to be carried out. Much to the frustration of SEDEMA, the mayor's office tends to prevent evictions from happening around election time (pers. Comm. Via interview).

In addition to influencing land regularization and eviction process, various actors can directly influence urbanization via land invasion, corruption, and illicit land sales (Flores Pena and Soto Alva, 2010; Gilbert, 2002; Padgett, 2014; Ward, 1998). The total area of urban land settled via large or political motivated land invasion has never been estimated. Illicit land sales can occur by *ejido* or community members directly selling property on the informal land market to settlers, economic intermediaries who buy from *ejido* members and resell to settlers, or through large housing developers who acquire land through manipulating the *ejido* governance process and bribing local government officials to alter zoning. Ironically, these developments can then be sold back to the city government as public housing projects, common especially in the Northern rapidly expanding metropolitan area in the State of Mexico, just outside city limits. Not all urbanization of *ejido* land, or land held in common given by the state after the 1917 Revolution, is clandestine, however, and portions of this land can be legally urbanized and sold since the 1992 reforms to Agrarian law.[3] Of the 17,000 ha of *ejido* land that has

[3] The 1992 reforms to Agrarian Law allowed certified *ejidos* through PROCEDE (Certification Program for *Ejidos*) to privatize legally sell some parts of their land, while other parts remain unalienable. Yet, this program was never implemented within the Federal District of Mexico in part because the inability to define legal property lines between *ejidos* and land titles originally given to indigenous communities, which in many cases were incongruent. These property lines are still being defined in Agrarian Tribunal Courts.

been privatized and sold in the metropolitan area, 14,000 ha were used for large housing developments authorized to build 800,000 homes since 1992 (Salazar, 2014). Despite this growth in the formal housing market in the State of Mexico, informal housing and development continues to grow (C. Salazar, 2012).

Government actors tend to blame informal settlements for environmental damage in the conservation zone, while ignoring the key role (and responsibility) that formal public policy and clientelism play in the urbanization patterns. On the other hand, some civil society groups argue that clientelism is one of the few mechanisms to access housing and services for the poor, despite the political obligations this transaction engenders. This thesis will strive to illuminate where clientelism, a contentious political issue affecting urban justice and environmental services, might play a role in the urban landscape.

Case II. Forest loss and narcotrafficking in Central America (Chapter 4)

The case of clandestine rural dynamics focuses on deforestation patterns over two decades along the Mesoamerican Biological Corridor. This case exemplifies the detection of illicit activities in frontier areas. Central America has maintained extensive and remote forested areas along the Caribbean coast. Nonetheless, land colonization and an expanding agricultural frontier at the perimeter of densely forested areas are common as elsewhere in Latin America. In contrast, and uncharacteristic for Latin America, isolated, rapid, and extensive forest clearing is observed in parts of Central America. Such deforestation over the past two decades (Redo et al., 2012) has accelerated, despite large-scale international and NGO-led efforts to reduce deforestation in general. This acceleration has, to a degree, been attributed to expanded narcotics trafficking networks and an increased flow of drugs through Central America (Mcsweeney et al., 2014).

In Central America, cocaine trafficking is estimated to currently contribute between 5 and 15% of national GDPs (UNDOC 2011). Huge illicit sums of money need to be registered under "legitimate" businesses for cocaine moving through the region. Illegal logging, forest conversion to pasture for cattle ranching, clandestine airstrips, and roads, and other forms of land change are undertaken by narco-organizations as a means to move drugs northward and launder trafficking profits (McSweeney et al., 2017). Caribbean regions of Guatemala, Honduras, and Nicaragua are characterized by both weak and plural land-use governance (overlapping state and indigenous governance), a history of smuggling drugs, and have high indices of poverty. Thus, barriers are low and payoffs are high to illegally sell land or move drugs. Roles that have been traditionally the domain of state support (e.g., healthcare, schools) are sometimes replaced by "Narcos", paying for or supporting such functions to win community loyalty. These social dynamics have been well documented in both Honduras (McSweeney et al., 2018) and Guatemala (Devine et al., 2018) as cartels move deeper into remote Central American forests in response to drug interdiction (Magliocca et al., 2019).

I collaborate with a group of researchers, known as LITCA (Landscapes in Transition, Central America).[4] LITCA revealed anomalous deforestation patterns (patches, or any contiguous area of deforestation, are statistically significantly larger in size and exhibit more rapid clearing rates than other deforestation patterns), showed high correlation with cocaine trafficking patterns in several departments in Honduras, Guatemala, and Nicaragua (Sesnie et al., 2017). Beyond these correlations, additional effort was required to measure the causal effect of narcotrafficking on forest loss, accomplished in this dissertation.

[4] LITCA is an interdisciplinary team of anthropologists, geographers, and ecologists who have been documenting the effects of cocaine on rural communities in Central America for the past 4 years. This work is funded through a SESYNC (National Center for Social and Environmental Synthesis) team project of which I am part.

Questions and Hypothesis for this dissertation

The rest of the dissertation is organized as depicted in Figure 4. It proceeds by understanding institutional conditions that promote informal urban expansion in Chapter 2 through interview analysis. This qualitative analysis is followed by efforts to "pixelize" social data and estimate causal effects using fixed effects panel regression in Chapters 3 and 4. These chapters measure the influence of politically motivated versus illicit economy driven transactions on land conversion at a landscape scale in Mexico City and Central America, respectively. Chapter 5 aims to "socialize" urban land change patterns, using methodologies similar to what has previously been achieved in studies of narcodeforestation, from the typology of informal urban expansion developed in Chapter 2. The concluding chapter summarizes what was learned in previous chapters and sets an agenda for future research. Specific research questions and an abstract of each chapter follow.

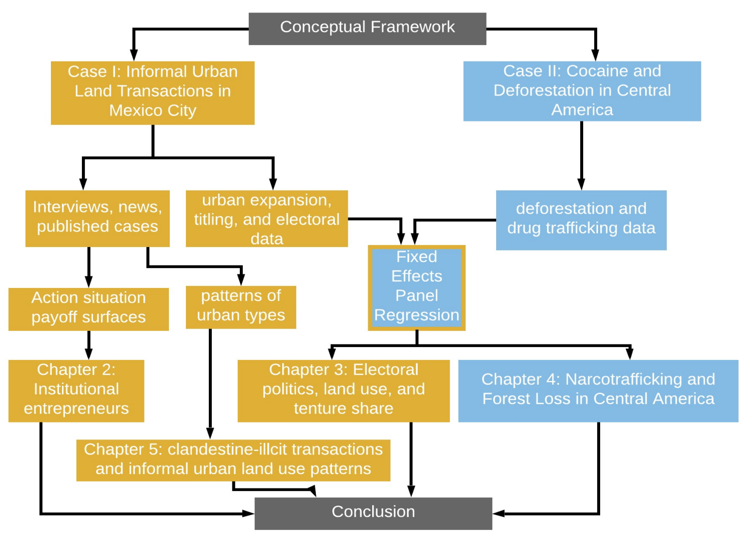

Figure 4. Roadmap of the dissertation.

Chapter 2: Institutional Entrepreneurs and Informal Urban Land Transactions in Mexico City

Research Questions:

1. What are the main types of clandestine land transactions in the Mexico City Metropolitan Area?
2. What institutional incentives and constraints produce the entrepreneurs that drive these main types?
3. What is the distribution of benefits and losses to actors in the action arena where these transactions take place?

Informal urban growth outpaces formal urbanization in the developing world. Understanding why this informality exists and persists is essential to counteract the common characterization that it is monolithic, chaotic, and ungovernable. This chapter seeks to disaggregate informality and develops a typology to reveal who shapes the rules ordering urbanization, consolidation, and legalization of informal urban growth in the Mexico City metropolis. Institutional analysis elucidates the distribution of payoffs in the "action situation" where decisions about urban land are made, and "institutional entrepreneurs", actors that repeatedly evade or alter formal rules or create new rules of urban land regulation. Interview data regarding the distribution of costs and benefits to actors shaping informal urbanization identifies potential leverage points for institutional change. Disaggregating informality into its component pervasive institutions and analyzing the distribution of payoffs in and beyond Mexico City provide insights about governance that may reduce threats of informality to urban sustainability.

Chapter 3: Do electoral politics influence land titling and expansion of informal settlements? The case of Mexico City

Research Questions:

1. How does the distribution of land titles vary with the electoral cycles and voting patterns in private and collective land tenures in Mexico City?
2. Does clientelism influence urban growth?

Hypotheses:

1. Urban land titling of informal settlements on collectively held and private land reflect political business cycles and increases prior to elections.
2. Titles are preferentially distributed to core party voters.
3. Urban expansion increases with the ratio of votes to the core party.

Informal settlements often lack access to basic services and have insecure tenure because they exist outside the formal urban zone and tend not to have property titles. Politicians may seek to provide support to settlers in the form of land titles, connection to urban services, and other ventures in exchange for their votes. While this relationship has long been recognized, the hypothesis that electoral politics may influence settlement expansion and the distribution of land titles has not been formally tested. This chapter tests that relationship using panel regressions to examine electoral cycles and voting patterns on the distribution of land titles and informal urban growth in conservation lands from 1997-2015 in Mexico City.

Chapter 4: Accounting for "illicit" activity in land change: Narcotrafficking and forest loss in Central America

Research Questions:

1. Does narcotrafficking have a causal effect on forest loss, controlling for other drivers and causes of deforestation?
2. Can a systematization of media reports represent narcotrafficking activities?

Hypotheses:

1. Forest loss covaries with the intensity and level of drug trafficking in Central America when it is transited through forested areas.
2. News media events (e.g., a law enforcement seizure of cocaine) represent the spatial and temporal variability of narcotrafficking and complement official data

to determine the connection between the location and timing of trafficking events and annual forest loss.

Illicit activity plays a significant role in land changes, such as forest loss. Despite this recognition, a paucity of data on illicit economies and behavior makes it difficult to incorporate into quantitative models of land change. This chapter offers a novel approach for an empirical demonstration of the use of data proxies of illicit activity to meet this challenge through the case of narcotrafficking and forest loss in Central America. Two narcotrafficking activity proxies were developed for modeling: i) an "official" proxy - government measured drug seizures for 14 sub national units; and, ii) and an "unofficial" proxy - spatialized media counts of narcotrafficking events. Evidence continues to build that narcotrafficking plays an important, yet often unreported, role in forest loss as traffickers clear land for money laundering operations and territorial control in response to interdiction efforts. This effect has not been systematically compared to the other well-known non-illicit causes of deforestation in the region, however, such as rural population increases and expansion of pasture for cattle. Longitudinal data on 50 sub-national units over a period of 16 years (2001-2016) is used in fixed effects regressions to estimate the role in narcotrafficking in deforested areas.

Chapter 5: Towards identifying informal urban land use patterns

Research Question:

1. Do distinct orders of social processes driving urban informality produce similarly ordered spatial morphology of urban land change?

Understanding how illicit and clandestine transactions influence land change is of increasing interest to land systems science, but "pixelizable" data on these activities is often unavailable. In this chapter, we employ techniques previously used in detecting illicit deforestation patterns in forest areas to the analysis of informal urbanization. We link distinct patterns of informal urban expansion observed in high resolution satellite imagery to the associated urban institutional processes each engenders. This approach could improve urban land prediction models and aid governance in the rapidly urbanizing Global South, characterized by high informality.

Chapter 6: Conclusion

This chapter summarizes the research presented on the topic and assesses the degree to which this dissertation successfully identified clandestine drivers of land change by either their unique spatial patterns of change or through correlations with proxies of illicit activity. It remarks on the advances and challenges making to both pixelizing and socializing approaches attempted in this dissertation and synthesizes results from case studies to remark on the role of clandestine activity in urban and forest systems. This chapter identifies an agenda for research in illicit activity in forest and urban systems, and the data and methods needed to make progress.

CHAPTER 2

INSTITUTIONAL ENTREPRENEURS AND INFORMAL URBAN LAND TRANSACTIONS IN MEXICO CITY

Abstract

Informal urban growth outpaces formal urbanization in the developing world. Understanding why this informality exists and persists is essential to counteract the common characterization that it is monolithic, chaotic, and ungovernable. This research seeks to disaggregate informality and develops a typology to reveal who shapes the rules ordering urbanization, consolidation, and legalization of informal urban growth in the Mexico City metropolis. Institutional analysis elucidates the distribution of payoffs in the "action situation" where decisions about urban land are made, and "institutional entrepreneurs", actors that repeatedly evade or alter formal rules or create new rules of urban land regulation. Interview data regarding the distribution of costs and benefits to actors shaping informal urbanization identifies potential leverage points for institutional change. Four types of informal urban land transactions are identified: i) urbanizing individual plots of land, ii) flipping or subdividing land into multiple parcels, iii) invading land, and iv) manipulating social and public housing developments. We find institutional entrepreneurs—intermediaries, developers, and politicians—disproportionately benefit from and reinforce unplanned urban expansion. These entrepreneurs provide housing for the urban poor, but with social and environmental costs, including exploitation of informal settlers and urbanization of conservation land and loss of environmental services. Disaggregating informality into its component pervasive institutions and analyzing the distribution of payoffs in and beyond Mexico City provide insights about governance that may reduce threats of informality to urban sustainability.

Introduction[5]

Over 90% of urban growth takes place in the Global South. A large portion of new urban residents move to informal, unplanned settlements where inhabitants have little to no tenure security, lack basic services, and construct homes in areas disproportionately vulnerable to "environmental" disaster and risk. Understanding why informal urban settlements exist and how they persist are essential to a large range of urban research and practice attempting to understand and govern urban land systems and enhance urban sustainability and equity.

Informal urban growth, or urban informality, is often characterized by urban planners and government authorities as chaotic and ungovernable (Lerner et al., 2018; Roy, 2005). It is either ignored or presumed to operate similarly to formal growth (Vermeiren et al., 2012). Most land change models fail to account for the socio-political dynamics shaping informal urban expansion (Roy et al., 2014, but see Patel et al., 2012)). This omission is unsurprising, given that the political incentives governing informal expansion are not well understood (Navarrete, 2016; Post, 2018).

Urban informality has been explained as a product of under-resourced governments unable to absorb the overwhelming rural-urban migration of impoverished populations unable to afford formal housing in a neoliberal era (Márquez López and Pradilla Cobos, 2016; Pradilla, 1995; Schteingart, 1989; Van Gelder, 2013). In contrast, De Soto (2000) argued informality flourishes because the process to obtain permits to urbanize legally is too slow and bureaucratic. As a result, residents access land more rapidly and much cheaper on the informal as opposed to the formal land market in Latin America. De Soto's influential work promoted eliminating informality via rapid titling programs in cities with mixed success (Gilbert, 2002; Jaramillo, 2008).

[5] This chapter was written in collaboration with Hallie Eakin, Felipe de Alba, and Marco Janssen and will be submitted for publication after final revisions.

The persistence of urban informality is undergirded by the political and economic incentives of actors with the authority and influence to shape urban expansion. Previous work describes how economic profits motivate mafias to shape urban land uses in slums in Nairobi (Henderson et al., 2016), or government officials to clear slums for shopping malls in Mumbai (Weinstein, 2008). Researchers have long recognized that rural populations moving to cities generate political capital—their vote— that political party-brokers seek to capture (Cornelius, 1972; Scott, 1969). As such, informal settlements are co-produced in conjunction with formal governance (McFarlane, 2012; Roy, 2005). Politicians achieve political support from informality by providing services, such as electricity and water (De Alba et al., 2014), ensuring slums are not evicted (Holland, 2016), promising to provide land titles (Connolly and Wigle, 2017a; Varley, 1998), and other such strategies.

Extensive, qualitative research on Mexico City has long recognized the political economy reinforcing informal settlements and their social and environmental consequences (Aguilar, 2008; Aguilar and Guerrero, 2013; Pezzoli, 2000; Schteingart and Salazar, 2010; Ward, 1976). It profiled the role of brokers or *caciques* (chiefs) in delivering urban services (Cornelius, 1972), identified different types of informal expansion dependent on location and land tenure type (Ward, 1976), and examined the politics of efforts to regulate (or eliminate) informal growth (Connolly and Wigle, 2017b; C. E. Salazar, 2012; Wigle, 2014). Yet, this scholarship tends to be rooted in a diversity of qualitative case studies from disparate disciplines and frameworks, making it difficult to identify the actors, incentives, and payoff schemes ordering informal urban expansion across the metropolis. We address this challenge by offering a novel approach to reveal the pan-metropolis structure of urban informality.

This paper examines the institutional arrangements that produce different types of informal urban expansion in Mexico City, one of the largest cities in the world, and characterized by informal growth. The Institutional Analysis and Development Framework, of which action arenas are a core element, is used to analyze decisions of "institutional entrepreneurs" or actors who repeatedly evade or alter formal rules or create new rules of urban land regulation. Urban informality is disaggregated into its component types to analyze the rules and actors governing social and institutional patterns. We introduce payoff surfaces as a way of visualizing the relative influence of material (economic) and non-material (social and political) incentives among actors. Examining payoff schemes reveals who profits from persistent informality and helps to clarify the role and root causes of clientelism, corruption, and other clandestine practices affecting urban development in Mexico City and elsewhere.

Three overarching questions guide this research:

1. What are the main types of informal land transactions and institutions in the Mexico City Metropolitan Area?
2. What institutional incentives and constraints produce the entrepreneurs that drive these main types?
3. What is the distribution of benefits and losses to actors in the action arena where these transactions take place?

The "action arena" payoff surface in informal urbanization

The persistence of social and ecological dynamics can be revealed through analyses of institutional arrangements and actors. Institutions are the sets of rules and norms that structure human interactions (North, 1990). The IAD (Institutional Analysis and Development Framework) focuses on the roles of specific actors and their interactions in decision situations (or action situations) (Ostrom 2011). It has been used to address a wide range of public policy and collective choice problems from metropolitan service distribution to irrigation system rules (Ostrom 2005).

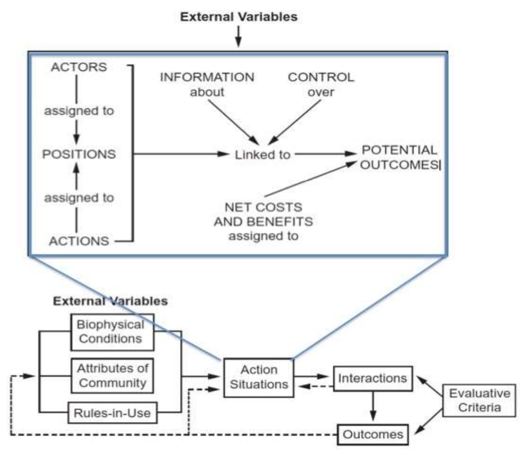

Figure 5. Institutional Analysis and Development Framework with a focus on the Action Situation (from Ostrom (2011)).

We use the IAD and action situation (Fig. 5) to understand informality. The biophysical context (land), the rules in use, and the attributes of the community shape the action situation "... where individuals interact, exchange goods and services, solve problems, dominate one another, or fight" (Ostrom, 2011 pp:10). Not all actors in the arena have equal footing. Each has a position, set of choices, access to information, and control over the outcome (or power). Beyond property rights, this power asymmetry largely influences who has access to the benefits of outcomes (Ribot and Peluso, 2009) and how this distribution of payoffs shapes institutional change (Knight, 1992). The outcome of the decision made in the action situation affects land use, rules in use, and social arrangements which set up a subsequent action situation and the next decision. Overtime, this iteration forms a pattern of rules in use and develops into an institution governing collective behavior.

Institutional analysis focuses on both formal and informal rules (Ostrom, 2005), and we focus on the latter for this paper because they largely shape informal urban settlement growth. We define informal institutions as "... socially shared rules, usually unwritten, that are created, communicated, and enforced outside of officially sanctioned channels" (Helmke and Levitsky 2004: 727). Analyzing informal institutions requires documenting the extensions, elaborations, and modifications of formal rules, socially sanctioned norms of behavior, and internally enforced standards of conduct (Navarrete, 2016).

Informal urban land transactions include rezoning, conversion, or purchases of land that occur outside of or in opposition to formal markets and governance processes. Informality in these transactions typically involves exchanges between marginalized urban residents who cannot afford access to formal urban land and services, and the actors with the power to fulfill these needs. Transactions are enforced through trust, intimidation, or violence (Lambsdorff et al., 2005b), characterized by clientelism[6], corruption[7], and rent-seeking[8].

Urban land transactions exhibit a wide range of other clandestine informal exchange, intentionally hidden from appropriate authorities or subverting informal norms and ethics (e.g., sanctions, taboos, customs, traditions, and codes of conduct). Not all informal activity is illicit or illegal, however. For example, politicians commonly provide cement to those building homes in urban conservation land in Mexico City, an activity that is not expressly illegal (Hagene, 2015). This activity is used to secure voter support, however, which in turn sends the message that the informal construction is permissible and authorities are likely to let it remain and, perhaps, supply services (e.g., water and electricity). This study focuses on informal land *transactions* as opposed to informal *settlements,* permitting a wider view than previous research focusing only urban land use that is "illegal" because it exists outside the regulated urban zone. An emphasis on transactions allows us to analyze, for example, legal urban developments

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[6] *Clientelism* is the contingent exchange of votes for public goods or services (Hicken, 2011; Stokes et al., 2012)

[7] *Corruption* is an unauthorized transaction between an elected or appointed official and a third party (Groenendijk, 1997).

[8] *Rent-seeking* is a special type of corruption. It occurs when regulation (e.g., laws against deforestation or urbanization) increases scarcity to a good (e.g. land), and a government actor facilitates access in exchange for an economic kick back (Krueger, 1974).

generated by clandestine exchange (e.g. a bribe to payoff an official to change zone regulations) that are not classified as informal settlements. Analyzing formal urban development shaped by informal transactions is important because it may be responsible for more urban land change than the informal settlements receiving the majority of research and policy attention.

In general, weak formal governance institutions in tandem with high rates of inequality or low transparency regarding the distribution of public goods makes the action situation favorable for clandestine activity. Interactions between powerful actors and less powerful marginalized urban residents may create a "Faustian bargain" in which the uncertainty of the livelihoods of the urban poor is reduced in the present, with the long-term costs of repeated unjust, risky, or even violent consequences (Wood, 2003). Powerful actors in this way convince marginalized actors to follow the rules benefiting the already powerful actors (Knight, 1992).[9]

Institutional Entrepreneurs and Payoff Surfaces

Institutional change and the formation of the action situation is dominated by actors with power and the ability to mobilize resources to affect outcomes (Avelino and Rotmans, 2009). These "institutional entrepreneurs" mobilize resources, such as informational, economic or political capital to create or transform institutions that favor his or her interest (Pacheco et al. 2010). Institutional entrepreneurs abide by, evade, or alter existing institutions and rules (Henrekson et al. 2010). Actors abide when they leverage existing institutions to their benefit, including engaging in rent-seeking, clientelism, graft, or leveraging existing social and political networks to access goods or services. They evade when they avoid existing regulations, such as by holding profits in

[9] Other explanations for why marginalized people participate in exploitation (not covered in this study) may reside in the "struggle for recognition" of informal settlers who feel ignored or invisible by formal actors but recognized by informal brokers and internalize their authority (Honneth, 1996)).

tax havens, bribing a government official to avert regulation, or threatening violence towards those who pursue to legal sanctions against them. Finally, actors alter existing institutions by creating new sets of rules or norms to distribute illegal goods and services (e.g., electricity and water). These entrepreneurs fulfil unmet demands of the urban poor, producing normatively "good" or "bad" outcomes depending on the constituencies they serve and the time scale at which the outcome is analyzed. In Mexico City, for example, entrepreneurs fulfill unmet housing demand for the urban poor in the short term, but reduce environmental (ecological) services in the long term for the city at large where that housing expands on conservation land (e.g., for water provisioning).

Institutional entrepreneurs have the skills of transformative agency, such as recognizing or creating and seizing windows of opportunity, facilitating social innovation, building trust and legitimacy, and leveraging social networks (Westley et al., 2013). Entrepreneurs leverage these skills in land transactions. They dominate the action situation because of their greater access to information, such as legal loopholes e.g. to obtain ownership via paying cadastral taxes for a specified number of years, and control over outcomes compared to other actors. Powerful actors distribute existing political, economic, and social capital to convince others to agree to their desired outcome (Knight, 1992). These dynamics ultimately determine a "surface" of the distribution of payoffs (Fig. 6).

Payoff surfaces can be used to analyze the incentives and constraints shaping decisions and subsequent outcomes. This qualitative visualization highlights which actors— the leverage points for institutional change—receive the largest cost and benefits and influence the land use outcome. At the risk of oversimplifying complex social and political dynamics, visualizing payoffs can help disentangle material and immaterial costs and benefits, demonstrating why and how informal institutions emerge. The payoff surface is static for one point in time; shifting rules in use, biophysical conditions, or power will change level of control for each actor and perceived costs and benefits.

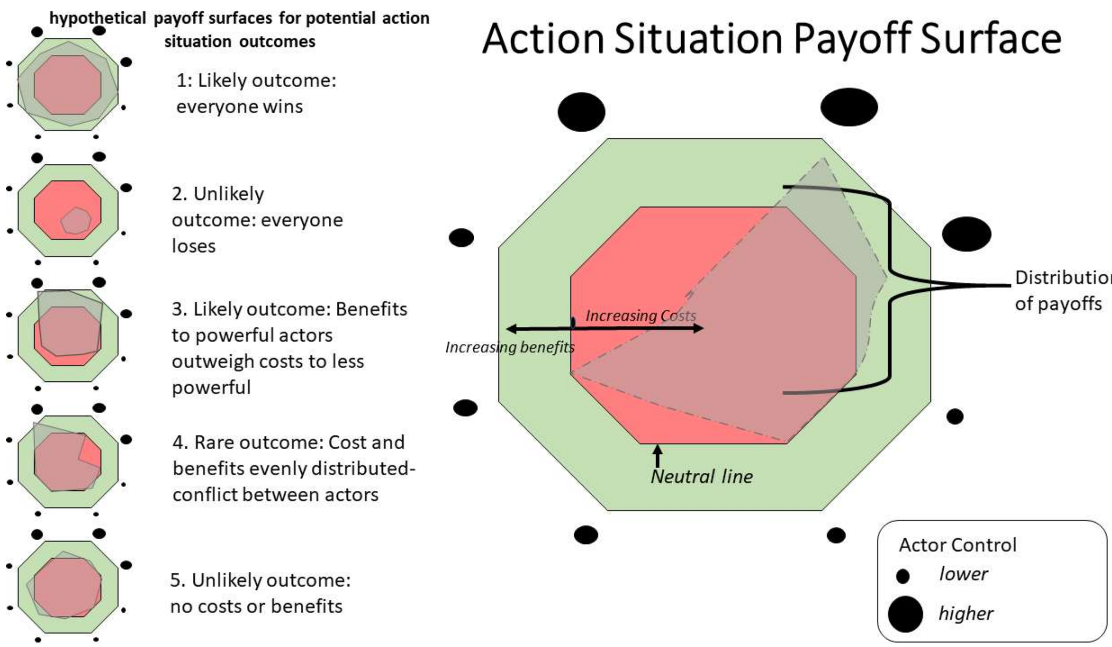


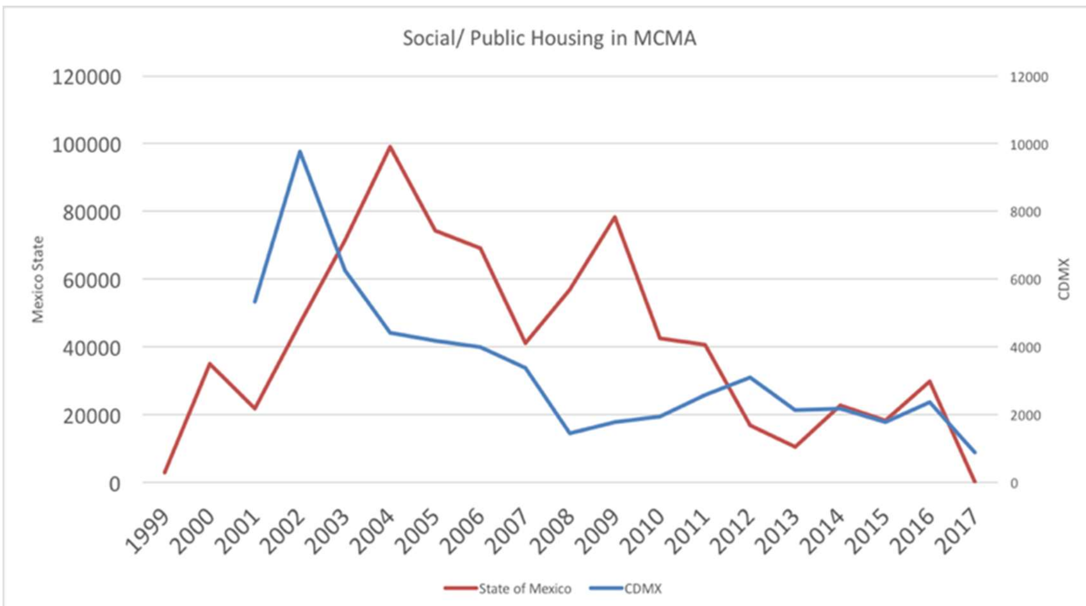
Figure 6. Hypothetical payoff surface of potential outcomes of the action situation. Distribution of payoffs is a surface (grey) shaped by the costs and benefits to each actor (black circles) arranged around the radial action surface. More powerful actors, with larger circles, have more to lose and gain in outcomes. The degree of cost (red shaded area) or benefit (green shaded area) for each actor is measured by the distance of their vertex to the neutral line. The edge of the cost and benefit area represents neutral or no payoff (e.g., actors with no stake in the outcome have their vertex at or near the neutral line). Connecting the vertices results in a polygon representing the distribution of payoffs among actors. Payoffs surfaces 1-5 are examples of potential distribution of payoffs given the degree of control, cost, and benefit of the potential outcome to each actor. An outcome is likely to occur if the green shaded area is larger than the red unshaded area (e.g. 1 and 3), and only sometimes occurs when the costs and benefits are similar (e.g. 4).

Informal Urbanization in Mexico City

Urbanization in Mexico City is largely informal and driven by a lack of affordable housing options, with nearly 9 million people in Ciudad de Mexico proper (hereafter, CDMX) and over 21 million in the metropolitan area extending into the State of Mexico (hereafter MCMA, Mexico City Metro Area, including CDMX). Since the 1930s most new housing in CDMX has been informal and unregulated (Connolly, 2009; Davis, 2010).

Despite investment in public housing projects (Fig. 7), the paucity of access to credit for the poor to purchase land makes the formal housing market inaccessible to them. The housing deficit is estimated at 250,000 and 650,000 units for CDMX and MCMA, respectively, despite 50,000 and 770,000 public housing units built in CDMX and MCMA, respectively over the past 15 years (based on data from INVI (Housing Institute of Mexico City) 2017, Instituto Mexiquense de la Vivienda Social 2017).

Figure 7. Social housing units built in the State of Mexico by Infonavit (National Housing Fund for Workers) (blue line) and Mexico City by INVI (National Institute of



Housing) (red line) since ~2000. Two axes are used since housing in State of Mexico is 10x that of Mexico City.

Informal settlements occupy land not zoned for urbanization. They exist on four distinct property regimes: federal land, such as a National Protected Areas, private lands not yet designated as formally urban, and two types of social property or land held in communal title, collectively termed agrarian land. Two types of social property (land

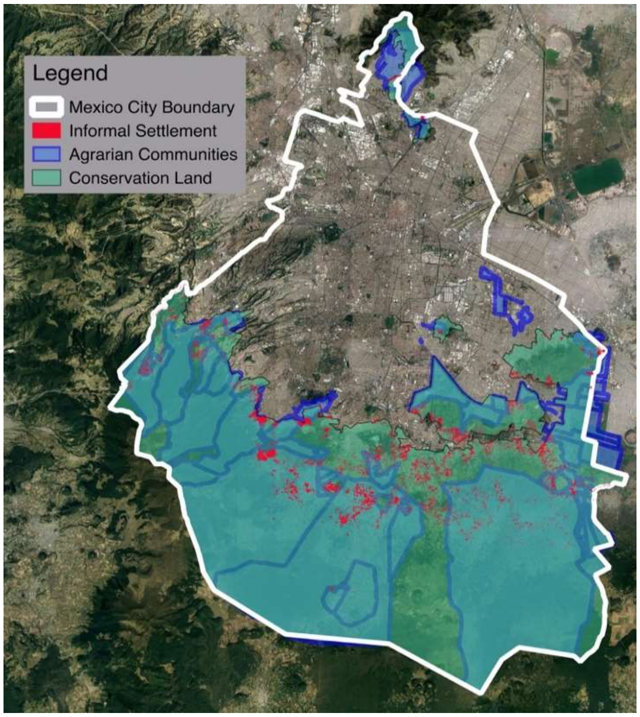


Figure 8. Informal settlements (SEDEMA 2016) and agrarian communities (inclusive of both *ejido* and communal land) in Mexico City (compiled for this study from RAN (National Agrarian Registry), SEDEMA (Mexico City Ministry of the Environment)).

held in common instead of individually) include *ejidos* (communally owned properties designated for agriculture in 1917) and community land (communally owned indigenous properties dating to the 1600s).[10] Social property include communal use areas and plots designated for individual members to use, which can be rented but cannot be legally sold.[11] Both individual use plots and communal areas are informally sold to residents in the MCMA. As some communities have been unable to achieve official recognition, the tenure of their lands remains in dispute. Communities and *ejidos* in CDMX are collectively referred to as "agrarian communities."

Most informal settlements in CDMX occur in agrarian communities on conservation land (Fig 8). Conservation land in the south of the city is not zoned for urban development. Permitted land uses there include a mixture of pasture, agricultural, forest, and rural agricultural homes. Productive activity in conservation land are subject

[10] Both the Spanish Crown post-conquest (known as communal titles) and the Mexican revolution granted social property land titles (known as *ejido* titles) which could not be bought or sold until the Mexican agrarian reform in 1992. Considerable dispute remains over overlapping claims between communal and *ejido* land claims, which remains unresolved in Tribunal Agrarian Courts . The term agrarian land is used to refer to include both.

[11] In article 48 of Mexican Agrarian Law, any one who uses land "peacefully" (that is, in "good faith", meaning the person does so with the permission of the land owner) gains *ejido* rights to the land in five years. In order to prove this "posesion pacifica", the *ejido* governing board will often charge informal settlers a yearly fee and a slip of paper they can use to prove their "peaceful" and "good faith" possession. Though selling *ejido* parcels is illegal, extending a "peaceful possession" grant, is not. This is a common informal way *ejido* members "sell" land to outsiders.

to restrictions including requiring permits for felling trees, construction, and certain types of agricultural inputs.

While no official data exist to estimate informal settlement land and population in the MCMA, in CDMX there are at least 3,200 ha of informally urbanized land and an estimated 480,000 people living in 859 informal settlements (Santos, 2013, Sedema 2016).[12]These populations are economically and socially marginalized (Aguilar, 2008; Aguilar and Guerrero, 2013; Aguilar and Lopez, 2015; Aguilar and Santos, 2011) and are often engaged in social and political relations that exploit their vulnerability (Cornelius, 1972; Flores Peña and Soto Alva, 2010; Lomnitz, 2017; Pezzoli, 2000).

The city has attempted to control informal urban growth on conservation land amid growing concern regarding environmental impacts of land change on flooding and aquifer recharge (Santos, 2013; Schteingart and Salazar, 2005). Formal programs designed to reduce urban expansion in the southern fringe of the city include the CDMX "Zero-Growth" plan forbidding urbanization on conservation land, eviction of settlers, and support for farmers in the Basin of Mexico via payments for environmental services (Perevochtchikova and Vasquez Beltran, 2010; Pezzoli, 2000). These programs have not stopped informal growth.

Regularization, the city's effort to accommodate irregular settlements into formal urban planning, has been a problematic solution to the crisis (Connolly and Wigle, 2017; Hiernaux and Lindón, 1996; Iracheta Cenecorta and Smolka, 2000; C. E. Salazar, 2012; Varley, 1998; Wigle, 2014, 2010). This process guarantees residents access to urban

[12] The population estimates are generated by the authors of this study via combined electoral and census data with the 2017 data on informal settlements from SEDEMA. Electoral data contains population estimates in rural areas that can be used to estimate population outside of the urban AGEB census data which does not cover at least 30% of existing document informal settlements. My counts are double the official population counts from SEDUVI. These figures only represent the population living on conservation land, which is not zoned for urban use, and does not include the thousands of squatters in buildings and urban lots in the city center, homes with private title issues, and the many other ways that characterize some type of "irregular" legal situation with respect to land use or tenure (Connolly, 2014).

services and the ability to sell and rent land legally (Cruz Rodriguez, 2000). The public sector cannot legally supply the physical infrastructure for water, sanitation, or electricity to informal settlements until their lands are "regularized." Regularization is a complex, multi institutional process, dependent on land tenure type and takes 5-20 years (Lerner et al., 2018; Schteingart and Salazar, 2010). As a result, many communities are never regularized. Informal urbanization has outpaced regularization.

Government actors blame informal settlements for environmental damage in the conservation zone (Connolly and Wigle, 2017a; Lerner et al., 2018), while ignoring the key role (and responsibility) of formal public policy and clientelism play in urbanization patterns (Azuela de la Cueva, 1987a; Duhau and Giglia, 2008; Hagene, 2010; Varley, 1998). Some civil society groups, however, argue that clientelism is one of the few mechanisms to access housing and services for the poor, despite the political obligations this transaction engenders (Eakin et al., 2016). Both government actors and previous research has focused on informal settlements, instead of on informal transactions. Previous work has paid little attention to the informal nature of exchange shaping urban expansion in formal development, such as the social and public housing sector, largely influenced by informal transactions.

In a given land area in MCMA, there are four possible outcomes that take place on urban land, each of which are considered in the action arena and analyzed: urbanization, regularization, eviction, or service provision. Urbanization is an outcome of the decision to change land use from forest or agriculture to build a residential home or apartment. Regularization involves land tenure or zone changes, such as granting land title or changing the zone from agricultural to urban. Eviction or "mitigating" urbanization involves the removal of homes or other activities to prevent urban growth.

Providing services includes informal or formal development of utilities such as water, electricity, or drainage services.

Methods

Interviews and participant observation

Preliminary fieldwork on informal settlements was conducted from June-October, 2016, undertaken in Spanish by the lead author. It included 10 interviews with academic experts on CDMX and MCMA urbanization and 10 actors shaping and regulating informal urbanization, including government officials, residents, and political leaders. These interviews influenced the typology of informal urbanization in the MCMA.

Interviews were selected for the various actors in each informal urbanization type (Table 1) based on snowball sampling (Bernard, 2006). Resident actors are those that purchased informal land to build a home or lived in social or public housing. Land owners and land "flippers" (those who resell many plots), private construction developers of social housing, and "intermediaries" (brokers of urban services to residents) were also interviewed. Other actors included leaders of political and civil society groups distributing urban services and titles. Formal governance actors included officials at ministries regulating land use and title and urban services. All interview personnel were selected through a snowball process, and due to the sensitive nature of the topic, an introduction from a trusted, existing contact facilitated their participation.[13] Fifty-four interviews took place from October 2016- August 2017 in the MCMA in government offices and communities where urbanization was taking place (Fig. 9

[13] Some actors declined interviews due to safety reasons and the sensitive nature of the topic. Interpretations provided in this research required triangulation between other interviewees, media, and additional academic research published by local scholars (Flores Peña and Soto Alva, 2010; Schteingart and Salazar, 2010). The most powerful actors were notorious, and interviewees often repeated similar stories about the same institutional entrepreneurs, making triangulation a viable strategy. Developers of social housing were also reluctant to grant interviews, save one. For all other urbanization and actor types, interviews reached "saturation", an indication that enough qualitative, empirical evidence was collected (see (Morse, 1995) for a definition of saturation). In general, interviewees were open about the topic and provided rich detail about corruption, clientelistic exchange, and the nature of land transactions.

identifies the approximate locations of 18 communities, intentionally mapped vaguely to protect identity of community and participants). A larger number of actors were interviewed for ant urbanization because it took longer to reach saturation due to the high amount of variance in transactions and actors involved.

Table 1. Categories of interviewees by urbanization* and actor type

urbanization type	civil society, political party	government official	land owner, flipper, developer, or intermediary	resident	Total
ant	2	10	8	7	27
invasion	4	1		1	6
illegal subdivision	1		3	2	6
public housing	1	2	1	1	5
regularization**	1	8			9
Total	9	21	12	12	54

*See explanation of the classification in the results section

**many government actors are involved in land titling. Of the 21 government actors interviewed, 4 regulate the environment and mitigating urbanization (PAOT (Procuraduría Ambiental y del Ordenamiento Territorial de la Ciudad de México/The Environmental and Regional Planning Attorney General's Office), AZP (Area de Zona Patrimonial), SEDEMA (Secretaria de Medio Ambiente de la Ciudad de México/ Secretariat of Environment of Mexico City)), 7 are involved in titling (CORETT (Comisión para la Regularización de la Tenencia de la Tierra/ Commission of Regularization and Land Tenure), DGRT(Dirección General de Regularización Territorial/Ministry of Land Regularization), RAN (Registro Agrario Nacional/National Agrarian Registry), FIFONAFE (Fondo Nacional de Fomento Ejidal/National Ejido Growth Fund), INSUS (Institutio National de Suelo Sustenable/ National Institute of Sustainable Land), 3 in urban service provision (CFE, SACMEX, city legislators), and 6 with urbanization directly (Local government, SEDUVI (Secretaria de Desarrollo Urbano y Vivenda de la Ciudad de México/Secretariat of Urban Development and Housing for Mexico City), INVI (Institutio de Vivienda de la CDMX/ Institute for Housing, Mexico City).

Semi-structured interviews were employed, aimed at understanding the perceived costs and benefits to each actor from the four land use outcomes: urbanization, regularization, eviction, or service provision. Interviews involved questions about buying or selling land, the motivations for exchange, conditions of transaction, the price, the time and process to access services and titles, and government agencies that hindered or facilitated the process (see appendix A for survey instrument). Government regulators were questioned regarding their role in regularization, eviction, and service provision, and other agencies that facilitated or obfuscated their mission. Selected quotes from the interviewees illustrate the results. Pseudonyms replace actual names.

Participant observation in field sites allowed for collection of additional information on actors, especially intermediaries. Government meetings attended include the CREX (Special Commission for Regularization, where representatives of government agencies decide which informal settlements receive title) and meetings to plan evictions. Leaders of political groups well known for leading squatter groups to settle in the land invasion type included *Antorcha Campesina* and the *Frente Popular Francisco Villa Independiente*. Leaders were asked to delineate the territories they were responsible for urbanizing using a GIS.

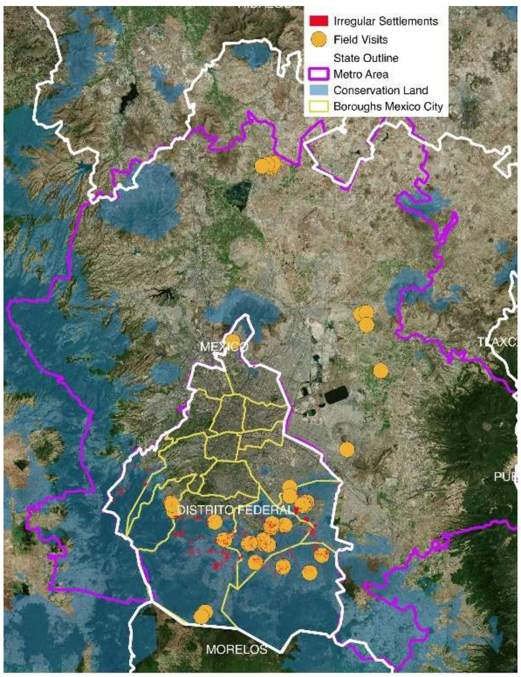


Figure 9. Map of field sites (approximate location) to informal urbanization sites across The Mexico City Metropolitan Area.

Coding and Analysis

All interviews were recorded and the transcribed notes thereof were analyzed using the qualitative analysis software Dedoose. Codes were based on the action situation variables, including access to information (high, medium, or low), control (high, medium, or low), and payoffs (positive, neutral, or negative) to each actor in four potential outcomes (or variables) of the action situation: urbanizing, regularizing, evicting, or providing services. Categories of high, medium, and low access to information and control were determined qualitatively based on interview quotes which directly asked respondents to comment on these factors.

In order to visualize the data as payoff surfaces, data for each of these variables from the action situation per actor were recorded in an institutional matrix for each of the four urbanization types studied. Qualitative information from these tables were recoded into level of control (high=3, medium=2, low=1) and presence or absence of payoffs (positive=1, neutral= 0, and negative = -1). The payoff surfaces (Fig 6) for each outcome are displayed by multiplying the level of control by the payoff (to plot the vertex of each actor) and drawing a polygon connecting all vertices. Thus, the most powerful actors (control = 3) shape the payoff distribution surface three times that of the least powerful actors (control=1). Payoffs include social, political, economic, and land based costs and benefits, detailed in the institutional matrices and indicated in action situation surface radial plots.

Results

Three types of informal urbanization have been identified previously and are confirmed in this study, and we add a fourth not recognized in previous assessments : i) ant urbanization (direct sale of one plot to one settler), ii) illegal subdivision (one actor who buys and sells many plots of land), iii) land invasion (a group of settlers illegally squatting on land), and, the added type, iv) social or public housing (city or federal subsidized housing for low or middle income populations).

Ant urbanization, or locally "*urbanizacion hormiga*", is the direct sale of a small plot of land between two parties, resulting in incremental settlement growth (Aguilar and Lopez, 2015; Aguilar and Santos, 2011; Ruíz-Gómez, 2006). Based on my results, ant urbanization likely represents the highest *number* of total informal urban transactions on conservation land and is the most common way of accessing informal urban land in

CDMX. Typically, a member of an agrarian community needs to sell an asset, or no longer wishes to farm and, advertises a parcel for sale on a sign or light poles, in the newspaper, or in a local store. Interested parties in purchasing land on the informal market, commonly from a rural area, call to arrange a price and sign a "*compra-venta*", or buy-sell contract with a notary. Often the seller offers credit to the buyer who pays in installments. This informal "sale" is not against the law, but the contract has no legal standing in court because the plot is either social property or of uncertain tenure.[14]

Subdivision is the second most common way to access CDMX conservation land, and the most common form of access in the MCMA. Most subdivision occurs exclusively on social property, unlike ant urbanization, which includes private land. In this arrangement, an intermediary typically purchases a large area with many plots, sometimes obtained through bribery, violence, or by exploiting legal uncertainties in ownership. These institutional entrepreneurs are locally referred to as "*fraccionadores*", which we translate to subdividers or land flippers. Large-scale subdivisioning (100+ lots) is common in the MCMA, with smaller scale subdivisioning on conservation land prevalent in CDMX. Together, ant urbanization and subdivision account for the 3,200 ha of informal urban growth in conservation land in CDMX (Connolly and Castro, 2016).[15]

The least common way to access land is land invasion. It is colloquially referred to as *paracaidismo,* or parachuting, indicating the arrival of many people suddenly descending onto a plot of land and constructing homes. Invasions are typically directed by a political leader and occur on public or federal land, such as parks, trash dumps, small urban plots, or buildings with uncertain legal status. This form of urbanization

14 Only parcels registered in the Public Property Registry have institutional backing for individual ownership. Some settlers may have "*posesion pacifica*", which does not guarantee legal ownership rights, but may be useful supporting documentation to "regularize" the property (give a private land title) if the settler seeks to gain legal title.

15 While exact numbers of informal urbanization are unavailable for the greater metropolitan area, census districts with at least 50% of their population in "*colonias populares*", which include both ant urbanization and subdivision, represented 66,000 ha (Connolly and Castro, 2016). The actual amount of urbanized land within these 66,000 ha is unknown.

was prevalent in Mexico City in the 1940s-1970s (Moctezuma, 1984; Ward, 1976), and immediately after the 1985 earthquake, but has since declined. New invasions continue to occur in CDMX and the MCMA, however, under the auspices of two groups, *Antorcha Campesina*, and *Frente Popular Francisco Villa* (FPFV). Participatory mapping with these two groups revealed they claim 37 communities on 600 ha, less than 2% of the area of urban land growth in the MCMA.

Public and social housing is commonly ignored in studies of informal urbanization, perhaps due to its mostly "legal" nature. Informal rules and transactions largely shape its development, however, warranting consideration when analyzing informality. This form of urbanization consumes the largest total land area, representing up to 11,000 ha of new urban growth on *ejido* land in MCMA (Salazar, 2014). Most government investment in social housing goes to the Infonavit (National Housing Fund for Workers) program. Access to such housing, however, is limited to those with jobs in the formal sector and incomes five times the Mexican minimum wage (see Flores Peña and Soto Alva, 2010). Infonavit homes are built in State of Mexico on the MCMA urban fringe by development construction companies on cheap agricultural, often *ejido* land. Developers leverage their political or economic capital to re-zone the land from agricultural to urban and build housing units sold to the government, which, in turn, offers subsidized housing credit to eligible citizens. Municipalities are required to provide urban services to Infonavit homes built in their region, even though developers make the profit from the capital gain this infrastructure generates. The government pays developers for the homes before they are occupied, which reduces uncertainty for the developer, keeps their profit margins high, and encourages construction in cheap land far from urban amenities.

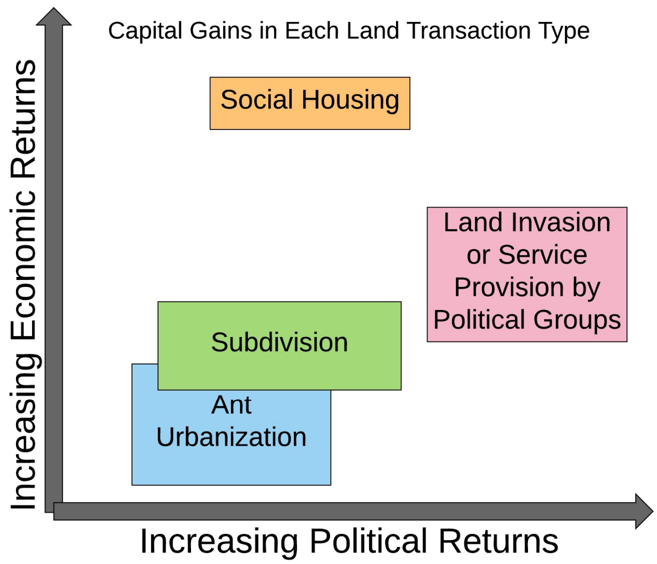


Figure 10. The main types of payoffs for the four urbanization types studied in the Mexico Metropolitan Area. Political returns include votes, political power used to climb position in one's political party, or ability to convene mass mobilization. Economic returns includes money receive through bribes, taxes, profits, or land sales.

The four types of urbanization can be summarized by the degree of political and economic payoffs in each informal urbanization institution based payoff surfaces described in detail below (Fig. 10). Ant urbanization generates the smallest concentration of economic and political capital relative to other types. The direct seller of land makes a modest amount money, but the returns are distributed through the various landowners. Subdivision generates larger economic returns than ant urbanization, concentrated in one actor. The political returns (e.g. votes, ability to climb party ranks, and capacity to convene protests) may be somewhat higher, but are similar to ant urbanization. Land invasion generates large political returns. The economic returns can be higher than subdivision, or similar, depending on the size of the invasion. Social housing generates the highest economic returns, concentrated in one developer. It is the largest and most concentrated set of economic returns to the development and, potentially, the *ejido* or municipality involved via taxes or kickbacks.

Distribution of benefits and losses and the emergent entrepreneurs in four informal urban settlement types

Four types of informal urbanization and their corresponding payoff surfaces identify the institutional entrepreneurs (with larger font) and distribution of losses and benefits (via payoff surfaces) in each four potential land use outcomes (Figs 11-14). Land outcomes are more persistent when payoff surfaces shade a larger portion of green area (benefits) compared to a revealed red area (costs). Details about the types of payoffs are summarized in the institutional matrix for each urbanization type in the supplementary materials (SI Tables 1-4).

Ant urbanization

Payoff surfaces promote urbanization and service provision but not regularization or environmental mitigation in ant urbanization. Most actors in the action situation gain when land is urbanized or services provided, only some gain when land is regularized, and only one actor, the Ministry of the Environment, gains when urbanization is mitigated via conservation efforts. The city at large may also gain ecosystem services when urban growth is prevented, but is not an actor making decision in this arena (except indirectly, via their vote in local elections).

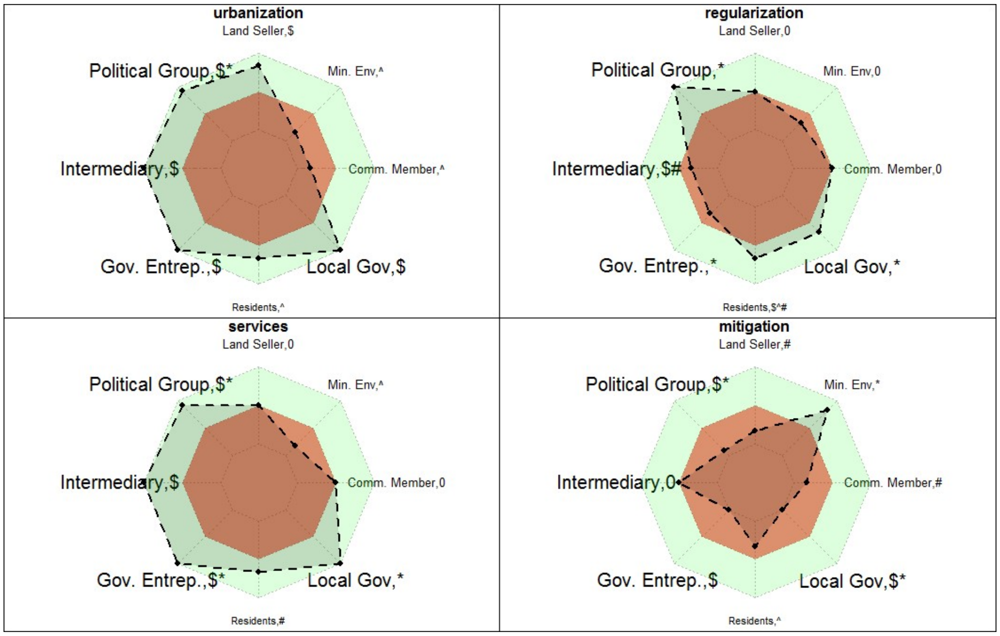


Figure 11. Payoff surfaces for ant urbanization. Benefits in green, losses in red. Low information/control in white, and higher information and control in darker grey. Payoff types for capitals in the following symbols:* = political (votes, climbing party ladder), $= economic (pesos, taxes, budgets), ^= land , #= social (exclusion, violence, prestige, control), 0= no stake, no payoff.

Intermediary actors or institutional entrepreneurs provide urban services. Intermediaries are either residents with higher political capital than their neighbors or political party brokers who profit by collecting fees from residents (~10,000 pesos [$500 USD] for enabling illegal services), a portion of which is paid to government utility employees that make the service connections. Intermediaries reportedly use violence and threats to enforce informal contracts with residents, especially in the case of non-payment or complaints about fees. As one resident reported:

> *"Darla*[16] *comes and she sells the electricity. And she passes the money to CFE [the federal electricity company]. She charged 10,000 pesos for electricity and another 10,500 for water and we must pay in cash. She is violent…one woman from a nearby community came and informally added her cable into our system, and she received threats [from Darla]."*

[16] All names are changed to protect identities.

In some cases, political brokers, often borough leaders or local legislators, provide services like electricity in exchange for political support in campaigns: "*Jones [a city legislator] helped with the electricity, but the local government put in the other 50%. We had to sign a promise to support his campaign."* High need, fear of losing services, and low access to information regarding rights leads to residents' compliance with these conditions of exchange.

Regularization rarely occurs, in part because of competing interests among actors (Fig. 11). Regularization benefits residents who gain certainty over land tenure and access to affordable legal, urban services, but provides mixed payoffs to land owners. Interviewees mentioned regularization enables legal landowners to "sell the land twice," first on the informal land market to the resident, and second to the government who compensates them for land expropriation to "formalize" the informal sale. Yet the economic benefit of expropriation is lower than informal market value of the land, and losing land to expropriation is an opportunity cost because that parcel can no longer benefit from use for tourism, agriculture, or environmental services.

In contrast, regularization represents a cost to institutional entrepreneurs (Fig 11) who lose opportunities to profit from "selling" informal services. Political actors often attempt to capture votes through the promise of regularization in campaigns, but ultimately are unable or unwilling to grant title. Regularization may also be blocked by environmental and civil protection agencies because it contradicts their institutional mandates to protect conservation land or to ensure residents do not live in areas with environmental hazards like landslides or flooding.

Actions to mitigate urbanization seldom occur because the costs largely outweigh the benefits. Only the Ministry of Environment benefits from preventing urbanization on conservation land, which is part of its mission. While it is the most informed actor regarding the rate and location of informal urbanization, it is under-resourced and must be selective in enforcing regulations, such as preserving conservation land, because eviction of informal settlements requires large portions of its small budget.

Institutional entrepreneurs, especially government officials, stand to gain both politically and economically from thwarting urbanization mitigation strategies. Interviewees explain that evictions are often blocked by *ejido* presidents, local borough leaders, or mayors, all who have legal jurisdiction to prevent an eviction. Evictions are prevented at inconvenient political periods [e.g., immediately before elections] or when entrepreneurs are profiting from urban services or charging “right to stay” fees. Interestingly, even when evictions occur, residents often return and rebuild.

Those who sell conservation land rarely experience consequences. Interviewees claim they do not report land-use violations unless they have a bad relationship with their neighbor: *“unless your neighbor really does not like you, they won’t report you*”. Even if the neighbor reports, government officials are easily bribed by residents to avoid sanction. Indeed less than 1000 reports of this kind were generated between 2000-13, about one percent of the Ant homes build over this time (Rodriguez Lopez et al., 2017a). *Ejido* or community members rarely sanction the member who sells a single plot of land. Importantly, the sale of conservation land resides in an “a-legal” grey area. Construction by residents on conservation land, however, is a punishable crime. The costs of regulating urbanization is highest for residents, even though they gain less relative to other actors in the informal land market (Fig. 11).

Financial incentives to landowners to increase the value of land for non-urban uses are lower than potential benefits from selling land informally (Fig. 11, in mitigation, the land seller vertex is close to the neutral line, but in urbanization, the vertex moves out into the green benefits space). Incentives include rural agricultural support programs

(Bausch et al., 2018) and payments for ecosystem services (Caro-borrero et al., 2015). Yet both *ejido* members and environment ministry employees agreed that environmental service payments (~1 peso/ha) are too far below opportunity costs of agricultural production (6 pesos/ha) or selling land on the informal urban market (50 pesos/m^2).

Subdivision

Payoffs for subdivision are similar to ant urbanization but profits are more concentrated in the "land flipper" (Fig. 12). In this case payoffs promote regularization, and there are no independent intermediaries providing services. Rather, a political party or group, a government official, or an *ejido* leader facilitates the transaction to provide services.

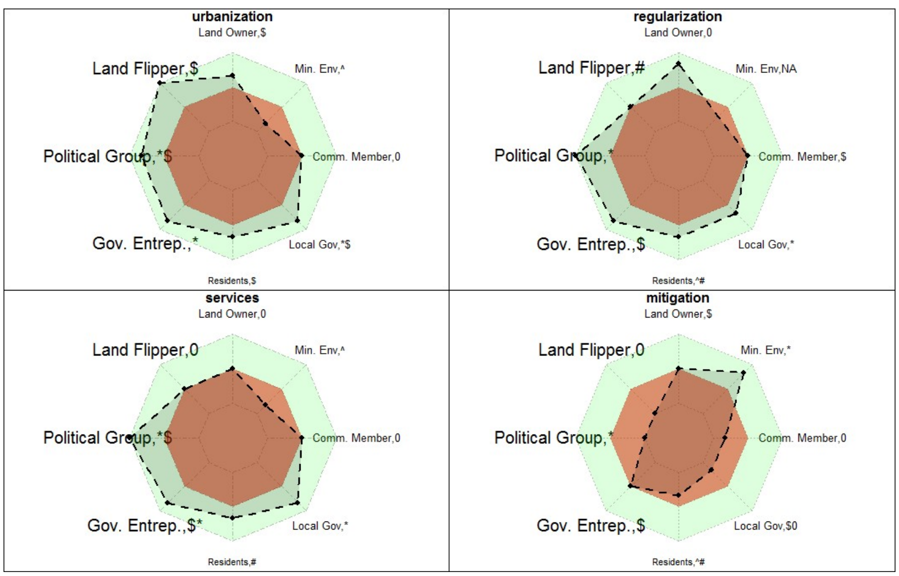


Figure 12. Payoff surfaces for subdivision.

Subdividers include a diversity of powerful actors whose political and economic gains increase in accordance with their institutional influence and area of land they transact. Subdividers include "*corredores*" who facilitate land subdivision for a fee at 10% interest to the land owners (Cruz Rodriguez, 2000), and entrepreneurial *ejido* or community members who buy land from extended family and resell lots through a lawyer (typically 10-50 lots). *Ejido* presidents may sell large tracts of land or facilitate sales for other members, and yet other illegal sub-dividers may sell land they do not own (100+ lots). The most influential subdividers are political parties that broker large deals with agrarian leaders and resell to poor residents with credit (100s-1000s of lots).

Of all actors in subdivisions, the subdividers receive the largest benefits for urbanizing land, gaining up to 1000% profit in some cases by our calculation. This power asymmetry ensures they can extract economic profits from informal land transactions, reportedly used to payoff government officials to avoid sanctions "…. *'if you each give me 10,000 pesos, nothing happened here.'"* These institutional entrepreneurs are reported to exploit legal uncertainty in communal property systems by falsifying property documents from other states outside CDMX through political connections, sell social property in communities awaiting legal title, and pay property taxes on lots they do not yet own to establish ownership.

Ejido members receive money from selling land to subdividers. *Ejido* members sell land to land flippers because legally selling the land themselves requires disincorporation from the *ejido*, requiring a high transaction cost. In other case, they are sometimes exploited when faced with significant pressure to sell. *Ejido* members also report being tricked by subdividers who disappear before full payment is received.

Regularization in subdivision benefits residents who receive title, and government officials facilitating the transaction gain politically and economically. Regularization represents an opportunity for graft in the centralized federal agency that regularizes *ejido* land where reportedly *"…expropriation is a business of corruption."* Regularization represents a relatively small benefit to *ejido* members because expropriation compensation is small.

Only the Ministry of Environment benefits from preventing subdivisioning, and there are rarely consequences for subdividers. Both interviews and previous literature documents how *ejidos* struggle to sanction members because of uncertain legal boundaries, social norms, threat of violence and even death (Ruíz-Gómez, 2006). They cannot sanction non-e*jido* family members who are often the entrepreneurs selling land. Agrarian communities cannot afford to pay the legal fees to agrarian courts to obtain the rights to sanction subdividers. Strong social norms prevent sanctioning: *"we don't get involved in people's inheritances. How do we sanction someone's grandson?"*

Local governments are incentivized to protect subdividers due to increasing tax revenue new settlers generate. One government official explained that his supervisor told him not to sanction a subdivider because his settlements brought more than two million pesos (~100,000 $USD) to the municipality annually. Subdividers exploit residents who don't understand formal property rights. In one court case, *"… the people [residents] showed their contracts on a napkin."* If eviction is evoked, the distribution of losses falls squarely on the resident who loses their home. Sometimes other institutional entrepreneurs reportedly use threat of eviction to punish bad voting behavior or extort residents for money.

<u>Invasion</u>

The payoff surface of urbanization, service provision, and regularization in land invasions generates political benefits to three entrepreneurs—informal service providers, political groups, and government actors—with little cost to other actors with influence (Fig. 13). As a result, all three of these land outcomes happen frequently and rapidly in land invasions. The information asymmetry between residents and the political groups offering land is smaller for land invasion than that for subdivision and ant urbanization.

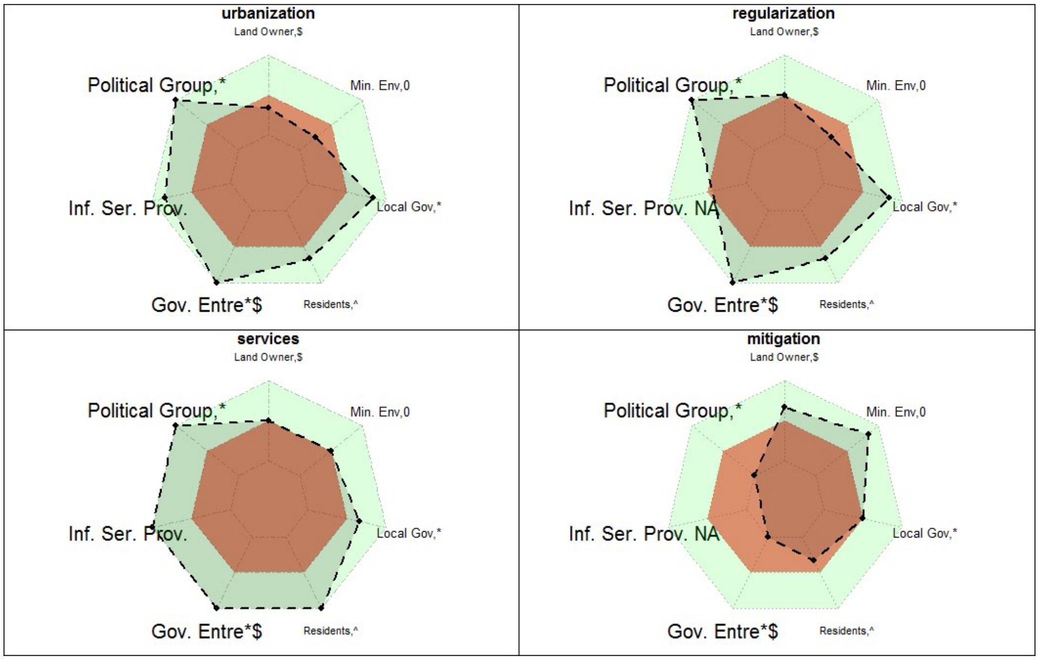


Figure 13. Payoff surfaces for invasion. Inf. Ser. Prov.= Informal service provider, such as the Mexican electricians union. NA is marked for outcomes in which they have no stake.

The distribution of costs and benefits between landowners and "invading" groups is unclear and sometimes the process of invasion and subdivision becomes fused, depending on the degree of consent attributed to actors in the process. While political groups like *Antorcha Campesina* are typically associated with land invasion in media and academic discourse (e.g., Hiernaux and Lindón, 1996), interviews revealed a more complex picture. *Antorcha* leadership and some public officials reported sales are always done with the consent of *ejido* leadership, and should not be considered invasions. Nevertheless, some *ejido* members characterized "consent" as coercion: *"Members of Antorcha steal crops, beat, or kill other members, so it's just better to sell [to Antorcha]."* A government official confirmed the use of violence to gain consent. : *"Antorcha…they make deals with the ejido members…with a pistol!"*

For the resident, land and services are more cheaply acquired through these political organizations than through intermediaries in subdivision or ant urbanization.

The organizations rely on political power, not bribes, to enforce contracts. Invading organizations sometimes have prearranged contracts for service provisioning, for example, with the Federal Electricity Agency (CFE) or the Union of Mexican Electricians. In other cases, invading organizations successfully broker services with local governments through mass mobilization. As one government official in the borough of Iztapalapa noted, "*…they take what they need. They don't ask for things, they demand them."* Local governments may facilitate informal service provision, for example, by *"… allowing a water pipe to lay around nearby so that someone can connect to it magically in the middle of the night."* Invading organizations solve the problem of service provision for informal settlements and in return, the government official enjoys political support from these groups and their residents.

It is through this political participation and support that residents pay the cost of urban service access. *Antorcha* requires a minimum of two years participation in protests and meetings for the right to purchase a plot at relatively low prices. Control over electric service provision is used to enforce participation with the politics of the organization, although the rates for utilities is also relatively low : "*They each pay 800 pesos, but we [land invasion leaders] cut their electricity if they don't participate---if they don't go to the protests. Cutting electricity is our control."* Yet for other residents, the transaction costs of political participation can be too high: *"we go to marches, and meetings each Sunday. We have to sign records of our attendance at protests and marches [when requested by the political party] We can't miss three events or they kick us out! …We have no secure life…. We can't even go to work!"* Despite the burden of time, residents enter the exchange because they have few alternatives, or perceive these terms to be better than ant urbanization or engaging in a subdivision.

The political transactions between residents and entrepreneurs facilitates regularization and can impede evictions. Politicians, often former invasion leaders themselves, use their invasion constituencies to climb the political ladder: *"that legislator put names on housing lists because there were electoral clients. She did not do it to keep her existing position, but to gain power in the same party"*. One powerful politician changed the boundary of a protected area to grant titles to her supporters. In one notorious case, an interviewee explained a politically powerful institutional entrepreneur enjoyed 10 years of political protection before an eviction was attempted. In other cases, former land-invasion group leaders became leaders of environmental regulatory agencies, using their position to prevent evictions for the groups who brought them to power.

Public and Social housing

Fewer actors constitute the action arena for social and public housing compared to other types of informal urbanization (Fig. 14). As no actors are working to mitigate social and public housing, it is not an outcome in the action arena and has no payoff surface. Benefits are largely distributed to developers and the government actors receiving their kickbacks.

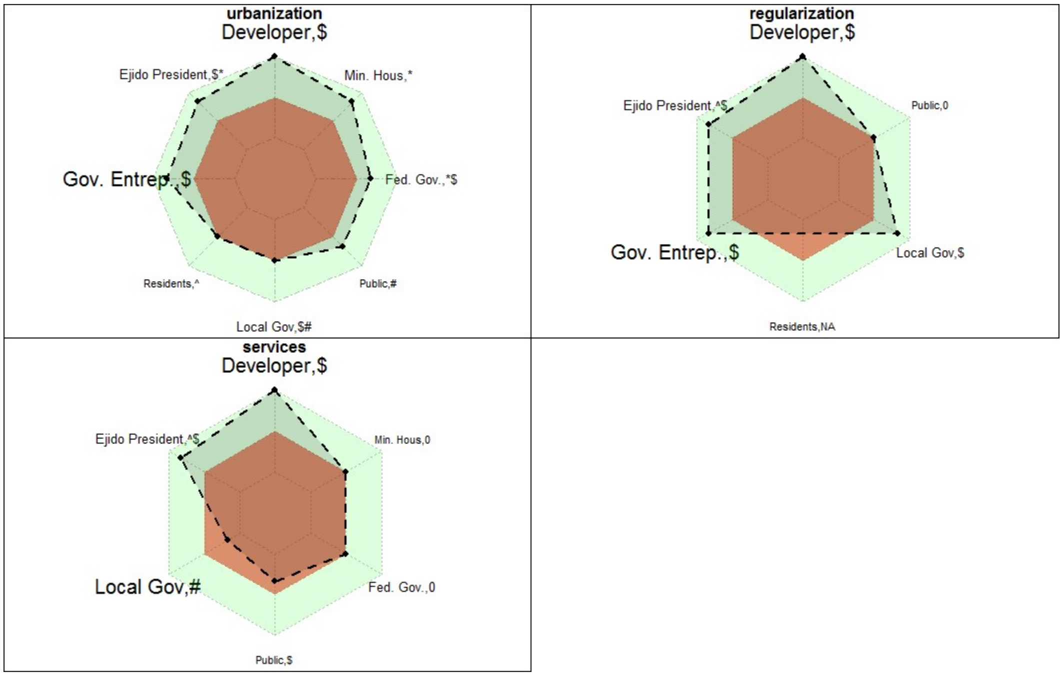


Figure 14. Payoff surfaces for public and social housing. There is no potential mitigation strategy to consider outcome since this cannot occur on conservation land- so is not a policy option.

The primary institutional entrepreneur is the developer. Their power resides in their access to regulatory information and their influence over local land zoning plans. Lack of planning capacity in local governments makes it easy for developers to manipulate land-use zoning to favor their interests. This control allows them to ensure profits from purchasing agricultural land and selling homes on newly zoned urban land with services supplied by the local government. Interviewees report that the "external" audits of these transactions are often done by the developers themselves. These political and economic arrangements allow the developer to secure significant payoffs:

> *"The State and local government have been our silent business partner….there are prearranged deals. They never oppose us. The developer says, 'how do we get this done,'…manages the environmental impact study…and pays for the new altered land zoning plan."*

Similar to subdivision, while the *ejido* earns some money from land sales, another institutional entrepreneur, the developer, captures larger profits (Fig.

14). *Ejido* land sales must be offered to members at a lower price before being sold to an outside entity (*derecho al tanto* in Mexican agrarian law). Interviewees asserted developers take advantage of this law by becoming an *ejido* member to purchase this discounted land but selling it for market value.

The benefits to municipalities of building social housing are mixed. Social housing tax existing under resources urban services, because municipalities are required to supply services. Municipalities benefit from increased tax revenue, however, some politicians enjoy kickbacks or even formal profit shares as many are investors in these development companies.

Paradoxically, the distribution of costs from social housing fall on the actors whom social housing is intended to benefit: residents and the public. Due to poor construction and distance from urban amenities, only 30% of constructed social homes are occupied. Residents often abandon homes, which developers attempt to recover and resell. In a bizarre overlap with land invasion, one architect reported developers made deals with *Antorcha Campesina* to invade abandoned social homes. This process brings the case in court, where the judge annuls ownership of the missing homeowners, and developers can resell.

In contrast to social housing, public housing in CDMX is accessible to low income residents, and with less interference from developers. However, the high transaction costs of paperwork to get one's name on a list is so high that citizens must work with political groups to access a home. The housing ministry recognized political groups influence the distribution of homes: *"They* [political groups] *buy their homes from the workers in the housing ministry. All the housing is distributed in the PRD [ruling left party] party. Then the leaders offer their members homes. The political and social* *benefits get mixed up."* Thus, the costs for public housing in CDMX to residents are similar to invasion, because access requires political participation.

Discussion

Informality influences urban expansion beyond informal settlements

This study disaggregated informal urban expansion for CDMX and MCMA, adding social and public housing, typically absent from studies of urban informality (Fig. 10). Previous work did not consider the last category, in part, because their approach to informality did not focus on transactions and the institutional analysis that guided our research (Connolly and Castro, 2016; Rodríguez, 2001; Ward, 1976). Other types of formal urban expansion are influenced by informal transactions to some degree (e.g. bribes to expedite construction permits), but social and public housing merit special attention in our typology for three reasons. First, social and public housing is intended to provide access to housing for the same populations living in informal settlements (via invasion, ant urbanization, and subdivision), but has been inefficient and inaccessible to them. Second, social housing represents a significant portion of MCMA's urban extent growth from 2000-2016. Finally, powerful rent-seeking actors who accrue benefits from the publicly funded housing that puts pressure on under-resourced municipalities for services. Studies of informal urban expansion in Mexico City and elsewhere should examine informal transactions in the public and social housing sector in addition to the more tangible informal settlements.

Payoff surfaces highlight how actors and their incentives shape persistent land use outcomes

The payoff "surfaces" depicted in Figures 11-14 favor urbanization, disfavor conservation and mitigation strategies, and illustrate conditions in which regularization stagnates (e.g., ant urbanization) versus succeeds (e.g., subdivision, invasion). Previous literature on Mexico City has made similar general conclusions regarding this pattern. This study, however, systematically identifies what and who generates these dynamics, expanding understanding of the processes with benefits for land system models and, potentially, for governance.

Urban expansion persists in Mexico City because “everybody wins”, as noted previously (Flores Peña and Soto Alva, 2010). However, our results nuance this observation, identifying how some actors win more than others, and the type of benefits they accrue depends on the urbanization type (Fig. 10). From developers to the *corredores,* to the political broker, to the *ejido* member, it is the person directly selling land, homes, or urban services to the poor that captures the majority of benefits from informal exchange. These actors use their access to information and existing economic and political capital to distribute goods to a marginalized population whose range of choice to fulfill these needs is limited.

Our results indicate differences in the degree of political and economic gain among the institutional entrepreneurs. Developers of social housing reap larger economic benefits than any other actor. The entrepreneurs directing land invasions, blocking eviction, providing services, and accessing land titles capture the highest political returns. Entrepreneurs aggregating larger tracts of land, such as a subdivider selling 1,000 lots, exert more influence over the conditions of exchange than those in ant urbanization. Recognizing this difference in agency among entrepreneurs is key for the operation of various land models, such as ABMs, and hints at the means to provide regulation, if such regulation is desired.

Extant research asserts that “inaction” toward informality in Mexico City (Azuela de la Cueva, 1987b; Connolly and Wigle, 2017b; Iracheta Cenecorta and Smolka, 2000) and elsewhere (Roy, 2005; Van Gelder, 2013) is produced by ineffective or politically motivated urban authorities and bureaucracies. We extend this finding, showing inaction is also shaped by intermediaries and political groups receiving specific payoffs. Efforts to eliminate informality (e.g., through eviction) or reduce it by rendering it legal (e.g., through regularization) are unlikely to succeed as they represent large political and economic costs to a variety of institutional entrepreneurs. Local governments receive tangible benefits from informal expansion and ensuing population growth via increasing budgets, tax revenues, and new votes to capture. As a result, strategies to eliminate informal settlements (eviction) run counter to incentives promoting expansion. Institutional incentives are compounded by personal incentives for political and economic gain. Actors preventing eviction gather clienteles of informal residents and receive promotion within their political party. Government officials may receive bribes and kickbacks from intermediaries, residents, or land flippers who seek to avoid sanction.

Previous work on regularization claims governments stall regularization for territorial control in conservation land (Connolly and Wigle, 2017b) and land titles are distributed via clientelism (Azuela de la Cueva, 1987a; Duhau, 1998; Varley, 1998). Stagnation or acceleration of land titling differs across types of urbanization, however, a distinction clearly made in this study. As examples, payoff surfaces favor regularization (e.g., zone changes and titling) for invasions, social housing, and subdivisions, but not ant urbanization. In land invasion, subdivision, or social housing, political and economic returns concentrate in institutional entrepreneurs with power to affect outcomes.

In contrast, because ant urbanization is dispersed across conservation land, cost and benefits of regularization are diffused among a diversity of actors (Fig. 11). Regularization represents a cost to intermediaries who distribute public goods informal residents cannot access, and to the Ministry of Environment who fears it incentivizes more urban growth. Regularization benefits local governments and political parties with informal residents' votes. These conflicting incentives generate inertia in land titling and perpetuates informality.

Consequences and benefits of informal urban expansion

Ultimately, this research raises questions not only about the effectiveness of current policies to control informal urban growth, but also why it is considered a problem in the first place. Perhaps the problem lies in the negative externalities associated with informal land transactions, and how they shape housing for the urban poor, degradation of conservation land, social exploitation of informal settlers, and rent-seeking of public officials.

Until housing needs for the urban poor are addressed, informal settlements will represent potential political and economic rents. Ant, subdivision, and invasion, emerged to fill this unmet demand and together provided housing for nearly twice as many residents (~100,000) as the public housing ministry (~54,000) from 2000-2015 in CDMX (INVI), almost all with electricity. The access created by land flippers, intermediaries, and political groups is pivotal in providing access to urban plots for the poor. In a sense, the "success" of urban expansion is made possible by the institutional innovation of entrepreneurs and the functional role clientelism, corruption, and rent-seeking plays in the existing system.

Reliance on informal settlements to meet housing needs has environmental costs, however (Aguilar and Santos, 2011; Santos, 2013). The potential consequences of informal growth in both water security and flooding is well recognized by residents and urban decision makers in Mexico City (Lerner et al., 2018). Yet the public and academic discourse focuses on ant urbanization, which only represents 3,200 ha, about 25% the land area compared to the 11,000 ha of inefficient and mostly vacant social housing constructed in MCMA. If environmental disservices are the issue of concern, subsequent research should compare the impact of ant urbanization to social housing, and consider which plays a larger role in eroding the aquifer.

Social costs of informality include exploitation and corruption. Institutional entrepreneurs who take advantage of residents' information asymmetry, legal vulnerability, already meagre paychecks, and votes. The degree of exploitation differs by urbanization type. Contrary to academic discourse, which has accused land invasion groups like *Antorcha Campesina* of "lack of transparent interests, violent action, and fascist tendencies" (Hiernaux and Lindón, 1996), residents may be less exploited in land invasions than the alternative informal processes. Corruption is a concern because it is a non-transparent distribution of public resources. There are two types of corruption: an adaptive response to high transaction costs and an opportunity for economic gain (rent-seeking). The latter is of larger concern for a variety of reasons. For example, in the CDMX 2017 earthquake a Mexican Watchdog NGO investigated 28 of 38 collapsed buildings and found evidence of public corruption in every case by construction companies avoiding regulation or paying off building inspectors (Mexicans Against Corruption and Impunity 2018).

Interventions to tackle negative outcomes of informal urban growth

Existing policies could be reexamined based on their ability to address the aforementioned issues of concern, instead of their ability to eliminate informality. Once a negative externality is identified, payoff surfaces locate the associated actor advancing undesirable outcomes. Potential strategies include regulating people, not (only) land, working with local institutions, and improving transparency and sanctioning of public actors.

Existing policies regulate land-use, not actors. Current initiatives to mitigate urban growth on conservation land include both carrots (environmental incentives (PES) to agrarian communities) and sticks (eviction). A growing set of land regulation instruments and “politics of containment” (Pezzoli, 2000) was implemented in the 1990s but has failed to mitigate growth. Local governments “regulate” urbanization through forgiveness rather than planning, updating land plans to reflect the most recent illegal urban expansion (Lerner et al., 2018). Eviction policies blame residents as the engines of environmental destruction instead of the actors who largely drive these processes.

Policies could regulate actors with influence — intermediaries and government officials providing or facilitating informal services, actors selling land, and local government. Increasing payments for environmental services or developing long-term conservation easements could disincentivize owners from selling conservation lands. The Ministry of the Environment currently has low to moderate power (and small budget!) to mitigate urban growth. As a result, in Mexico City and elsewhere in Latin America, local politicians block evictions to gain political capital with settlers (aka “forbearance” (Holland, 2016)). Centralizing decisions in a ministry with unelected officials would be one way to remove political capital from the equation and encourage efforts to mitigate urban growth. Increasing transparency via improved monitoring efforts of public actors and intermediaries and following through on sanctions could combat rent seeking and exploitation.

Working with, rather than against, the existing institutions providing material and urban services could reduce the environmental impact of urban growth. The entrepreneurship of existing intermediaries and government officials providing informal urban services illegally could be leveraged to transition communities in conservation land to environmentally friendly services. Local governments could offer subsidized rainwater capture, solar power system, or compost based sewage. Residents themselves could become institutional entrepreneurs. In the borough of Xochimilco, which has primarily been settled informally, residents in both formal and informal neighborhoods demonstrate the agency and ability to build social innovation and seize windows of opportunity (Charli-Joseph et al., 2018). Decades of research in urban planning support examples of institutional entrepreneurs in informal settlements who have successfully transformed social environmental conditions (e.g (Jane Jacobs, 1965).

Conclusion

Informality is often discussed as external to the norm. Informal rules are the norm in the urbanizing Global South, however. Framing informality as normatively bad or immoral can obscure the function these transactions perform in cities. Analyzing informality as an institution (set of rules and norms) allow us to understand the logic responsible for its persistence.

Focusing on the institutions, informal urban expansion in Mexico City and its environment maintains four major types: ant urbanization, subdivision, land invasion, and social and public housing. Institutional entrepreneurs—developers, political groups, rent-seeking politicians, and intermediaries—largely shape the processes and capture most of the political and economic benefits in each. Using institutional analysis to elucidate payoffs schemes among component types of urbanization could make the "chaos" of urban informality interpretable for land simulation modeling efforts, like agent-based models, used to predict scenarios of urban growth. Previous qualitative case studies do not systematically identify the actors, rules sets, degree of control, and structure of incentives in each type of informal urban expansion identified in this study. The typology and payoff surfaces presented here disentangle urban informality, making its dynamics more legible not only for modeling, but also for governance.

Discourse and policy has focused on eliminating informality by either regularizing or evicting residents who are, paradoxically, the victims and assumed source of the problem. This study points to the kind of analyses that provide critical information for potential interventions to mitigate identified harm to society and the environment from existing informal urban expansion.

Informality is not an unpredictable, unusual, or even merely a “material” part of the urban growth process. Cities are constructed by people, and incentives and rules are formed by the conditions in which people make decisions. Urban sustainability relies on the ability to analyze the patterns and consequences of these decisions, and to reshape institutions to improve social environmental outcomes.

CHAPTER 3

DO ELECTORAL POLITICS INFLUENCE LAND TITLING AND EXPANSION OF INFORMAL SETTLEMENTS? THE CASE OF MEXICO CITY

Abstract

A large portion of urban expansion occurs informally and in the developing world. These settlements often lack access to basic services and have insecure tenure. By definition, they exist in areas where urbanization is not permitted and thus lack formal title. Politicians may seek to provide support to settlers by facilitating land titling, connection to urban services, and other ventures in exchange for their votes. While this relationship has long been recognized, the hypothesis that electoral politics may influence settlement expansion and the distribution of land titles has not been formally tested. This research tests these relationships using fixed effects panel regressions to examine the influence of electoral cycles and voting patterns on the distribution of land titles and informal urban growth in conservation lands in Mexico City from 1997-2015 . Parties attract voters through activities including distributing cement for housing, paving roads, and illegally connecting communities to urban utilities. We find that the distribution of land titles for informal settlements on private land increases in the months leading up to local elections, and that more titles are given to core voters of the historically dominant party. Land titling for settlements on collective property, however, has no apparent electoral signature. Urban expansion increases within districts with high electoral competition on both collective and private property. These results demonstrate empirically the influence of politics on urban growth both in terms of land cover and expansion of the legal city boundary.

Introduction[17]

[17] This article will be revised and submitted for publication with Meha Jain, Hallie Eakin, Felipe de Alba, and Dylan Connor.

Over 90% of all urban growth takes places in the Global South. A large portion of this growth occurs via informal settlements (30% in Latin America), where inhabitants have little to no tenure security and lack basic services (UN Habitat, 2016). One effort to improve welfare for households in these settlements has been to provide formal property titles, enabling connection to urban services. Increasingly pluralistic municipal electoral processes, and political and administrative decentralization has accompanied these efforts in "regularizing" land tenure (Post, 2018). The synergy of increasing informal growth, mass suffrage in local elections, and local urban management provides an opportunity for electoral candidates and actors elected to office to capture votes from informal settlers.

Previous research demonstrates politicians fulfill the property titling and urban service demands of marginalized residents living in informal settlements in exchange for political support (Ch 2, Cornelius, 1972; de Alba and Hernández Gamboa, 2014; Eakin et al., 2016, Post et al 2018). Despite evidence of this causal mechanism, no study has empirically tested or estimated the causal effects of electoral politics on the distribution of titles and informal urban expansion. Various research and initiatives of practice are affected by this empirical gap. For example, urban initiatives that seek to improve responses to extreme events, such as UN Habitat III or the 100 Resilient Cities initiatives, may prove to be inadequate owing to lack of consideration of these dynamics in urban planning (Eakin et al., 2017). This study seeks to fulfill the gap in question by estimating the relationship between electoral politics, land titles, and informal urban growth in conservation lands from 1997-2015 in Mexico City using fixed effects panel regression.

Clientelism and electoral cycles in urban property titling and land-use changes: The Research Problem Defined

Researchers have long recognized and theorized how politicians decide who receives public (non-excludable) and private goods and when they are distributed (Cornelius, 1972; Guasti et al., 1977; Scott, 1969). The temporal distribution of goods is predicted to occur just before elections, a phenomenon known as the "political business cycle." Incumbent politicians seeking to maintain their office increase fiscal spending just before elections to demonstrate their legitimacy when voters are paying the most attention to the electoral process (Drazen and Eslava, 2010; Khemani, 2004; Rogoff, 1990). The political business cycle has been empirically demonstrated in India, where electricity is redistributed during election years to help incumbents win legislative seats (Baskaran et al., 2015; Min and Golden, 2014). The electoral cycle of land change has also been demonstrated in forest systems in both Brazil and Indonesia; forest loss increases in the year of election in incumbent candidate districts (Burgess et al., 2012; Pailler, 2018). After the agrarian reform in Mexico in 1919, collective titles of agrarian land that where inalienable (e.g. could not be sold) were offered to communities and groups of farmers, called *ejidos*. These titles were more likely to be distributed in electoral years (Albertus et al., 2016). Many of these agrarian lands, however, have since been informally sold and urbanized, and many settlers have no legal title to the urbanized land. To our knowledge, no research has yet examined the role of electoral cycles in influencing land titling in urban informal settlements. The significance of electoral politics for urban land tenure could have important implications for accurately modeling and planning for urban growth.

Competing theories exist regarding who is more likely to receive public and private goods. Goods could be rewarded to patrons and core-voters of a dominant party, used to recruit new voters in competitive electoral districts, or distributed in districts where core voters support is declining to prevent defection (Diaz-Cayeros et al., 2016). The distribution of goods can be clientelistic, or contingent on reciprocated exchange of votes and services between patrons (politicians) and clients (voters) (Hicken, 2011). In this version of clientelism, goods are rewarded to loyal voters and withheld from defectors. Likewise, voters reward politicians for distributing goods, and punish them by voting for another party if services are not delivered. In contrast, when politicians consistently distribute goods to their core voting population but do not punish defectors or reward new voters, this strategy is labeled “pork barrel” instead of clientelistic (Stokes et al., 2012).

Clientelistic goods could be targeted either to loyal and core voters, to recruit voters in swing districts, or prevent defection in declining support areas (Diaz-Cayeros et al., 2016; Stokes et al., 2012). Studies of clientelism in urban systems find that core voters, instead of swing voters, are usually targeted (Post, 2018). Urban utilities, such as water, are subject to clientelistic distribution, which results in unequal access to water for citizens and erodes performance and maintenance of public infrastructure systems (Herrera, 2017). Additional views posit that goods that can be finely targeted in urban areas, such as policing, local taxation, and variations in zoning, will be distributed to core voters (Cox and Mccubbins, 1986). Diaz Cayeros (2016) tested this theory empirically with the cash transfer programs in Mexico, finding transfers were distributed to areas with core voters of the main party, the PRI (Institutional Revolutionary Party). Among these core voting areas, more transfers were given to places that had started to defect from the PRI, with a notable decline in core support and an increase in votes to new parties (Diaz-Cayeros et al., 2016).

Informal settlers without land tenure are also targets of clientelistic strategies by politicians, who condition permission to stay on political support (Post, 2018). This particular type of clientelism is known as forbearance, or the “intentional and revocable government leniency towards violations of the law” (Holland, 2016 p233). Holland (2016) found forbearance was practiced by politicians who ensured continued support by preventing eviction of informal settlements in Lima, Peru, and Bogota, Colombia. One study examining the role of clientelism in land title distribution within informal settlements in common property (*ejidos*) across Mexico from 1994-2012 (Larreguey et al. 2015) found that voters were less likely to reward incumbents in municipal elections after receiving title, but had no effect on federal elections. No studies to our knowledge have examined the role of clientelism on land-cover change of any kind, including urban expansion.

While property titles may be distributed preferentially to key voters, paradoxically, the formalization of property rights may decrease the conditions under which clientelism flourishes. Property rights can liberate citizens from relying on “patron” political parties for economic development. This liberation is supported by empirical analysis of Mexico’s PROCEDE program (Certification Program for Ejido Rights and Titling for Urban Centers), which privatizes collective *ejido* lands and allows individual farmers to sell property on formal land markets. Rural regions benefitting from increasing titling efforts have tended to vote for the opposition party, suggesting that property rights may erode clientelism (Castañeda Dower and Pfutze, 2015; de Janvry et al., 2014). It remains unknown if these findings translate to urban areas, however. Research suggests formalizing property titles in informal settlements can, in certain conditions, improve household welfare (Webster et al., 2016), but does secure land tenure reduce the need for informal urban residents to rely on political exchange to secure services like water and electricity?

Given the need to better understand the social-political nature of urban form among various research communities, this study examines the spatial-temporal distribution of land titling and informal settlement expansion in Mexico City from 1997-2015 using remote sensing and government voting records. It is guided by three working hypotheses:

1. Urban land titling of informal settlements on collectively held and private land exhibit a political business cycle and increases prior to elections.
2. Titles are preferentially distributed to core party voters.
3. Urban expansion increases with the ratio of votes to the core party.

This study represents the first empirical examination of political dynamics of urbanization and land titling in an urban land system. Previous research has quantified the political business cycle of deforestation in rural land systems in Indonesia and Brazil (Burgess et al., 2012; Pailler, 2018), but this mechanism has never been tested in an urban system. This research seeks to clarify the role politics plays in land use in Mexico City, potentially advancing efforts in urban growth modeling and governance of land titling. More generally, it demonstrates that politics in urban land systems can be quantified, contributing to a range of research such as that undertaken in political science, land systems science, and vulnerability studies (Eakin et al., 2017; Post, 2018; Tellman et al., n.d.)

Informal Settlements and Political Relationships in the Study Area: Backdrop for Analysis

Land titling and informal settlements in Mexico City's conservation lands

Most of Mexico City's urban expansion since the 1930s has been informal, undertaken on lands not formally designated as urban (Connolly and Castro, 2016). Much of the ensuing urban growth occurred in the southern portion of the city, an important area of aquifer recharge and other environmental services. In part to protect this part of the urban watershed, the city established a conservation zone in 1992 and ecological zoning constraints in 2000 (Sheinbaum Pardo, 2008). These declarations recognize the presence of rural settlements and agrarian communities who were long settled in these conservation lands. Seventy percent of the conservation land in question belonged to agrarian communities, who held collective title in *ejidos* (communally owned properties designated for agriculture in 1917) and communities (communally owned indigenous properties dating to the 1600s).[18] These communities were permitted to continue practicing agriculture, pasture, and forestry, albeit with some restrictions. They were not allowed to sell land, construct homes, or pave roads.

Nonetheless, informal purchase of conservation land represents one of the most affordable ways to access land for housing in Mexico City for the urban poor (Ch 2). Currently, an estimated 480,000 people in over 800 informal settlement communities have urbanized 3,200 ha of conservation land (Fig. 8). Local governments are prohibited from building infrastructure for formal services, such as piped water and electricity. Intermediary actors, sometimes with tacit support or via bribes with government actors, commonly provide illegal services to residents at high economic cost or through forced political participation (Ch 2). In conjunction with the Mexico City Ministry of the Environment (SEDEMA), local governments may also evict residents and destroy housing structures. Paradoxically, politicians campaigning for or in office may offer to

[18] Both the Spanish Crown post-conquest (known as communal titles) and the Mexican revolution granted social property land titles (known as *ejido* titles) which could not be bought or sold until the Mexican agrarian reform in 1992. Considerable dispute remains over overlapping claims between communal and *ejido* land claims, which remains unresolved in Tribunal Agrarian Courts to this day. The term agrarian land is used to include both.

help consolidate informal communities through service provision, housing materials, or participation in government programs, especially during electoral periods (Hagene, 2015, 2010; also Ch 2). In order to obtain formal urban services, gain secure land tenure secure, increase the property value of their plot, and avoid exploitation by intermediaries, many residents desire to be "regularized", or have their property included in the formal urban zone and be given a formal property title.

Land titling in communal and private property in Mexico City

There are distinct processes for informal settlers to obtain land titles in agrarian communities (blue area, Fig. 8) as opposed to private lands (green area, Fig. 8). The former requires a federal agency, CORETT (Commission of Regularization and Land Tenure) to remove the area from the collective property land register by the government claiming ownership, known as expropriation. Expropriation is initiated by a presidential decree. CORETT pays the agrarian community for the land purchase based on a price set by another federal agency (INDABIN, Institute for the Administration and Evaluation of National Goods). CORETT then emits land titles to each resident, which can then be registered in the National Land Registry. This bureaucratic process can take 5-20 years, and for some informal settlements, is never completed.

Obtaining an individual property title on private lands, however, is managed by the Mexico City agency, DGRT (Ministry of Land Regularization). The process involves informal residents petitioning the local borough/delegation government to change land-zoning plans to allow urban development. This change (prior to 2012, year of implementation differs by borough) must be approved by the city's legislative assembly, ALDF (Legislative Assembly of Mexico City), and the ministry of urban development (SEDUVI, Secretariat of Urban Development and Housing for Mexico City) before the land can be registered in the National Land Registry and land titles are distributed to the residents.

Some delegations established processes specific for regularization on conservation land in the late 2000s, establishing a "Special Commission on Regularization," or a CREX, which includes various city ministries including water, housing, urban development, environment, and civil protection.[19] These commissions vote on changing land zones to "urban" for settlements based on their level of consolidation (e.g., how long they have been there and if they already have acquired services) and exposure to environmental hazards. These commissions can change land-use zones directly without requiring approval from the legislative assembly, and may require residents to pay environmental harm fees before property titles are procured. Obtaining land titles for private land, similar to agrarian land, can take 5-20 years.

There is a significant amount of corruption, political negotiation, side-payments, and other informal transactions involved in the regularization and land titling process for both agrarian and private land. Regularization is a "political chip" (*moneda politica)* politicians regularly use in campaign promises in local elections in southern Mexico City where informal settlements reside (Connolly and Wigle, 2017). Residents also report incumbents and candidates appear in electoral periods to pave roads, install water and electricity services, and dole out bags of cement in exchange for political support (Ch 2). Previous research demonstrates that water supply to informal settlements increases in electoral periods (de Alba and Hernández Gamboa, 2014). An extensive literature documents the mechanisms by which politicians distribute titles and urban services in exchange for political support across the city (Castro, 2004; Cornelius, 1972; Eakin et al., 2016; Pezzoli, 2000; Varley, 1998,; alsoCh 2). Yet none of these studies has attempted a

[19] CREX have been established for Xochimilco (2008), Tlahuac (2008), Tlalpan (2010), and are in the process of implementation in Milpa Alta and Magdalena Conteras.

quantitative analysis of land titling and urban growth in relation to electoral data that could indicate the degree to which politics influences urban outcomes.

Electoral Politics in Mexico City

The government of Mexico instated borough chief, legislative assembly, and mayoral elections for Mexico City in 1997 to meet growing urban demands for representation (Davis, 2010). Legislative and borough elections are held every three years, with mayoral elections every six years. From 1997-2015, the PRD (Revolutionary Democratic Party) has retained the mayoral seat, and the large majority of the boroughs (white areas, Fig. 15) and 40 legislative seats. It controls urban administrations and the distribution of services, such as water. Environmental regulation and land-use zoning and titling is co-managed by the city in conjunction with the local borough, and sometimes the legislative assembly.

Legislators are important brokers and intermediaries who may pressure city urban administrations to expedite titling or urban service processes (Ch 2). There are two kinds of legislative representatives, proportional representation and relative majority. Legislators are elected directly with their names on the ballot for each of the 40 districts for the relative majority seat, and an additional 40 seats are distributed for each party to appoint based on the party level vote received. The legislators elected directly via relative majority are typically the brokers facilitating urban services in informal settlements.

The PRD, which included urban social movement leaders, has enjoyed widespread support from urban populations in Mexico City since the early 2000s ((de Alba, 2016; Moctezuma, 2001). Support for the PRD, however, has declined since the emergence of a new left party, MORENA (National Regeneration Movement) in 2015, which won both the presidency, mayoral seat, and most borough districts in Mexico City in 2018. During the 2000-2015 period, other parties, the PAN (National Action Party) and PRI, controlled the presidency and federal agencies responsible for land titling of informal settlements in collective property.

Methods and Data

Urban land titles on both private and *ejido* land from 1997-2012 were digitized and georeferenced from official documents. Urban expansion data in conservation lands was provided by the Mexico City Ministry of the Environment, which was produced by manual digitization via very high resolution (<2m) satellite imagery from 2005-2015. Voting records for ~5,530 districts were obtained for local elections from 2000-2015, which occurred every 3 years.

Dependent Variables

The dependent variables in this study are land titles and urban expansion (summarized in Table 2, * denoting dependent variables). Land title data were obtained for collective property from the National Agrarian Registry (RAN) (2017), which contains information on the land tenure history of each agrarian community in Mexico. This study used the area of land in hectares expropriated by CORETT for every agrarian community in Mexico City from 1971-2007 (the date of the last presidential decree). Information regarding the number of lots regularized in the informal settlement was not available. 287 original paper maps of the areas of expropriation in each of 85 decrees were obtained through visits to the CORETT Mexico City office in 2017-2018, and subsequently georeferenced and digitized (Fig. 15a). Expropriation areas were only digitized for agrarian communities or in boroughs with conservation land area[20] The spatial data are represented in Figure 15a and temporal data in Figure 16 regarding seven

[20]Private land titles were thus not digitized in Azcapotzalco, Venestuziano Carranza, Itzacalco, and Coyoacan. Collective land titles were not digitized in Azcapotzalco, Venestuziano Carranza, Itzacalco, Benito Juarez, Migual Hidalgo, and Coyoacan.

presidential electoral periods (July of election year to July of the previous year, a 12 month period) marked in pink (Fig 16).

Land title data for private property were obtained by searching the archives of the *Gaceta Oficial*, or Official Gazette, which publishes legal decrees in Mexico City (Conjesuria Juridica y de Servicios Legales, 2017). We used the search term "*regularización*" or regularization, to identify 275 documents with information about titles given to informal settlers in private lands for 11 boroughs with conservation lands from 1997-2012, when the titling decree ended[20]. Each of 475 unique land titling observations (identified by a date, location, and decree number) were recorded, including the date and number of parcels (individual households) receiving title, area regularized, and coordinates or cross streets of the location. Thirty-six updates to these decrees (*Fe de Erratas*) were recorded and used to update additional lots that were given title. Digitizing individual lots of each title was not possible because coordinates were only published with some decrees, and in most cases the projection information needed to translate and map coordinates was not provided. Instead, we used a coordinate point to approximate the central location of titling using the cross street information and community name provided. Georeferencing was done using OpenStreetMap data. These spatial data are represented in Figure 15b with the time series of parcels "regularized" or titled in Figure 16, with 6 local electoral periods.

Table 2. Variables created from digitized data for this study. *for dependent variables

Name of variable	Explanation	Method	Spatial and temporal scale	Unit	Source data
Area of *ejido* title*	Polygons of area expropriated from *ejidos*	Georeferencing topographic maps, relating to presidential decree	1997-2012	Date of Decree, Hectares	CORETT and RAN (Registro Agrario Nacional)
Area of private property title*	Points of regularization decrees	Place point at crossroads mentioned in official city decree, record area, location, number of lots	1997-2012	M^2	Gaceta Oficial
Number of private property titles*				Number of lots	
Area of urban expansion*	Area of informal expansion in years of available imagery	Handtracing structures in conservation land from very high resolution satellite imagery	~2m², 2000, 2005, 2008, 2009, 2011, 2012, 2015	M^2, 46,026 polygons	SEDEMA (Mexico City Ministry of Environment)
Months to election	Months from the date of the decree of land title until the next election	Calculate months until next local elections for private property and presidential elections for collective property	Month, per decree	month	Gaceta Oficial/Corett
Core voter statistic	Degree to which a district outperforms the city level vote market over time	$\boldsymbol{\alpha} = \overline{\boldsymbol{V_d}} - \left(\frac{\boldsymbol{Cov}[\boldsymbol{V_d V_c}]}{\boldsymbol{Var}\ [\boldsymbol{V_d}]}\right)\overline{\boldsymbol{V_c}}$ V_d = district votes to PRD V_c= city votes to PRD (Diaz-Cayeros et al., 2016)	2000-2012 (summarized across the time when PRD was dominant)	5523 districts	IEDF (Instituto Electoral de Distrito Federal)
Percent voting for PRD	Percent of district voting for the mayor's party (PRD)	% PRD= votes for PRD/total votes	2000-2015 (elections every 3 years, n=6)		
Margin of win	Measure of electoral competition	$margin\ of\ win_i = (V_{d1i} - V_{d2i})/V_{totali}$ V_{d1i}=votes to highest ranking party time i V_{d2i}= votes to second highest ranking party time i V_{totali}= total votes per district time i			

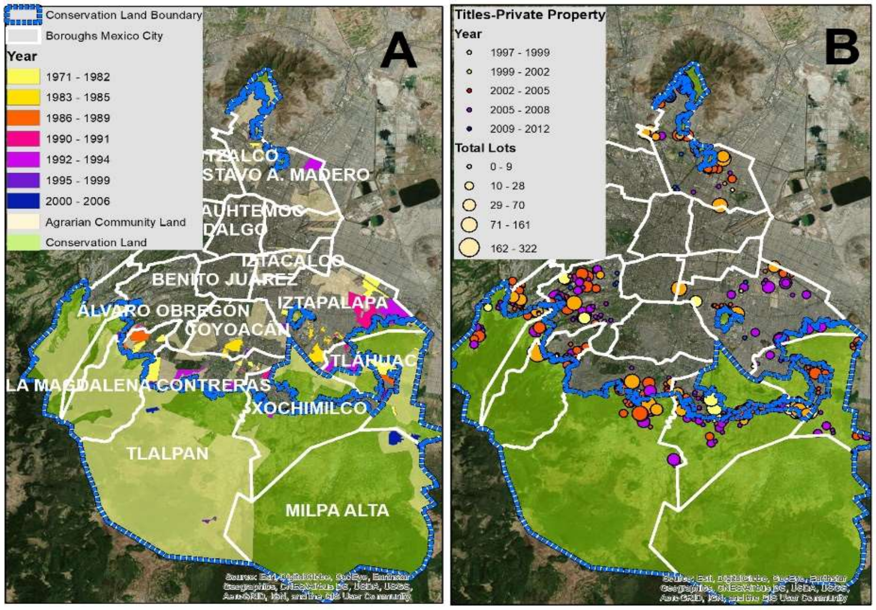


Figure 15. Regularization and land titling in private and collective lands. A. Titles in collective property (*ejidos*) from 1971-2007 in boroughs with conservation land. Tan areas indicate original agrarian community areas for *ejidos* and communities from RAN (National Agrarian Registry). B. Approximate locations of titling in private property from 1997-2012. Size of dot indicates number of lots receiving title in that area, colored yellow for older titles, and blue for more recent titles.

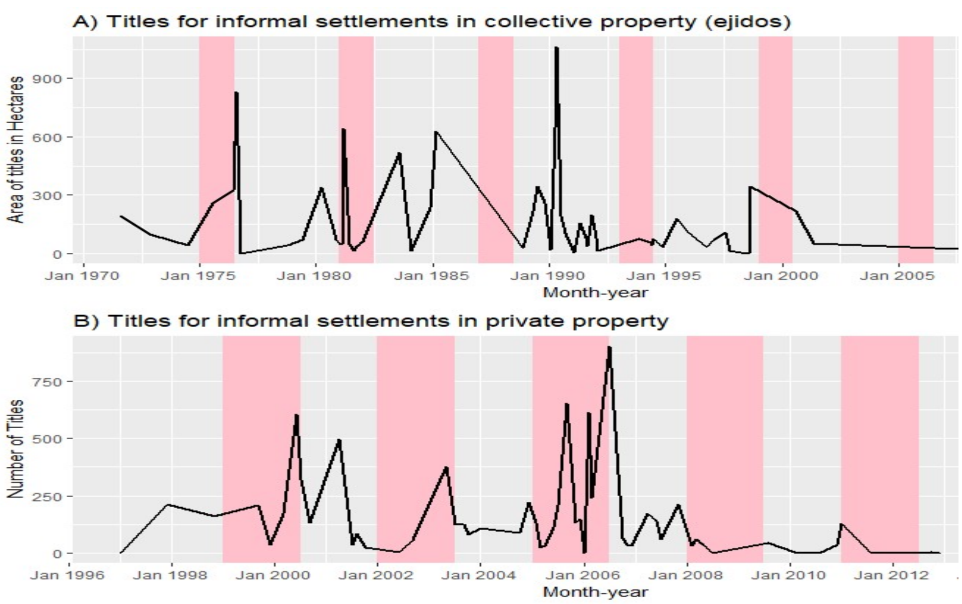


Figure 16. Temporal variability in land titling in collective and private property and elections. **A)** Monthly time series of land titling data for collective property (*ejidos*) and B) private property (bottom). Pink bars indicate the 12 months leading up to the next election (for collective property, presidential only, every 6 years; for private property, local elections, every 3 years).

Urban expansion data of informal settlements in conservation land were obtained from the Mexico City Ministry of the Environment (SEDEMA) (Fig. 17). These data were produced by tracing constructions on very high-resolution satellite imagery (~$2m^2$) when available, resulting in 46,026 polygons. The first year of data, 2000, represents all settlements existing outside of permitted urban or residential areas identified in the Ministry of the Environment Ecological Zoning Ordinance. Subsequent years (2005, 2008 ,2010 ,2011, 2012, and 2015), represent all areas constructed and identified as "urban" that occurred between the last year of available imagery and appeared in the next available image for the first time. For example, urban areas identified in 2008 could have been constructed in 2006, 2007, or in 2008 before the image was taken. Data are identified by the temporal resolution of "year" (months and dates are not provided in the SEDEMA dataset). Attempts to reconstruct a consistent annual time series of informal urban growth with Landsat data (30m) using methods from Goldblatt and associates (2018) proved unsuccessful because small informal settlements were not captured in lower resolution Landsat data.

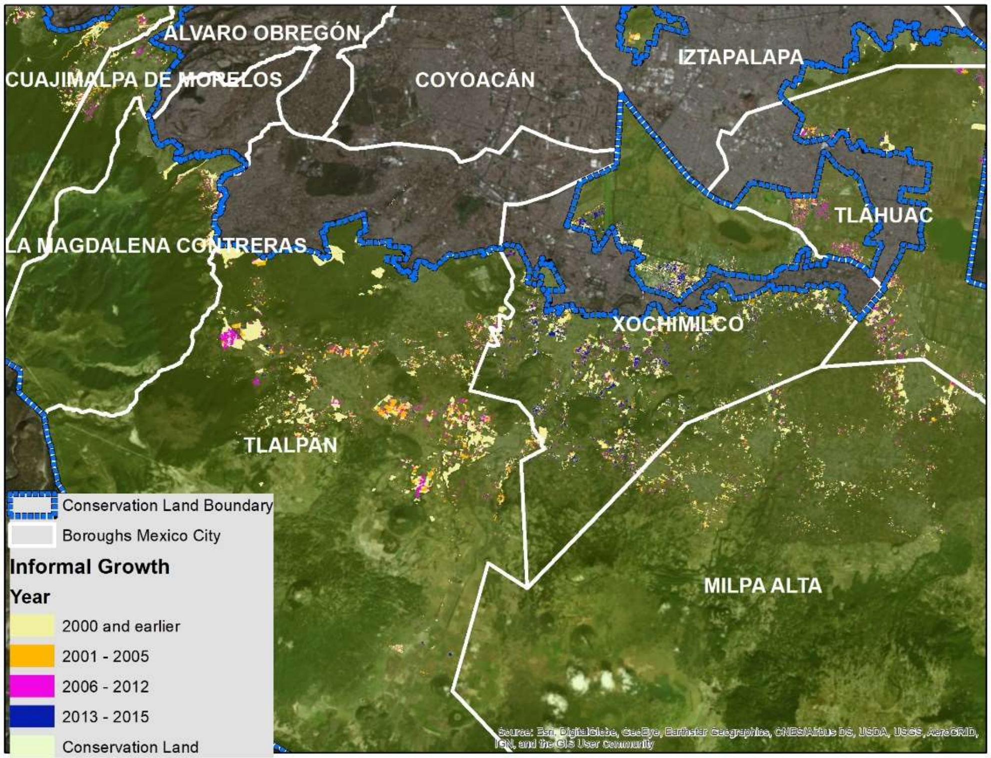


Figure 17. Urban expansion of informal settlements in conservation land in Mexico City, 2000-2015.

Independent Variables

Independent variables used to test hypotheses regarding the political business cycle of land titles and political dynamics of urban expansion were selected from political science theory and previous studies. These variables are listed in Table 2 and described below. Testing if the timing land titling distribution increase near elections and follows the political business cycle (Rogoff, 1990) required calculating the time, here measured in months, until the next election when each title was given. The hypothesis that land titles were preferentially distributed to core voters is tested based on the number of titles given to each electoral district and how consistently that district supported the main party in power based on the core voter alpha statistic (Diaz-Cayeros et al., 2016). Finally, testing the relationships between urban expansion increases and patronage or electoral competition involved measuring the percent of votes to the main party in power and margin of win in each election per district, respectively.

Months to Election Variable

Months to election are calculated by taking the date of each land title and counting the number of months until the next election. As expropriations in *ejidos* are controlled by a federal agency and through presidential decree, it is expected that collective property titles will follow the presidential electoral cycle, which occurs every six years. Months until election are calculated until the next local election (borough chief) for private property titles, because this process is controlled by coordination between the local borough, who must change land zoning regulations from agricultural or forest to residential as the first step in the regularization process. Another key part of the titling process, approval in the city legislative assembly (ALDF), is controlled by actors who are up for re-election every three years.

Electoral Competition, Core Voters, and Patronage Variables

Electoral data on voting records for the mayoral, legislative, and municipal elections were downloaded on the IEDF (Electoral Institution of the Distrito Federal) website for each election. These data included the number of voters registered and participating in elections in each district and year. The 5,539 electoral district boundaries for 2015 and 2012 were available for download online as a geospatial .kml file. Previous electoral districts (2009, 2006, 2003, 2000) were only available in .pdf format, and were digitized and georeferenced using ArcGIS. Twenty-five electoral districts have changed over time, shifting boroughs, fusing with other districts, or appearing for the first time as informal settlements grew and population changed. Digitizing the unique electoral district geography in each election preserved these changes and ensured urban expansion and titling data were attributed to the correct district for the correct year. Delegation heads and legislative officials have the largest agency in the private property land titling and activities that could influence urban expansion.

A proxy for patronage in each electoral year was calculated as the proportion of votes in each district in borough chief and legislative elections that went to the dominant party in Mexico City, the PRD. Note that in some years, party coalitions formed in joint tickets for legislators and borough chiefs. If the PRD was a part of that coalition, we counted that coalition vote as a vote for the PRD.

Electoral competition was calculated for each electoral year via the margin of win for each district as in Eq. 1.

Eq. 1 $margin\ of\ win_i = (V_{d1i} - V_{d2i})/V_{totali}$

V_{d1i} is the total number of votes cast for the party that received the majority votes for district d in time i. V_{d2i} is the votes cast for the party receiving the second highest number of votes. V_{totali} is the total votes cast for that district in election i. This statistic calculated is a measure of electoral competition, such that a lower margin of win signifies a more competitive or divided district. Figure 18 shows how margin of win varies over elections across the city for borough chief elections.

The core voter statistic measures the degree to which an electoral district "out-performs" other districts over time in voting for the dominant political party. It is not calculated in each electoral year, but represents one number over a long time period. This statistic was originally proposed by Cox and Mccubbins (1986) and replicated by Diaz Cayeros (2016) to demonstrate risk averse political party strategies, whereby parties in power distribute goods to their core constituency. Equation 2 shows how this statistic, alpha, is calculated

$$\text{Eq. 2}\ \alpha = \overline{V_d} - \left(\frac{Cov[V_d V_c]}{Var\ [V_d]}\right)\overline{V_c}$$

V_d is the proportion of district votes to PRD, and V_c is proportion of city votes to PRD. Alpha is calculated by taking the average district support for the PRD, and adjusting by risk (the covariance of district and city votes divided by district variance and multiplied by average support for the PRD across the city). Alpha represents how well a district outperforms (if the number is high) versus underperforms (if the number is low) the city-level vote market. High alpha indicate local offices (like delegations or legislatures) and brokers assure high support levels above the city level average. Lower alpha indicates places where the main party is likely to lose and does not have a core base, based on past behavior. We calculated the core voter statistics for the PRD using data from 2000-2012, because in 2015 a new left party began to split the left and the electoral situation changed.

Generating Panel Time Series across Heterogeneous Spatial and Temporal Units

Independent and dependent variables were available at distinct spatial and temporal resolutions. Land titles data contain the date of title and are represented spatially via point centroids of the approximate city block where the titles were extended. The land titling data was temporally auto correlated at the daily time step, and was thus aggregated into a monthly time series so each observation would be independent in regressions. Due to lack of precision in the land title locations, they were aggregated to the electoral district spatial scale.

Testing the influence of voting patterns on the distribution of private titles required aggregating titles in each three year electoral period, since electoral data is only available in the year of election. Testing the influence of core-voter statistic on land title distribution required summing land titles over the 2000-2012 period, because the core-voter statistic is a measure over time of patronage from many elections, and does not measure year-to-year fluctuations. Likewise, the total area urbanized per districted was calculated from 2000-2012 and used as a control in the OLS (ordinary least square model) in hypothesis 2b.

Annual urban growth data was unavailable for this study, and a data set from the Mexico City government that measured urban growth when satellite imagery was available was used. Testing the influence of voting patterns on urban expansion involved aggregating urban growth between each election from 2006-2015 (e.g. 2005 growth to the 2006 election, 2008+ 2009 growth to the 2009 election, 2011+2012 growth to the 2012 election, and 2015 growth to the 2015 election). Urban growth data, which was a vector dataset hand digitized from 2m resolution imagery, was aggregated to the coarser spatial unit of electoral district, the highest resolution unit at which spatial voting data is publicly available No urban expansion data were available prior to 2005, and the 2000 and 2003 election could not be examined. Any year and unit for which either urban expansion or land titling was not observed received a value of zero.

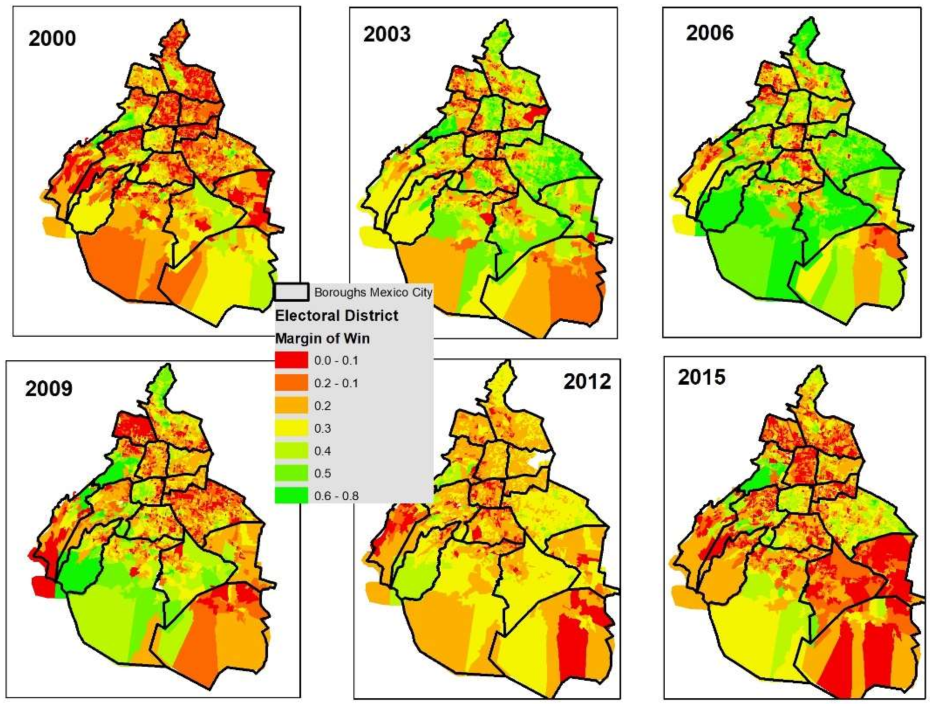


Figure 18. Time series of electoral data for 5,539 districts in Mexico City, 2000-2015. Margin of win displayed for each election per district, with more competition in red colors, and lower competition in green colors.

Model Specifications for Hypothesis Testing

The models and approach used to test the hypotheses are summarized in Table 3. All outcome data (except for sum of titles over time, Hypothesis 2b) were log linearly distributed, but with a mass point at zero, with the variance much higher than the mean, violating the assumptions of the Poisson distribution. As a result, generalized linear models were used with a negative binomial distribution, with fixed effects for time and unit as in equation 3. Coefficient estimates are fit through maximum likelihood estimation.

$eq.3\ f(y_{it}) = exp\ (\beta' x_{it} + \alpha_i + \gamma_t)$

Y = the dependent variable measured in each unit of time(t) per spatial unit (i)

γ_t = the time fixed effect

α_{I} = is the spatial unit intercept

$\beta' x_{it}$= independent variables

Table 3. Models and variables used to test each hypothesis.

Hypothesis	**Dependent variable**	**Independent variable (s)**	**Regression technique**	**Spatial and time unit, temporal period & # observations**
1a.Titling in *Ejidos* follows the Political Business Cycle (Presidential Elections)	Area (ha)	Months until the next presidential election, year	Generalized Linear Model with Fixed effects	Borough, months (1971-2007),n=85)
1b.Titling in private property follows the Political Business Cycle (Local Elections)	Titles (number of lots) and area (m^2)	Months until the next local election, year,		Borough, months (1997-2012), n=475
2.a Private property titles are distributed to clients of the main party (PRD)	Titles (number of lots) and area (m^2	Percent voting for the PRD		Electoral district, 6 local elections (2000-2012), n=1,065
2.b Private land titles are distributed to core voters	Titles (number of lots)	Core voter statistic in borough and legislative elections, informal settlement area 2000-2015, Hectares	Ordinary Least Squares	Electoral district with land title >0, n=388
3. Informal urban expansion increases with competition	Area urbanized in m^2	Margin of win, percent of votes for main party (PRD) borough	Generalized Linear Model with Fixed effects	Electoral districts with informal urban growth >0, 4 elections (2006-2015) n=1231

Fixed effects are used to help control for omitted variable bias in hypothesis testing, assuming that the errors are correlated with the spatial unit. This control allows for consistent estimation of coefficients and standard errors in comparison to random effects models. Any variation between units that is constant over time that could influence either titling or informal settlement growth (e.g., size of unit, slope, distance to urban center, distance to roads, etc.) is implicitly included in the intercept term of the model.

As both the urban growth and land titling data were gamma distributed with a mass point at 0, a negative binomial distribution was used. However, fixed effects panel models with negative binomial distributions using conditional maximum likelihood do not provide a true fixed effect (Guimarães, 2008). We thus either add in dummy variables for each unit in negative binomial regressions, or used a Poisson distribution with adjustments to standard errors as suggested by Allison and Waterman (2002). All fixed effects models were run in STATA version 15 (StataCorp, 2017). We did not use a Hausman test to examine whether fixed effects is a better choice over random effects because this test is not useful in generalized linear models. Importantly, urban growth is not count data, in contrast to land title data. No continuous distribution, however, with true 0 measures for a fixed effects model is available for estimation.

One hypothesis test, the influence of the core voter statistic on land titling distribution, was formulated with the Ordinary Least Squares Model (OLS). In this model, only the districts that had received titles were used as observations, and the distribution was not zero inflated, so an OLS model was used. This model included dummy variables for borough and total urban growth from 2000-2015 to control for the availability of homes for titling.

Results

Does land titling of informal settlements follow the political business cycle?

Regression results confirmed hypothesis 1b but not 1a: land title distribution follows the political business cycle for private property, but not for collective property. Specifically, land title distribution significantly increases in the months leading up to the election for private property titles and titled area, but not for collective property titles (Table 4). These results were robust to monthly lags and leads, up to one month in a lag and 3 months leading the dependent variable (SI Tables 2 and 3). In private property, the months to election continued to predict increased property titles for up to a three month lead, with the magnitude of the coefficient declining from the one month lag (-0.0332, P<.001) to the three month lag (-0.0183, P<.1) (SI Table 2). Likewise, the months to election continued to predict area titled in private property for months until election for up to 5 months, and a similar decline in magnitude in each passing month (e.g., lag month 1= -0.0349 $p<.001$, and lag month 5= -0.0264, $p<.05$). This suggested that while the months leading up to the election predict increase titling, this result was not precise at the monthly time step, but rather, within a 3-5 month period.

Table 4. The political business cycle of land titles in private and collective property. 95% confidence interval in brackets.

	(1)	(2)	(3)
	Titles, Private Property	Area Titled, Private Property, m^2	Area Titled, Collective Property, ha
Months until Election	-0.0352***	-0.0354***	-0.000349
	[-0.0548,-0.0156]	[-0.0555,-0.0153]	[-0.0115,0.0108]
1999	-1.819*	-2.193**	
	[-3.278,-0.360]	[-3.683,-0.703]	
2000	-1.359*	-1.638**	
	[-2.490,-0.228]	[-2.800,-0.477]	
2001	-0.962	-1.356*	
	[-1.979,0.0544]	[-2.393,-0.319]	
2002	-1.382*	-1.622*	
	[-2.625,-0.140]	[-2.893,-0.351]	
2008	-2.015**	-2.363***	
	[-3.242,-0.788]	[-3.614,-1.113]	
2010	-1.554**	-1.761**	
	[-2.730,-0.378]	[-2.950,-0.572]	
2011	-1.875*	-2.203**	
	[-3.303,-0.447]	[-3.651,-0.755]	
2012	-1.115*	-1.295*	
	[-2.204,-0.0255]	[-2.394,-0.196]	
Azcapotzalco			1.376
			[-0.277,3.028]
Coyoacan			-14.48
			[-1823.5,1794.6]
Cuajimalpa	-1.055**	-1.145***	0.703
	[-1.789,-0.320]	[-1.815,-0.475]	[-1.189,2.595]
Gustavo Madero	-0.602	-0.695*	1.362
	[-1.244,0.0396]	[-1.281,-0.109]	[-0.240,2.963]
Iztapalapa	-1.523***	-1.420***	1.679*
	[-2.293,-0.753]	[-2.119,-0.722]	[0.114,3.243]
Magdalena Contreras	-1.131**	-1.051**	1.093
	[-1.857,-0.405]	[-1.719,-0.382]	[-0.549,2.735]
Milpa Alta			-14.99
			[-2410.4,2380.5]
Tlahuac	-1.369***	-1.376***	2.090**
	[-2.174,-0.564]	[-2.089,-0.662]	[0.545,3.636]
Tlalpan	-1.263***	-1.158***	1.404
	[-1.985,-0.541]	[-1.831,-0.485]	[-0.221,3.029]
Xochimilco	0.166	0.0866	-0.0641
	[-0.450,0.783]	[-0.468,0.641]	[-2.099,1.971]
_cons	-0.106	-0.569	-4.970***
	[-1.213,1.001]	[-1.698,0.561]	[-6.474,-3.466]
N	438	440	616
AIC	2026.8	4045.6	1159.2

*years with no significant effects removed from this table to preserve space. See SI tables 1-3 for full results.

Is private property title distribution correlated with core voters of the PRD?

Hypothesis 2b was confirmed, although with caveats. Private property land titles over the 1997-2012 period are positively correlated to core voter support of the PRD party, but the core voter statistic only explains a small portion, 2-4% of variation in both number and area of titles distributed (SI Figs. 1-4). Regression models in general explained a small but significant portion of variance in title distribution when using the core voter statistic for both borough (R^2= 0.0704 for area titled and 0.085 for number of titles) and legislative elections (R^2= 0.081 for area titled and 0.108 for number of titles) (Table 5).

The results also varied by borough. Interaction models reveal variations in coefficient estimates of core voters and land titling, with a significantly stronger relationships between core voters and titling in Gustavo Madero and Tlahuac (Map, Figure 19).

Table 5. Distribution of land titles based on core voter statistics for each election type, prediction area of land titles and number of titles. Standard error in parentheses. Model 5 interacts borough with core voter for borough elections and Model 6 interactions borough with core voter for legislative elections.

	Dependent variable:					
	titles-legislative	area-legislative	titles-borough	area-borough	titles-legislative	
	(1)	(2)	(3)	(4)	(5)	(6)
informal settlement area 2000-2015 HA	0.028	0.018	0.032	0.022	0.026	0.028
	(0.017)	(0.013)	(0.023)	(0.018)	(0.017)	(0.024)
core voter	4.249***	3.582***	2.210**	2.205**	0.185	-0.681
	(1.189)	(0.892)	(1.108)	(0.857)	(2.958)	(3.415)
Cuajimalpa	-0.312	-0.227	-0.395	-0.234	-0.721	-0.815
	(0.402)	(0.302)	(0.579)	(0.447)	(0.494)	(0.713)
Gustavo Madero	0.010	-0.189	0.013	-0.183	-0.967	-0.918
	(0.385)	(0.289)	(0.555)	(0.429)	(0.709)	(1.006)
Iztapalapa	-0.275	-0.710*	-0.582	-0.998*	-1.658	-2.293*
	(0.537)	(0.403)	(0.666)	(0.515)	(1.192)	(1.299)
Magdalena Contreras	-0.686*	-0.482	-0.699	-0.481	-1.207*	-1.234
	(0.415)	(0.311)	(0.590)	(0.456)	(0.676)	(0.867)
Tlahuac	-1.837***	-0.468	-1.765***	-0.411	-5.797***	-3.627***
	(0.413)	(0.310)	(0.586)	(0.453)	(0.962)	(1.338)
Tlalpan	-0.067	0.197	-0.271	0.077	-0.378	-0.598
	(0.377)	(0.283)	(0.527)	(0.408)	(0.522)	(0.830)
Xochimilco	-0.981***	-0.676***	-0.804*	-0.559	-1.280**	-1.500*
	(0.345)	(0.259)	(0.476)	(0.368)	(0.556)	(0.822)
core*Cuajimalpa					1.426	0.876
					(4.807)	(3.852)
core*Gustavo Madero					7.988*	6.134
					(4.760)	(5.419)
core*Iztapalapa					10.743	10.507
					(7.826)	(6.776)
core*Magdalena Contreras					4.962	4.427
					(5.727)	(5.620)
core*Tlahuac					30.260***	13.382
					(6.740)	(8.557)
core*Tlalpan					2.395	2.538
					(3.830)	(4.842)
core*Xochimilco					3.202	4.386
					(3.589)	(4.141)
Constant	2.432***	7.965***	2.599***	8.060***	2.874***	2.984***
	(0.309)	(0.232)	(0.426)	(0.329)	(0.423)	(0.604)
Observations	388	388	213	213	388	213
R^2	0.108	0.081	0.085	0.074	0.162	0.115
Adjusted R^2	0.087	0.059	0.045	0.033	0.126	0.043
Residual Std. Error	1.822 (df = 378)	1.367 (df = 378)	1.835 (df = 203)	1.418 (df = 203)	1.783 (df = 371)	1.837 (df = 196)
F Statistic	5.107*** (df = 9; 378)	3.697*** (df = 9; 378)	2.104** (df = 9; 203)	1.798* (df = 9; 203)	4.486*** (df = 16; 371)	1.593* (df = 16; 196)
Note:						*p<0.1; **p<0.05; ***p<0.01

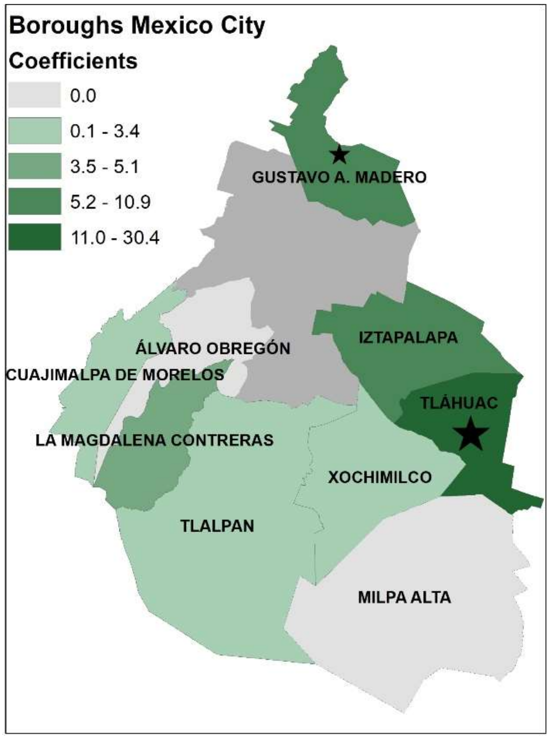


Figure 19. Core voter coefficient for land title distribution, by borough. Coefficient estimates from model 5, Mexico City borough elections and core voter support measure.

Null results were found for hypotheses 2b, which examined if changes in patronage that varied over time explained distribution of titling. A fixed effects panel regression finds no significant effect on the number of titles in a given electoral period with voting data. Neither patronage nor competition influence the number of titles distributed. This indicates that while more titles are distributed to core voters, titling does not increase in concert with changing voter behavior in a specific election. Spatial analysis of land titling data also yielded that 24% of all land titles occurred in conservation land. Of these, 72% were in areas already built before 2000.

Does electoral competitiveness or patronage explain urban expansion?

Overall, results from urban expansion models indicate electoral competitiveness (lower margin of win) increases with urban expansion in borough and legislative elections. As patronage decreases, urban expansion increases (Table 5). These results are significant only in the contemporaneous year with the negative binomial distribution. Lagging and leading the dependent variable by one electoral period caused electoral variables to lose significance (SI Tables 6 and 7). Using the Poisson distribution, however, electoral competition remains a significant predictor of urban growth when the dependent variable is subject to both a lag and lead of one election, respectively (SI Tables 8 and 9, p<.0001). In addition, in one robustness check, contrary to other results, higher patronage significantly *increases* when urban growth is led by one electoral period. The failure of these robustness checks suggests endogeneity; that urban growth and electoral variables may influence each other.

Table 6. Informal urban expansion and electoral competition vs. patronage in borough and legislature elections. Brackets indicate standard error. ***, **, * indicates Significance at 1%, 5%, 10% level.

	Negative Binomial		**Poisson**		**Negative Binomial**		**Poisson**		Null Model (Poisson)
	Borough Elections				**Legislative Elections**				
Competition	-1.81*** [0.2783]		-2.6151*** [0.0103]		-0.465 [0.3226]		-0.4908*** [0.0129]		
Patronage		-1.52532*** [0.305891]		-5.5263*** [0.016421]		-0.96889 [0.4240703]		-5.6903*** [0.019263]	
2009	-1.232*** (-12.46)	-1.071*** (-11.80)	-1.482*** (-9.61)	-1.264*** (-9.22)	-1.021*** (-8.73)	-1.166*** (-8.18)	-1.147*** (-4.89)	-1.625*** (-3.50)	-1.194*** (-13.43)
2012	-0.971*** (-10.03)	-0.631*** (-7.52)	-1.091*** (-8.15)	-0.760*** (-6.82)	-0.690*** (-7.16)	-0.799*** (-7.01)	-0.707*** (-5.95)	-1.073** (-3.28)	-0.776*** (-6.35)
2015	-1.356*** (-12.27)	-1.590*** (-11.41)	-1.279*** (-6.60)	-1.124** (-2.85)	-1.045*** (-7.84)	-1.273*** (-6.85)	-0.574* (-2.18)	-1.494* (-2.04)	-0.600*** (-3.92)
Pseudo R2			.8491	.8624			.8327	.8562	0.8322

Figure 20 displays borough level model coefficients, with solid bars for those that are significant. If patronage universally caused urban expansion, all the bars in the

Figure 20 would be positive and significant, indicating that higher margin of win and patronage to the PRD, the dominant party, correlates with urban expansion. If competitiveness universally caused urban expansion, the reverse would be true; all bars would be negative. Instead, the results are mixed and vary by borough. While the mean effect across the city indicates urban expansion increases with electoral competition, the borough analysis indicates this result is potentially largely driven by Xochimilco. Patronage to the PRD significantly increases with urban expansion in three boroughs (Gustavo Madero, Milpa Alta, and Cuajimalpa). Reduced competition significantly increases with urban expansion in only two boroughs, Milpa Alta and Alvaro Obregon.

Notably, Xochimilco is the only borough with increasing urban growth in 2015 (Fig 21), the same year the PRD in Mexico City split, creating a new competitor party, MORENA. MORENA won elections in three boroughs in 2015 (Table 6). Tlahuac, the only other borough where electoral competition increases with urban expansion in a borough level analysis, also switched to the MORENA party in 2015, and was the borough with the second highest area of urban expansion. In Tlalpan, however, MORENA won local elections, but electoral competition does not significantly increase with urban growth.

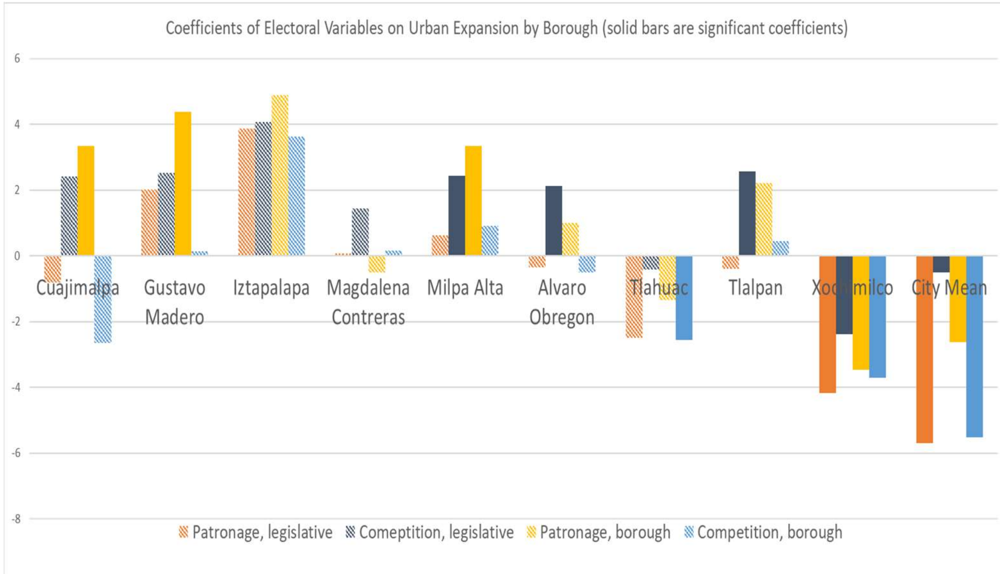


Figure 20. Coefficient plots for each borough in Mexico City for competition versus patronage in explaining variation in urban expansion from 2006-2015 across 4 elections. Solid bars indicate significant coefficients at the P<.05 level. Patterned and lighter bars are insignificant.

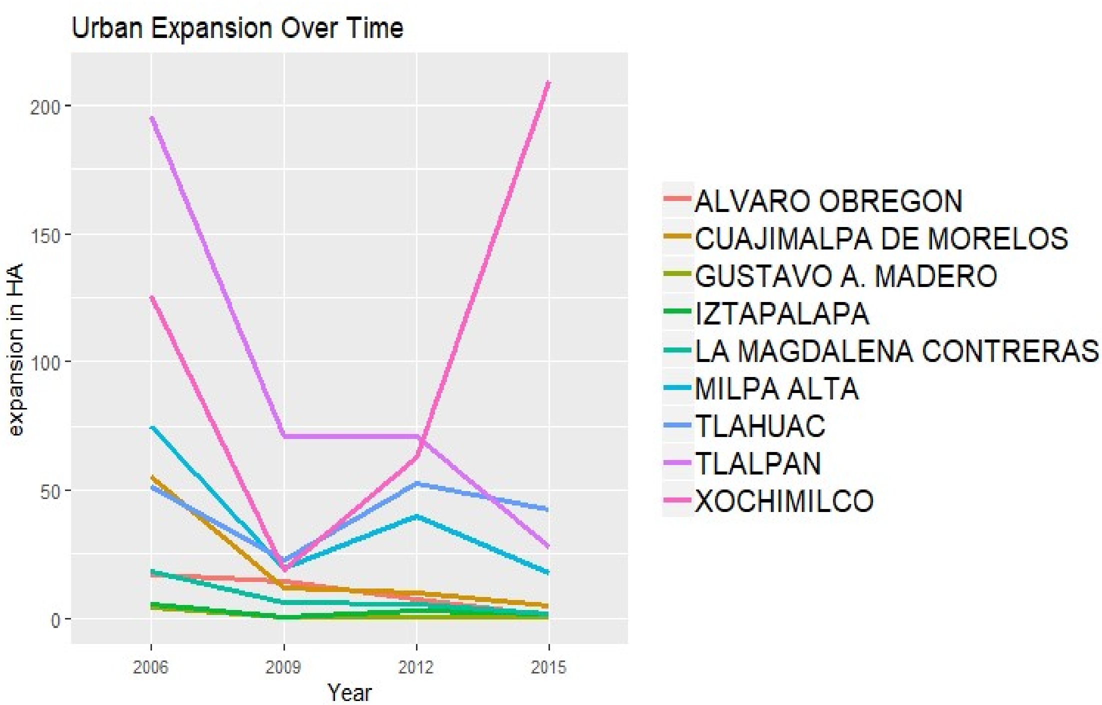


Figure 21. Total informal urbanized area in m^2 per borough 2006-2015.

Table 7. Initials of the winning borough party in each election. Electoral flips to a new party highlighted in yellow. Estimated percentage of population living in informal settlements (based on Ministry of Environment and Census Data collected in 2010)

Borough	2015	2012	2009	2006	2003	% of population informal
Alvaro Obregon	PRD_PT	PRD_PT_MC	PRD_PT	PRD	PRD	1.3
Cuajimalpa	PRI-PVEM	PRI_PVEM	PAN	PRD	PRD	27.7
Gustavo a. Madero	PRD_PT	PRD_PT_MC	PRD	PRD	PRD	.9
Iztapalapa	PRD_PT_NA	PRD_PT_MC	PT*	PRD	PRD	.8
Magdalena Contreras	PRI-PVEM	PRD_PT_MC	PRD	PRD	PRD	10.1
Milpa Alta	PRI-PVEM	PRD_PT_MC	PRD_PT	PRD	PRI	54.5
Tlahuac	MORENA	PRD_PT_MC	PRD_PT	PRD	PRD	16.5
Tlalpan	MORENA	PRD_PT_MC	PRD	PRD	PRD	16.0
Xochimilco	MORENA	PRD_PT_MC	PRD	PRD	PRD	35.2

*The PT (Workers Party) is left and aligned with the Party of Democratic Revolution (PRD). Due to issues with the PRD candidate for the 2009 elections in Iztapalapa (Clara Brugada), Andres Manual Lopez Obrador, the mayor of Mexico City instructed voters to vote for her on the PT party ticket. Here the PT is considered the with the PRD. MC = Citizen Movement party; PVEM = Ecologist Green Party of Mexico; NA = New Alliance party.

Discussion

Urban informality and clientelism in Mexico City

Land titles are distributed in a political business cycle in private but not collectively titled lands. This initial test of relationships about the distribution of private property titles in Mexico City and the political business cycle echoes dynamics regarding titling and clientelism in rural Mexico, that is, privately targeted goods are preferentially distributed to core voters (Diaz-Cayeros et al., 2016). Contrary to findings from studies conducted in rural areas, (Albertus et al., 2016; Castañeda Dower and Pfutze, 2015), we did not find titling in Mexico City induced defection from the core party, PRD, in contrast with what was found with the PRI in rural areas. This result indicates that titling is a pork barrel policy, given to supporters, but is not withheld nor rewarded to supporters or defectors. Consistent with existing literature for Mexico, the rural PRI tactics of clientelism and particularistic distribution of benefits (de Alba, 2016; Hagene, 2015) was reproduced by the PRD in Mexico City (de Alba, 2016) in the distribution of land titles from 1997-2012. While land titling is legally an administrative procedure, the clear temporal signature of when these titles are distributed indicates political manipulation of what has been assumed to be a bureaucratic process in Mexico City.

The distribution of land titles in private property, under administrative purview of Mexico City, followed political business cycles, with titles increasing in the months leading up to local elections. Interestingly, titling in collective property, controlled at the federal level with either the PRI or PAN administrations, did not follow this same trend. This result is in line with core voter theory explaining the distribution of privately targetable goods by governments. The PRI or PAN parties cannot reliably recruit voters in the PRD-dominated informal settlements of Mexico City. It is not surprising these administrations would not waste resources to focus titling efforts on a population that would likely yield little to no electoral returns. In addition, neither PRI or PAN have won the mayoral seat in Mexico City since local elections were established in 1997. Notably, in 2018, a left party, MORENA, won the Mexican presidency for the first time, and secured the mayoral seat in Mexico City and most of the southern boroughs.

One surprising result of this study was that the majority of land titled occurred on private lands that had already been urbanized by 2000. This indicates that the titling process likely takes many years, and does not occur in newly established urban settlements. Additional analysis and a much longer time series would be required to assess if land titling has an effect on urban expansion, and to estimate the average time from initial construction to property titling. Importantly, many urban authorities in Mexico City, especially in the Ministry of Environment, assume that land titling will exacerbate urban expansion on conservation land. This assumption has resulted in the establishment of new regulations to require settlers pay environmental fees as well as the completion of environmental impact studies, both of which have stagnated the titling process (Wigle, 2014, 2010). Indeed, the number of titles has decreased over time in Mexico City (Fig. 16), despite continued urban expansion in regions like Xochimilco (Figure 21).

Urban expansion is associated with electoral competition, but only in two boroughs where there was high electoral competition between two left parties that split in 2015 (Xochimilco and Tlahuac). Xochimilco is the only borough that increases urban growth rates in this electoral period, and it has the second largest percentage of population living in informal settlements (35.2%). Informal settlements in the south of the city have been an important voting block for the PRD, the main party in power. MORENA, the new left party, competes for voters in these same informal settlements. Therefore, it is possible that urban growth only increases with electoral competition between two parties similar in ideology competing for the same voting bloc.

Results indicate that on average urban expansion increases with electoral competition in boroughs, which is the administrative level with greatest ability to promote or restrict settlement consolidation via eviction. In the absence of annual temporal resolution urban expansion data, it is difficult to assess if political parties are attracted to already expanding urban areas, or if the arrival of parties causes expansion.

Urban expansion is also correlated with increased competition in legislative districts. Legislators typically influence urban expansion by acting as brokers to exercise political capital within their party to, for example, bribe the electricity utility to install an illegal system (Ch 2). They may also act as intermediaries to intervention in eviction process by filing legal protections (*amparos*) in court. Some legislators are current or former leaders of informal settlements themselves. While some empirical data from this research and previous articles supports these mechanisms, more work is needed to understand why these relationships vary by borough and region across the city, and tease apart potential endogeneity.

Paradoxically, urban growth is associated with patronage in five boroughs. In these locations (Cuajimalpa, Gustavo Madero, Milpa Alta, Alvaro Obregon, and Tlalpan), urban growth was highest in earlier electoral periods (2006). Notably, electoral competition was lowest in 2006 compared to other years, and the core party (PRD) won every borough election (Table 7). The fact that these results vary by region could suggest that political parties may shift strategies overtime, engaging in activities to recruit new voters or reward supporting core voters dependent on specific spatial and electoral contexts.

The strength and significance of relationship between land titles and core party support also varied by region (Figure 19). Notably, this relationship was strongest in the Eastern side of the city (Iztapalapa, Tlahuac and Gustavo Madero), and only significant in two boroughs (Gustavo Madero and Tlahuac). This could be because patronage to the PRD was very high in this region of the city in both 2003 and 2006 (Figure 18), incidentally the electoral periods when that land titling was highest on private lands in Mexico City.

Land titles, which are an excludable good, are correlated with increased core party support. In contrast, urban expansion increases in areas of competition instead of core support. The seemingly contradictory finding that more land titles go to core voters, yet assistance in urban consolidation (e.g., building roads and urban utilities) may be directed to recruit new voters, is consistent with previous literature regarding clientelism in rural areas in Mexico. Diaz Cayeros (2016) found that goods that are private and excludable, such as cash transfers, are typically given to core voters, while goods that are public, such as installing a park, are typically directed towards competitive districts. This appears to be because excludable goods are expensive, and it is too risky for parties to waste the most expensive resources on voters who may not vote for them. Likewise, in Mexico City, goods with private benefits (i.e., land titles) are associated with areas of higher core voter support. We assume the mechanism of urban expansion is due to the efforts of competing political parties aiding informal settlement consolidation through non-excludable goods (e.g., roads, urban services, and eviction prevention of that community). These findings suggest that political parties may influence the urban land system in Mexico City by granting titles to supporters but helping informal settlements consolidate in competitive electoral districts.

Quantifying political transactions in informal urban land use and tenure

This study helps clarify and quantify how informal settlements and land markets respond to political incentives, a need identified in research from sustainability and land system science to political science (Eakin et al., 2017; Post, 2018). It underscores that politics shape land tenure change and land use, influencing both when and where these activities occur, and which populations benefit. Administrative procedures, such as land titling in the case of Mexico City, are manipulated by governments. This particularistic distribution distorts urban services in ways that may benefit the party in power, instead of distributed evenly to citizens with demonstrated needs in a defined institutional procedure. While this mechanism has been asserted and demonstrated in qualitative studies (Azuela de la Cueva, 1987a; Connolly and Wigle, 2017a; Varley, 1998), this study sheds new empirical light to confirm this mechanism operates at the city scale by the main party in power. It further clarifies that only private property titling, not collective property titles controlled by national level governments, follows electoral cycles. This suggests that local urban politics, as opposed to national politics, may play a larger role in influencing land tenure changes in informally settled areas.

Land tenure changes can have wide-ranging impacts on the urban socio-ecological systems. Land titles can improve well-being of populations in informal settlements by increasing the value of land, allowing the installation of urban services, serving as collateral for loans, and preventing the threat of eviction. One study on informal settlements in China found titles can reduce poverty under certain conditions (Webster et al., 2016). Other studies in rural Mexico have found titling efforts can "break" clientelism and poverty traps by allowing farmers to rely on the market, instead of political parties, for economic well-being (Albertus et al., 2016). Lack of title and legal uncertainty can increase social and economic marginalization of informal residents and subject them to in relationships with intermediaries that exploit their vulnerability (Ch 2 Aguilar and Guerrero, 2013). Other studies have found elite capture of the benefits of urban land titling efforts in Buenos Aires, for example (Van Gelder, 2013). The distribution of secure land tenure is thus a question of justice, human rights, and urban resilience. Quantifying the political influence on titling makes the political nature of this distribution, and to what degree it is distorted, more transparent than otherwise. The proliferation of urban land titling efforts promoted by the World Bank since De Soto's (2000) influential work to promote formalization of land tenure has paid little attention to the possibility that these processes would be used for political gain (Gilbert, 2002). While politicians need to wield capital and prove their effectiveness to voters to win and retain office, whether land titles should be included as part of their strategy is a normative question.

Electoral politics may influence urban expansion. Yet, virtually no land change models, agent based or otherwise, or even empirical studies of what drives of urban growth, include electoral competition or patronage as a potential factor. Future work to examine the relationship between politics and urban growth, as in this study, in both formal and informal areas for a wide range of cities, is needed to inform models of land systems, urban or rural. Elucidating the connection between complex political incentives to land use and land tenure outcomes is not straightforward, but this study showed a significant mechanism exists. Studies that fail to capture this mechanism, especially those that exhibit a high degree of informality, are not capturing the system as it is and reduces the accuracy of land system models. Ever increasing open data sets from cities, and the increasing spatial temporal resolution of satellites, should make it possible to begin to quantify political dynamics long asserted in qualitative research.

Limitations

The relationship between electoral politics and urban expansion is complex and context dependent, and the models presented here lack the specification or sample size to tease apart these complex relationships. Future work could involve developing an annual time series of urban expansion, or surveys with informal settlers about specific relationships with legislators and their borough chiefs. Additional efforts in increasing the sample size may also allow for improved model specification with fixed effects to control for variation. While this research employs a negative binomial distribution with fixed effects, the model does not converge when dummy variables for each electoral district were added. Without adding these dummy variables, a negative binomial model may not provide a "true" fixed effect (Allison and Waterman, 2002; Guimarães, 2008). Instead, a correction for over dispersion was applied to standard errors for hypothesis testing in the Poisson model, which provides a true fixed effect. Finally, the negative binomial and Poisson distributions are typically used for count data. While number of land titles qualifies as a count, urban growth (while it is a positive integer of area constructed per year in meters, and gamma distributed) may not fit this definition. Future work should explore other ways of modeling non-linear urban growth patterns with electoral data beyond the methods approached here, such as the tweedie distribution (Zhang, 2013).

Urban growth in unregulated areas, for example, the conservation lands of Mexico City, can erode environmental services like aquifer recharge. Informal settlements often occur on marginal lands that are of low value and exposed to environmental hazards, such as floodplains and hillsides at risk of landslides (Fraser, 2017). While monitoring where this growth occurs for its regulation, of equal importance is ascertaining if an actor in power is promoting it. Improving methods to estimate relationships between urban growth and ancillary data (like electoral data) could identify regions where politicians are potentially inducing the growth they are charged with regulating.

Conclusion

Land tenure and land use change maintains a strong political component that is muted in much of the research and modeling about land systems. This study found electoral politics influence the pace, timing, and distribution of land titles to informal settlements in Mexico City in private but not *ejido* lands. Results also indicate political parties may influence informal urban expansion in conservation land, but this relationship is complex and varies by context. Public discourse assumes informal settlements are responsible for urban expansion on conservation land (Lerner et al., 2018), but this study indicates political parties may also play a role. Bridging political science research and methods with geographic approaches to understand the spatial temporal distribution of land tenure and use changes is required to improve understanding of how urban land systems work and improve land system models. Given the large expected increases in informal urban expansion in the coming decades, especially in decentralized urban political systems, improved understanding of how politics influence titling efforts and land use changes is essential for a large range of research and practice.

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CHAPTER 4

ACCOUNTING FOR ILLICIT ACTIVITY IN LAND CHANGE WITH NEWS MEDIA: NARCOTRAFFICKING AND FOREST LOSS IN CENTRAL AMERICA

Abstract

Land Systems Science aims to understand why land use changes, but has struggled to understand the role of illegal economies in environmental change. Illicit activity from illegal logging to drug cultivation has been inferred as a driver of land changes, such as forest loss. Despite this recognition, a paucity of data on illegal economies and behavior makes it difficult to incorporate illicit activities into causal inference models of land change. This study presents a novel empirical strategy to meet this challenge through the case of narcotrafficking and forest loss in Central America by using media reports as a data proxy for increased narcotrafficking activity. Evidence continues to build that narcotrafficking plays an important, yet often unreported, role in forest loss as traffickers clear land for money laundering operations and territorial control in response to interdiction efforts. This effect has not been systematically compared to the other well-known causes of deforestation in the region, such as rural population increases and expansion of forest clearing for cattle pastures. Longitudinal data on 50 sub-national units over a period of 16 years (2001-2016) are used in fixed effects regressions to estimate the role of narcotrafficking in deforested areas. Two narcotrafficking activity proxies were developed for modeling: i) an "official" proxy - government measured drug seizures for 14 sub national units; and, ii) an "unofficial" proxy - spatialized media counts of narcotrafficking events. Both proxies indicate narcotrafficking is a statistically significant contributor to forest loss in the region, especially in Honduras, Nicaragua, and Guatemala. This study showed the ability of media, despite an urban bias, to capture the signal of illicit activity in land use changes such as forest loss. Similar methods to

those used in this study could be applied to estimate the causal effect of illicit activities in other land systems.

Illicit and Clandestine Drivers of Land Change[21]

Land Systems Science (LSS) is an interdisciplinary field focusing on understanding where, why, and how land systems change (Turner et al., 2007). One of its major aims is to identify the relevant drivers and establish the causes of land change.[22] Establishing a driver as a cause of change requires evidence of both a causal mechanism and an estimated causal effect (Meyfroidt 2016). LSS has addressed individual behavior, collective and state actions, market enterprise, and globalization as drivers (Meyfroidt et al., 2018; Munroe, McSweeney, Olson, & Mansfield, 2014; Turner et al., 2007). Illicit activity has been inferred as a driver of land change in studies including illegal logging (Hosonuma et al., 2012; Lawson et al., 2014), "land grabbing" (Davis et al., 2015; Ruilli et al., 2012), crop production (Dávalos et al., 2011; Grau and Aide, 2008), and cocaine transit (Devine et al., 2018; McSweeney et al., 2018, 2017). There has been limited attempts to date, however, to estimate the causal effects of illegal economies on land systems (Tellman et al, nd). Establishing causality is necessary to incorporate illicit activity into existing theory, modeling, and governance of land systems.

Part of the challenge of incorporating illicit drivers in models or tests lies in the difficulty of collecting spatial and temporal quantitative data sufficient to permit causal inferences. Illicit activities are intentionally hidden. As a result, observations of them are

[21] This chapter will be revised for an article co-authors, Steven E. Sesnie, Nick Magliocca, Erik Nielsen, Jennifer Devine, Kendra McSweeney, David Wrathall, Meha Jain, Anayasi (ghost author), Karina Benessaiah

[22] Henceforth in this study, a driver constitutes a phenomenon associated with an outcome. A cause is a driver for which processual mechanisms exist that are at least partially responsible for the outcome constituting an explanation (Meyfroidt, 2016). A factor is any variable that mediates an outcome.

often incomplete, fragmented, or unreliable, whether they are based on ethnographic anecdotes, tangential information obtained during field surveys, official statistics, data "leaks" (e.g., The Panama Papers), or the media (Tellman et al., nd; Hudson, 2014). Collecting field data on illicit activities can be dangerous, often precluding researchers from broaching the subject directly (Hall, 2012). The research community requires methodological and even epistemological innovation to overcome these challenges.

One promising approach to collect spatial and temporal data on illicit activities safely is the use of news media reporting. Investigative journalism and media reports are one of the only sources of data beyond official statistics documenting them (Hudson, 2014). News media has recently been used as an effective data source to monitor the illegal wildlife trade (Basu, 2014; Nijman, 2015; Patel et al., 2015; Siriwat and Nijman, 2018). Yet outside of wildlife studies, to our knowledge, online news media have not been developed as a primary data source for illicit activities and land changes such as forest loss. This study compares media reports with official drug trafficking statistics across the region to evaluate their congruence and assess the potential of news media data as a proxy for trafficking intensity.

Narcodeforesation in Central America

Narcodeforestation in Central America is a unique case of illicit deforestation (McSweeney et al., 2014). Central America is central node of transit in the cocaine supply chain. An estimated 86% of cocaine move through the region, accruing 9,0000-10,000 $USD of additional value per kilo and $6 billion dollars in total annual profits (UNODC, 2010). Central America is a central battleground in the War on Drugs, where the United States government spends over $3 billion annually to intercept cocaine in transit. These interdiction activities cause highly adaptive cartels to move and shift cocaine transport sites around Central America in response to risks in their supply chain (Magliocca et al., 2019). The movement of the cocaine supply chain and it associated capital across Central America occurs in remote forested regions.

Despite some evidence of a forest transition and reforestation for dry tropical forests in Central America over the past two decades (Aide et al., 2013; Hecht and Saatchi, 2007; Portillo-Quintero and Smith, 2018; Redo et al., 2012), forest loss in wet tropical areas remains high. Identified causes, drivers, and factors of forest loss include a growing agricultural frontier, infrastructure development, human colonization, and in particular, expanded pasture lands in Honduras, Northern Guatemala, and Nicaragua (Armenteras et al., 2017; Bebbington et al., 2018a; Carr et al., 2009; Graesser et al., 2015; Schlesinger et al., 2017; WCS and CONAP, 2018). The Wildlife Conservation Society (2017) estimates that nearly 90% of all deforestation in protected areas in Central America is due to illegal cattle ranching.

Beyond these conventional causes of forest loss, profits and activities associated with narcotrafficking could be an underlying cause in forest loss because of cartels' need to launder money and establish territorial control. Drug dollars must be "legitimized" legally, and one of the easiest ways to do so in rural areas is through cattle ranching and agribusiness. Narcotraffickers in eastern Honduras and Guatemala clear forest land in protected and indigenous areas for pasture and agribusiness, using these "businesses" to legitimize profits from cocaine (Devine et al., 2018; McSweeney et al., 2017). Cartels also re-title and illegally invade forest land in remote protected areas to establish control of their ever-changing supply chain routes in response to U.S. interdiction. Acquiring this land is a way that the cartel signals to rival drug trafficking organizations (DTOs) territorial control. The land is used for airstrips and to move supplies inland and northward. Drug traffickers also engage in illegal and speculative land acquisition to further increase their profits, using forest clearing to establish usufruct ownership

(McSweeney et al., 2017). Drug trafficking, therefore, does not directly cause forest loss in Central America as does coca production in South America (Dávalos et al., 2011). When the capital influx from drug trafficking lands in remote rural economies like eastern Honduras, it exacerbates existing pressures to clear forested land. We hypothesize drug trafficking indirectly causes "narco-deforestation" through activities such as cattle ranching, fires, airstrips, roads, and clear cuts to establish ownership.

The scale of narco-deforestation from 2001-2004 in parts of Central America is illuminated by Sesnie and associates (2017) based on analysis of spatial patterns of remotely sensed forest loss and official statistics on drug seizures from the U.S. interdiction coordinator. Rapid and unusual forest clearings were correlated with increased drug shipments in at least five Caribbean departments in Honduras, Nicaragua, and Guatemala. These rapid clearings, assumed associated with narco-trafficking, accounted for 15% to 30% of forest loss in the region. This important research, however, did not establish a causal effect, which the LSS community seeks for theory building and modeling, because it did not account for counterfactuals (rapid deforestation not linked to narcotics) or use causal inference methods. The study was also limited in geographic scope (only 14 of the 50 departments in Central America) and relied on official drug seizure data with many missing values and biases due in part to underreporting of hidden illegal transactions.

From Driver to Cause: Illicit Narcodeforestation

This study seeks to i) determine if media data can estimate spatial and temporal changes in trafficking intensity, and ii) assess if narcotrafficking has a causal effect on forest loss in light of other established causes and mediating factors. To accomplish this goal, media accounts of a specific instance of spatially explicit drug-related activity (e.g., a law enforcement seizure of cocaine in a named municipality) were collected across

Central America. The media event analysis was developed to provide a more spatially and temporally complete time series compared to official statistics. Fixed effects regression models, including relevant causes of land change beyond drug trafficking, were used to estimate causal effects of forest loss. With these new data and methods, we seek to move illicit drivers to the status of causes of land change.

Data

Study area

The fixed effects regressions required consistent annual data for sub-country department units in Central America over multiple years on the dependent variable of forest loss and independent variables of conventional land change drivers and drug trafficking activities. Country level analyses would represent too small of sample size (n=5) for this method, while villages and municipalities represent administrative units that were too small given locational uncertainties of drug trafficking activity reports.

We focused on moist tropical forest, the biome that has the highest rates of forest loss in Central America, in comparison to dry forest which has been stable over the past two decades (Portillo-Quintero and Smith, 2018). Departments with moist forests were identified by calculating the area of forest with >50% canopy cover in 2000 (Hansen et al., 2013) inside the boundaries of the Moist Tropical Forest Terrestrial Ecoregion (Olson et al., 2001). Departments containing >300 km^2 of identified moist tropical forest in 2000 (n = 50 departments, Fig. 22) were used as the study area.

Dependent variable: Forest loss data

Annual, spatially explicit (30 m), and validated forest loss data consistent over the Central American region was obtained from the University of Maryland Department of Geographical Sciences Global Forest Change version 1.4 (see: https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.4.html accessed 2/1/2018-4/1/2018; Hansen et al., 2013). Continuous forest patches measuring ≤2 ha, representing minor areas of forest loss or potential noise, were removed from the analysis. Forest loss percentages, 2001-2016 (Fig. 22) were aggregated by administrative departments in Central America using the GADM (Global Administrative Unit) Department or Province Areas (GADM, 2015).

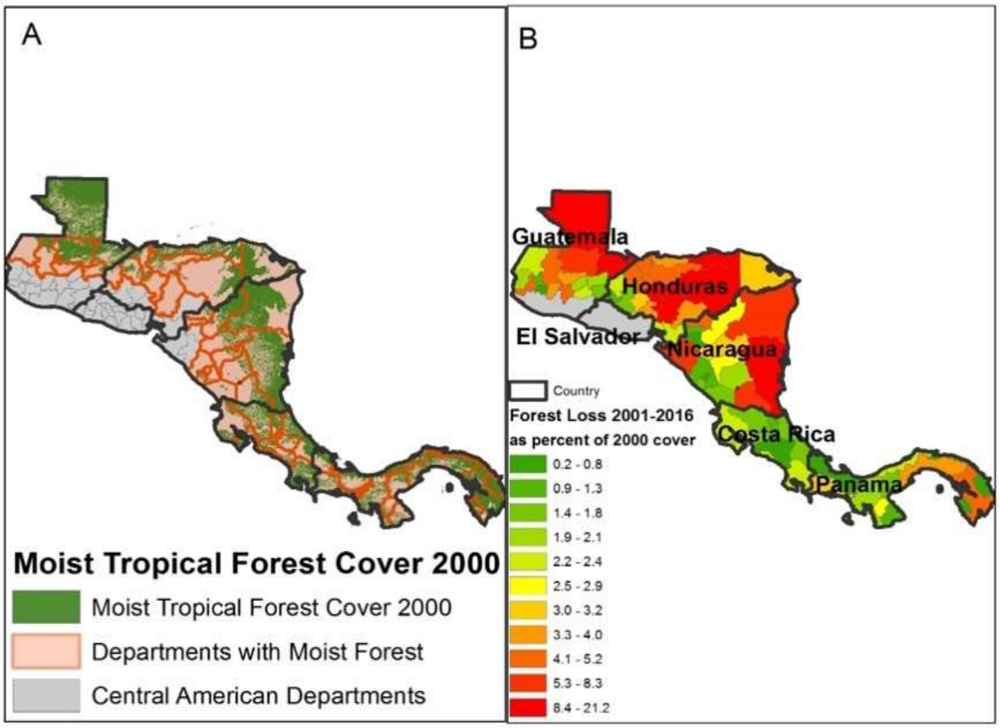

Figure 22. Forest loss and study area**.** A) Study area highlighted in red and orange with forest cover in 2000. B) Total standardized forest loss percentages (following (Puyravaud, 2003)) from 2001-2016 for each department in Central America. Calculated by Authors from Hansen et al. (2013) forest loss data.

Independent variables: drivers, causes, and factors of forest loss in Central America

Conventional land use change drivers and causes include crop and pasture expansion, population (growth and density), road infrastructure and economic development. Mediating factors include fires, primarily anthropogenic, rainfall patterns, and policy and institutional changes (i.e., changing boundaries of a protected area, indigenous tenure/titling, political changes). Consistent, annual data across Central America at the department scale exist for a subset of these variables (Table 8). Cropland

and pasture expansion was estimated by calculating the annual total percent of cropland, plantations, and pasture per department (Graesser et al., 2015). Annual estimates of rural population growth were generated by masking out urban areas as defined by GRUMP (Global Rural-Urban Mapping Project), and summing population outside these areas per department from the annual Landscan population data set (Bright et al., 2016). Annual GDP growth rates served as a proxy for changes in economic development. Anthropogenic burning, associated with agriculture, constitutes a driver, especially fires that extend beyond the intended agricultural lands, for example, in the Petén department in Guatemala in dry El Niño years (Radachowsky et al., 2012; WCS and CONAP, 2018). Two variables estimated this factor: an estimate of annual burned area and dry season precipitation. Other known factors of forest loss for which data were unavailable at the time of this analysis includes road infrastructure and resource extraction (Bebbington et al., 2018b), land tenure changes such as titling indigenous lands (Liscow, 2013; Stocks et al., 2007). Plantation crops, such as oil palm are not a driver of forest loss in Central America (with the exception of the Petén) because they mostly replace previous cropland and pastureland (Furumo and Aide, 2017). Note that because we used fixed effects for political departments in regressions, time invariant variables that may influence forest loss, such as slope, size of the department, protected area, and other features are not explicitly incorporated in models as variables, but rather are indirectly incorporated through model intercepts for each department.

Table 8. Annual Central America-wide model covariates attributed to each study area province or department

Variable	Description	Temporal Scale, Resolution, Unit	Source
Agricultural Production	Cropland, pasture, and citrus/coffee (plantations), aggregated as percent per department	2001-2014, 100m. %	(Graesser et al., 2015)
Population total	People per department	2001-2016, 1km, people	LandScan (Bright et al., 2016)
Rural population	Rural population calculated by using grump to mask out urban area population	2001-2016, 1km, people	From LandScan and GRUMP (Balk, 2009)
Economic development	GDP growth	2000-2016, Country, rate	(The World Bank, 2018)
Fires	Area burned	2000-2017, monthly, 500m, ha	NASA (Giglio et al., 2013)
Climate	Dry season precipitation	2000-2017, 1km, mm	CHRIPS (Funk et al., 2015)

Independent variables: Drug trafficking data used in regressions

Two data sources represent drug trafficking activity in regression models (Table 9): counter narcotics data, extracted from the Consolidated Counter Drug Database (CCDB), and media reports analyzed and coded by the authors. The CCDB data managed by the U.S. Interdiction Coordinator are the officially vetted and sole source of interdiction and cocaine flows data used by the US government to assess drug policy performance (Joint Drug Control Interagency Policy, 2010). They are generated by a variety of U.S. government agencies, and vetted in an interagency working group. These data were obtained from the interdiction coordinator. CCBD data have been used in previous studies to analyze anomalous patterns of forest loss (Sesnie et al. 2017) and model interdiction patterns in an agent-based model (Magliocca et al 2019). For this study, the annual quantity of cocaine detected includes the amount of cocaine (kg) seized (confiscated by law enforcement), lost (discarded over land or sea during interdiction), or delivered (known to be received) to a destination in Central America. The vast majority of these data represent cocaine "delivered" at the country, and for some regions, department scale (SI Fig. 1). Hereafter, the term CCDB SLD to refers to these data.

The CCDB SLD data have known limitations and bias. The first is that department level data are not available for all regions and years leaving spatial and temporal gaps in information on drug flows with in a department. Second, they are considered to be conservative estimates for actual cocaine flows because they focus on non-commercial marine and air traffic routes directly from South America and do not consider overland or the "secondary" movement of drugs along commercial routes- such as in shipping containers. Location specific data are only added if SOUTHCOM (U.S Southern Command, Department of Defense) and the Coast Guard agree on the exact location of activity. If an exact geographic department of delivery is uncertain, which is often the case in tracking illicit activity, that event is not included in the dataset. Finally, counter narcotics data suffer from a form of bias called the "spot light effect", meaning that assets for data collection are focused on areas of suspected activity, according to available intelligence. Data tend to be collected after trafficking routes have been identified, and due to resource limitations, in strategic locations with a high likelihood for seizures. This spotlight effect creates a spatial and temporal lag in the data and an uneven pattern of interdiction effort across the region. CCDB data are largely incomplete before 2003, and most department observations have less than 10 years of data available. Together these limitations reduce sample size, power in statistical analyses, and ability of CCDB data to measure causal effects, increasing the risk of type II statistical error (Crewe et al., 2016).

To address these limitations, a new dataset was created using news media reports clearly attributing drug trafficking events as a proxy to capture a much wider range of narcotrafficking activity than what is accounted for in the CCDB. We considered relevant media reports if they documented events including cocaine traveling over land, capture of property of known narcotraffickers, conflicts in communities with competing DTOs (drug trafficking organizations), discoveries of clandestine airstrips, as well as a range of other "events" linked to specific geographic locations. One media report could contain multiple narcotrafficking events.

Although media cover a larger spatial and temporal range than the CCDB data, media reports are also subject to different types of bias. Central American media are subject to urban bias, with underreporting in rural areas. An additional limitation is that economic elites, who are sometimes involved in narcotrafficking, own many newspapers and may selectively influence the content of coverage in order to protect drug trafficking routes (Salzman and Salzman, 2009)

How events from media reports were recorded and coded to create a dataset (hereafter referred to as "media data") are detailed in the supplementary methods, but are summarized here. For each country, key search terms were used to scan digital and hard copy media for drug trafficking activity reported in national newspapers. Discrete trafficking events in each media report were coded by date, location, and amount or values seized. The data were manually checked by Spanish speaking technicians to ensure no duplicate events were recorded. Media events were summarized per department and year and used as a proxy for narcotrafficking activity in regressions.

In contrast to CCDB data, where the U.S. interdiction coordinator told us that missing data could not be considered evidence for no cocaine flows due the spotlight effect, the absence of media reports could either represent missing data (no reporting was available) or truly indicate no narcotrafficking activity (e.g., 0 reports). Therefore, we ran three separate regressions using CCDB data alone, media data with an absence of events coded as a zero, and using media data with an absence of events coded as a missing value for that year and department.

Table 9. Annual department level narcotrafficking data

Data	Explanation	Unit and N	Spatial and Temporal Scale	Source
Counter narcotics data	Cocaine seized, lost or, delivered as tracked by US military	Kilos of cocaine, 135 observations	Select departments, 14 of 56 f2000-2014, but only 114 observations due to missing years	Consolidated Counter Drug Database (CCDB)
Media Data	Media report with department specific narco trafficking activity events	2217 events	All departments from 2000-2017. Some missing years when no events are detected	Coded newspaper articles from major media outlets

Additional narcotrafficking data to assess media data validity

The media data was tested for its ability to represent the spatial and temporal variability in drug trafficking activities via comparison with independent datasets at both the country and department scale. Media were compared at these two scales because while drug trafficking data at the country level is more spatially and temporally complete, this coarse spatial resolution is not the unit of analysis selected for this study. Often, data will correlate at coarser scales of aggregation (countries) but not at finer scale (departments), known as the modifiable areal unit problem (Openshaw, 1984). Therefore, even if media data show congruence with country level narcotrafficking data, these results could not be extended to assume congruence at the department aggregation. The country and department data that we used in comparisons to assess the validity of using media data as a proxy for drug trafficking are described below (Table 10), followed by a description of the method used to assess media validity.

<u>Country level drug trafficking data to assess media data validity</u>

We used three country-scale annual measures of narcotrafficking activity: i) seizures in kilos reported by UNODC 2000-2017 (United Nations Organization on Drug

Control) (Unodc, 2017), ii) seizures in kilos reported by INCSR 200-2017 (U.S International Narcotics and Strategy Control Report), and iii) number of cocaine shipments received, reported by CCDB 2001-2014. UNODC seizure data relies on self-reporting by each country. In the years countries do not self-report, UNODC uses information from INCSR (International Narcotics Control Strategy Report), CICAD (InterAmerican Drug Abuse Control Commission), and reports from national drug enforcement agencies. These data are subject to country-level biases, including interdiction effort, resource allocation (sampling effort), and politically motivated over-reporting (UNODC, 2018). The INCSR data are prepared by the U.S. State Department using a variety of intelligence sources. The CCDB data at the country level is reported in number of drug shipments of cocaine into each country in Central America from the cocaine producing country of origin. INCSR and UNODC data supply an additional three years of data, but CCDB data is generally considered to be of higher quality.

Department level drug trafficking data to assess media validity

We tested the media data against three other proxies of drug activities at the department scale: sites of clandestine airstrips in Gracias a Dios Honduras, cartel land holdings in Petén, Guatemala and land seizures in protected areas in Petén, Guatemala. Data include coordinates for 66 airstrip locations obtained from the Honduran military in interdiction efforts called "Operation Hammer," and an additional 23 airstrips identified by local ethnographers and field contacts in the Caribbean reaches of Honduras (SI, Fig. 3). The year each airstrip emerged provided by the Honduran military was identified in Landsat Satellite imagery in Google Timelapse, and 23 airstrips where secondarily verified using high spatial resolution imagery accessed via the Digital Globe Enhanced View webhosting service (www.digitalglobe.com/products/enhanced view-web-hosting).

Data in Petén, Guatemala, include the locations of cartel land holdings and seized property in protected areas (SI Fig. 3 and 4). Cartel land holdings were identified via registered private lands under names of drug cartel members identified in a 2011 InSight Crime report. We calculated the area of forest loss per year in each of these holdings. These data were digitized and georeferenced, and used to estimate hectares of annual forest loss. Seized properties in protected areas are known to be linked to narcotrafficking activity (Devine et al., 2018). Both data sets, reported annually from 2000-2017, were obtained from the Guatemalan government. The SI provides details.

Table 10. Additional narcotrafficking data to assess media data validity

Data	Explanation	Unit and N	Spatial and temporal scale	Source
Country seizures	Self-reported country seizures of cocaine in kilos to UNODC	Cocaine seized in kilos	2000-2014, annual, country	UNODC
	US intelligence from various sources		2000-2018, annual	INCSR
Country shipments of cocaine	Detected shipments of cocaine arriving	75 shipments, 15 per country	2000-2014, annual, country	CCDB
Landing strips, Honduras	Points of recognized landing strips in Google Earth identified by research team plus airstrips from US funded "operacion martillo"	73 Airstrip point coordinates	2000-2017, annual, Gracias a Dios, Paraiso, Olancho, and Colon, Honduras	Honduran Military, ethnography
Land seizures in protected areas, Guatemala	Accusations registered by the Guatemala government of illegal land seizures in Protected Areas	20,000 accusations registered per municipality	2000-2017, annual, Guatemalan municipalities	Ministerio Publico, Guatemala
Forest cleared in cartel land holdings, Petén	Summary of forest loss per year in digitized and georeferenced private land holding linked to identified cartels	80 polygons over 100,000 ha	Land holdings present from 2004-2011, Petén, Guatemala	Insight Crime (2011)

Methods

Media Validity Analyses

Media data were assessed for quality in three ways: i) in terms of the data's spatial and temporal congruence with additional drug trafficking data, ii) the spatial representativeness of the data based on expected narcotrafficking patterns, iii) expert opinion with field-based researchers who interpreted the results of the congruence and representativeness analyses.

Media data were compared to country and department level drug trafficking data (Table 10) to understand the spatial and temporal correlation and potential lags between datasets. Spatial agreement was assessed by comparing total number of events to kilos estimated in CCDB using linear regression to calculate a coefficient of determination (R^2). Temporal correlation was assessed using cross-correlation analysis, which served to estimate temporal lags between media and country seizure data in seven departments with CCDB SLD kilo data with ≥10 years of observations, the airstrip data in Gracias a Dios, Honduras, and land seizure data and cartel land holding forest loss in Petén, Guatemala (R version 3.5.2, 'stats package' [Venables and Ripley, 2002]). Given the potential for the spotlight effect to cause delays of several years, we report correlation coefficients for up to 5 years in both directions (lags and leads).

An analysis of the spatial representativeness of narcotrafficking as reported in the media was required due to the urban and reporting bias of Central American media. This quantitative analysis was completed by comparing the spatial distribution of media events to an expected spatial distribution of narcotrafficking activities from Magliocca et al, (2019) (see SI for details, but summarized here). The expected spatial distribution of narcotrafficking activities is based on a suitability surface developed for the Narco-Logic ABM (Magliocca et al 2019) which assumes activities are more likely in protected areas, near coasts and borders, in remote areas, and in less developed areas (e.g.,. in forests instead of croplands). Representativeness analysis (Schmill et al., 2014) was completed for each country by calculating the average narcosuitability score for each municipality. Fifteen equal frequency bins of the narcosuitability distribution were calculated for each country. Media counts were summed for each of these bins. Graphing the media counts per narcosuitability bin allowed for comparisons between the expected narcotrafficking distribution and the media reports. The results of the temporal and spatial correlation and representativeness analyses were interpreted by country experts and are reported in the SI.

Fixed Effects Panel Regression

We used panel regression models to determine which factors were significant drivers of forest loss and to estimate the causal effect of narcotrafficking on forest loss. All drivers noted above were included in the analysis, run together with drug trafficking variables (Table 8). Separate models were estimated using the two different measures of drug trafficking (Table 9) and compared to the coefficient of determination in conventional models using the same spatial and temporal scale (see Table 11 for a summary of models).

Table 11. Models used to estimate causal effects of narcotrafficking on forest loss

<table>
<tr><th>Name</th><th>Explanation</th><th>Spatial and Temporal Scale</th></tr>
<tr><td>Conventional</td><td>Includes conventional drivers of forest loss. Excluding drug trafficking data</td><td>50 departments with moist forest (regional), 14 departments with official data, or country subsets 2001-2016</td></tr>
<tr><td>Drug trafficking with official data</td><td>Includes conventional drivers of forest loss and CCDB data</td><td>14 departments with official data 2001-2014</td></tr>
<tr><td>Drug trafficking with media data 1 (absence of report = 0)</td><td>Includes conventional drivers of forest loss and media data</td><td rowspan="2">50 departments with moist forest (regional) and country and subsets 2001-2016</td></tr>
<tr><td>Drug trafficking with media data 2 (absence of report = missing data</td><td>Includes conventional drivers of forest loss and media data</td></tr>
</table>

Models subsets were first run at the level of departments (n = 14) where CCDB SLD data were available, and with all departments with moist tropical forest where media data were avaialble (n = 50, Fig. 2). We also ran fixed effects panel regression models for each individual country with the media data to understand if there are different associations between narcotrafficking and deforestation across countries. In all cases, we compare model fit using R^2 between forest loss models including and excluding drug trafficking as an explanatory variable. Fixed effects panel statistics were employed to control for any time invariant departmental factors that could influence forest loss (e.g., slope or area) We used the *plm* R package (Croissant and Millo, 2008) for computation in a two-way fixed effects model using the following equation:

$$eq. 1\ Y_{it} = \alpha + B_{it}x_{it} \ldots + C_i + \gamma_t + \varepsilon_{it}$$

Where

Y is the total number of hectares of forest area lost each year (t) per department (i);

γ_t is the time fixed effect at time t ;

C is the department fixed effect;

α is the average of fixed and time effects across all department

and $B_1 x_{it}$. are the independent variables listed in Tables 8 and 9.

ε_{it} is the error term for each year (t) per department (i);

α is akin to determining an intercept that is the weighted mean of time and individual effects (Gould, 2013), which controls for variation in forest loss explained by factors or causes in the linear model that are constant over time. This model is useful for hypothesis testing, not prediction, because the fixed intercept controls for other factors, allowing us to isolate how increases in narcotrafficking are related to forest loss.

A two-way fixed effects model was used to test for the influence of cocaine trafficking, while controlling for time invariant differences between departments that influence the amount of forest loss (e.g., size of extant forest, protected areas, road networks, and other unobserved differences) and year of measurement. Our expectation was that trafficking variables would explain variation in forest loss beyond that already controlled for by the conventional drivers (rural population rates, increases in pasture and cropped area, changes in precipitation and burned area), and by time (e.g., deforestation has a temporal trend). These considerations reduce the chance that endogeneity or omitted variable bias would influence the results. An omitted variable would have to be correlated with both departments and temporal trends of deforestation to cause bias and confound results.

Robustness checks included lagging and leading forest loss variables to more concretely assess causal inferences for factors showing a positive effect on forest loss. We expected significant explanatory variables to lose significance when the dependent variable is lagged by multiple years. If we were to find, for example, that narcotrafficking remained significant when leading or lagging deforestation several years, it would indicate that narcotrafficking is correlated with places of high deforestation, but that it does not cause deforestation at a specific time point. The square root of the variable inflation factors (VIF) were measured for all linear models, and any combination that was > 2 was discarded. Residual plots were examined for every model to ensure no outliers were outside of 0.5 for cooks distance. Fixed effects models used a log transformation of deforested area in hectares, which improved the normality of residuals. Coefficient plots transform coefficients and standard errors by two standard deviations of each variable so that regions coefficients of independent variables are directly comparable to each other (Gelman, 2008)

Results

The results are reported in two sections: (i) reporting the media data validity analyses; and (ii) the land change regressions. The results of collecting narcotrafficking data in the media and the validity analyses used to assess representativeness as well as spatial and temporal congruence with other indicators of drug trafficking are undertaken at the country and department scale. Finally, the results from fixed effect panel regressions using both CCDB and media data are reported for the Central American region and in country-specific model subsets.

Media Validity Analyses

Media data were correlated spatially at both the country and department level when compared to other drug trafficking data (R^2 ranging from .44 to .70). Data were temporally correlated with an average of drug trafficking data lagging 2 years behind media data (r= .35-.74 depending on the country and dataset).

Honduras had the greatest number of events (826), followed by Guatemala (566), Panama (327), Nicaragua (165), and Costa Rica (124). Media data increased the sample size relative to CCDB data (700 vs 114 department- year observations, respectively) and enlarged temporal and spatial coverage (SI Fig. 2, Fig. 23). Completeness, as measured by the number of years of non-zero data (e.g. no absence of CCDB data or media reports) available for that department, is shown in C and D in Figure 23.

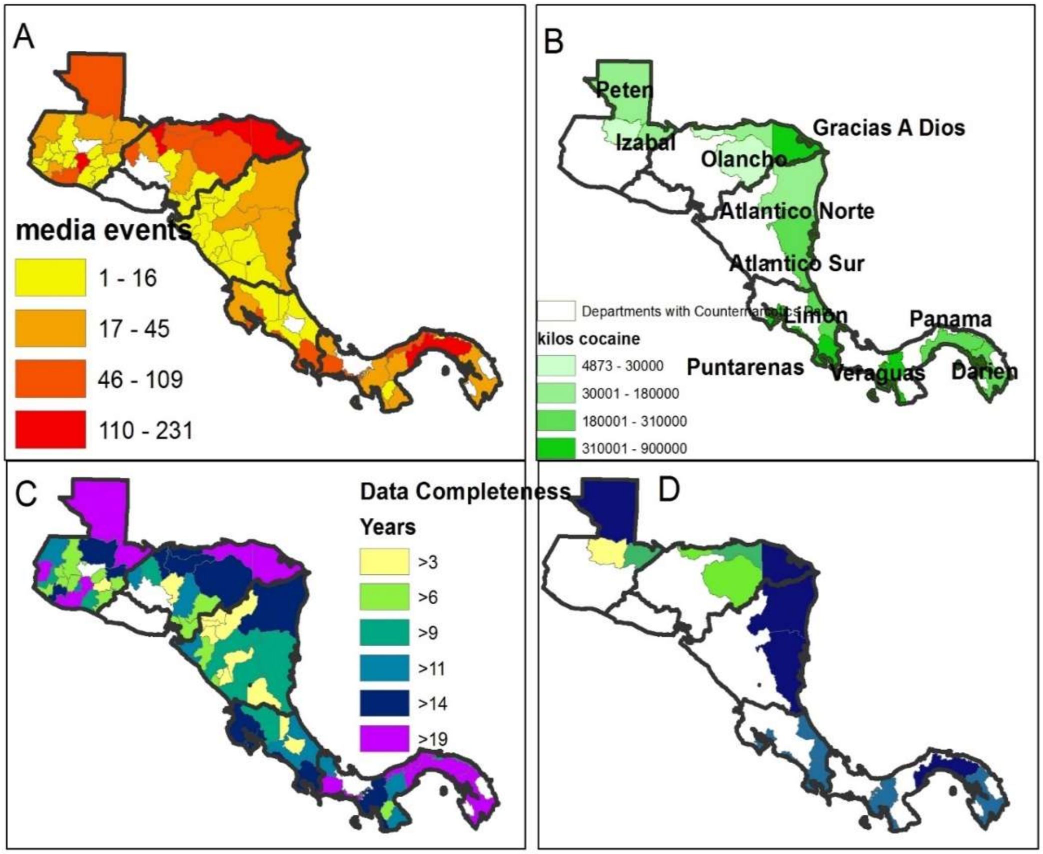

Figure 23. Media and CCDB data coverage and completeness over Central America**.** A) Total media events per department from 2000-2017. B) Total kilos of cocaine seized, lost, and delivered from 2000-2014, with labeled names of departments. White areas represent no data. C) Completeness measured in years of media observations present per department. D) Completeness measured in years of CCDB data per department, shared legend with C. All white areas are no data.

<u>Media Validity at the Country Level: Spatial Correlation</u>

The number of annual media events at the country level were compared to three national level drug trafficking datasets to determine if media was capturing the intensity of narcotrafficking spatially (Fig. 23). A linear regression was used to compare media events for each country-year observation, controlling for country level effects, to compare the spatial correlation between datasets (SI table 4). CCDB department level data had the highest total correlation (R^2 with media data = 0.70, followed by UNODC seizures [R^2=0.59], CCDB Shipments [R^2=0.55], and INCSR seizures [R^2=0..44]. The high correlation with CCDB SLD data was influenced by outliers in Honduras (Fig. SI 8). Media events and UNODC seizure data showed a significantly greater positive correlation in Guatemala and Honduras than for other countries (SI Table 4, Fig. SI 8).

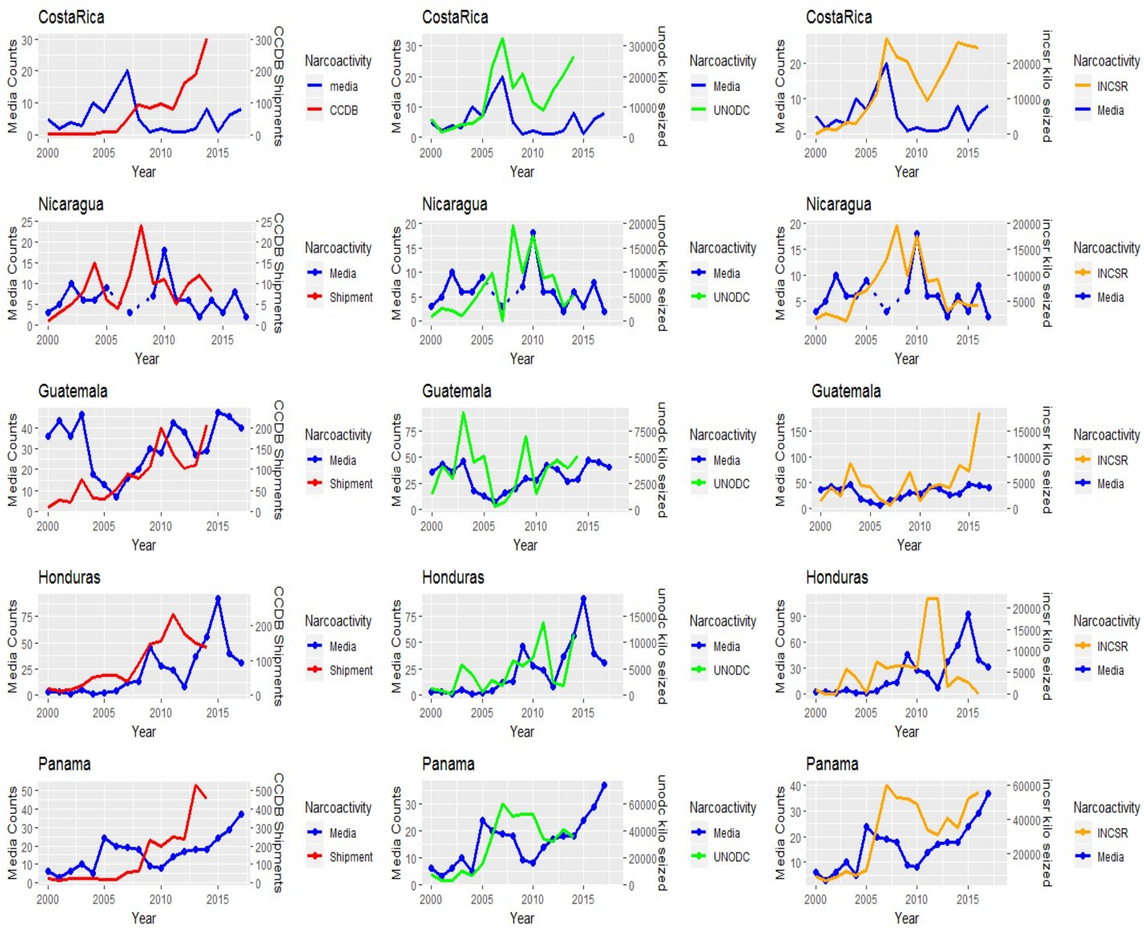

Figure 24. Country comparisons of media events to other measures of trafficking activity. CCDB shipment versus media data per country. Red lines are kilos of cocaine reported by CCDB, green lines UNODC; seizure data orange line, kilos of cocaine seized reported by INCSR; and blue line, number of media events per year. Dotted blue line represents missing data with linear interpolation (Nicaragua).

<u>Media Validity at the Country Level: Temporal Correlation</u>

Linear regressions are not appropriate for determining correlation between time series dataset, thus cross-correlation analyses were used to determine if media captured the timing of narcotrafficking intensity at country and department scales. All cross-correlation plots are available in the supplementary materials (SI 11-14) and the results are summarized in (Table SI 6 and in Fig. SI 9). Media was correlated to CCDB shipments in all countries except Guatemala (r= 0.403, std 0.349). Lag times varied by 2.14 years (std 2.15 years) on average, but this varied by country. Media was correlated to UNODC data at similar levels (r =.424, std .246), yet with little to no temporal lag (-.25 years, std=1.26 years). Correlation levels and lags were similar for all countries. A one-way ANOVA test indicated no significant difference between the mean correlations across countries.

Media Validity at the Department Level: Temporal Correlation

Media data were significantly correlated with drug activity data at the department level in some cases using cross-correlation analysis. Figure 25 displays department level data with media time series. At the department level, media was significantly correlated to four of the seven departments with 10+ years of CCDB, including Gracias a Dios, Honduras (r=0.586), Petén, Guatemala (r=0.563, with 4 year lag), Darien, Panama (r=0.79), and Region de Atlántico Norte, Nicaragua (r=0.97, with 1 year lag). Departmental data for Panama, Panama, Puntarenas, Costa Rica, and Region de Atlántico Sur, Nicaragua were not significantly correlated with media data.

Media data was significantly correlated with land seizure data in Petén and Izabal, Guatemala with land seizures lagging two years behind media reports (r= 0.36) and with forest loss in cartel land holdings in Petén, Guatemala, with a one year lag (r= 0.69). Media was significantly correlated with the date that an airstrip was observed as “bombed” in satellite imagery in the simultaneous year (r =.740), but not the year the airstrip was first observed as constructed. Airstrips were bombed in the same year they were constructed in most cases, but for some observations, airstrips were bombed 2-5 years after initial construction. These results indicate media data are reporting on highly visible interdiction activity in this region, but may not accurately capture all narcotrafficking activities.

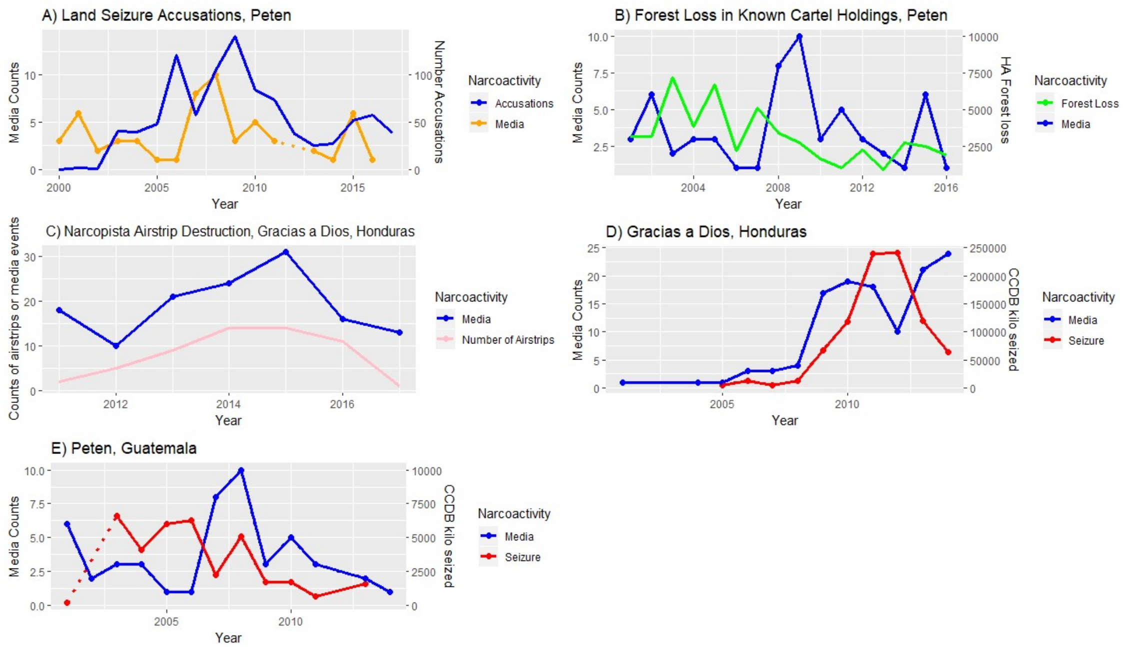

Figure 25. Media events per department and ancillary data correlations. A) Land seizures in the Petén are significantly correlated at a 2 year lag (r= 0.357). B) Forest loss in cartel land holdings in the Petén are significantly correlated at a one year lag (r=.634). C) Airstrips in Gracias a Dios are correlation in the same year (r-.704). D) CCDB seizure data correlates in Gracias a Dios (r= 0.59) with no lag, and E) with Petén at a 4 year lag (r= 0.56).

<u>Media Representativeness Analysis</u>

Countries varied widely by type of bias and coverage of narcotrafficking (Table 1 SI and Fig. SI 6). Of all Central American countries, Honduras had the highest proportion of media reports in the narco-suitability bin (41%), followed by Costa Rica (31%), Nicaragua (25%), Guatemala (13%), and Panama (6%). Urban bias was strong in Panama and Guatemala (with over 30% of reports coming from the capital city in each country), and to a lesser degree, Nicaragua with high reporting in Managua. Under reporting in rural areas was strongest in Guatemala and Panama in rural areas such as the Petén, Guatemala, and Darien, Panama.

Fixed Effects Panel Regressions of Forest Loss

Narcotrafficking has a significant positive causal effect on forest loss at the regional level as measured by both official data and media proxies. In country model subsets, official data had a causal effect on forest loss in Nicaragua, and media data had a causal effect in Honduras. Drug trafficking models explain additional variance in forest loss overtime as compared to conventional models. The R^2 reported of the fixed effects models is small, because it only describes the additional variation in forest loss explained by time variant drivers of land change that cannot be accounted for by time-invariant and department-specific effects.

Regional Models

Table 12 reports the regression model results at the regional level. Standardized coefficients are plotted in figure 26. In the conventional model, agricultural production (crop and pasture) and rural population growth showed a significant and positive relationship with forests loss. Narcotrafficking activity has a significant positive causal effect on forest loss, and explains an additional 4-9% of variance (R^2= 0.27 and R^2= 0.11, respectively) when compared to conventional models (R^2=0.18 and R^2=0.06, respectively).

In conventional models, reduced economic development was significantly correlated with forest loss, but this effect became insignificant in models with kilos SLD. Robustness checks (Table 7 SI) reveal SLD was not correlated with lags or leads of forest loss, but media data were correlated with 1 year lag and 1 and 2 years lead of forest loss. This indicates that either media data, or the relationship between narcotrafficking and forest loss, is somewhat imprecise temporally.

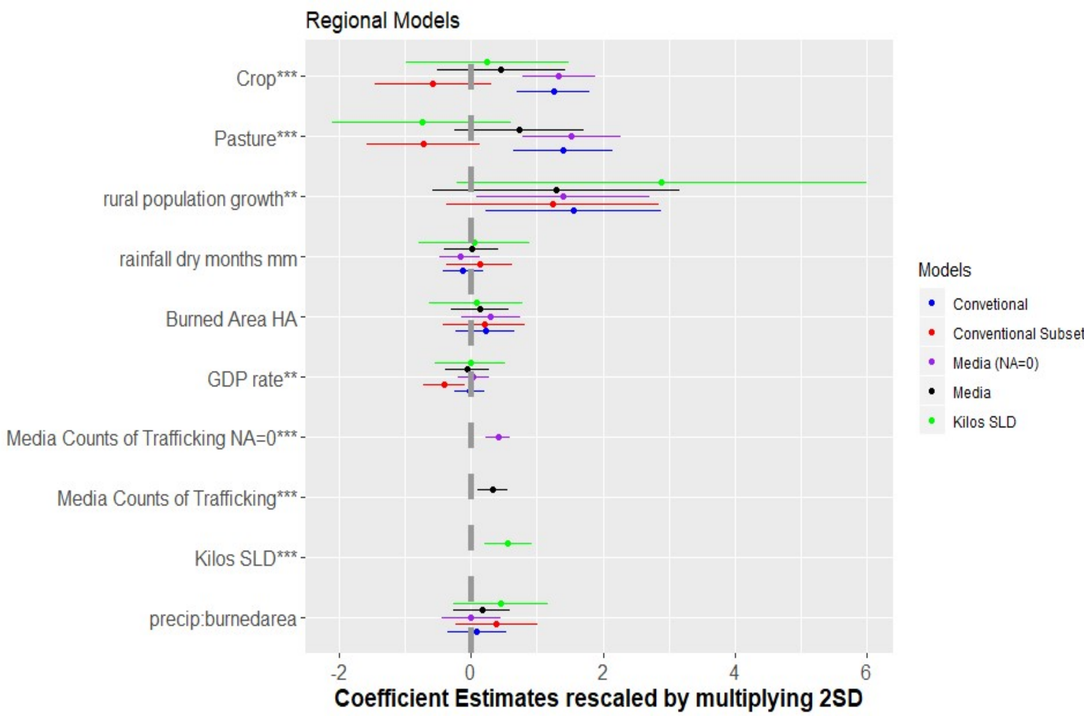

Figure 26. Coefficient plot of regional models with point estimates and standard deviations. Bars rescaled to 2 standard deviations of variables to directly compare coefficients. Variables that do not cross the "0" line are significant at the p<.05 level. Left axis also identifies significance, with * for p<.1, ** for p<.05, and *** for p<.001.

Table 12. Regional model comparisons with conventional and narcotrafficking variables for HA of forest loss per year from 2001-2016. The Conventional subset is to 14 departments and years for which CCDB kilos SLD data were available. NA=0 means department years with no media observations were given a value of 0.

Regional Forest Loss Models

	Dependent variable:				
	Logged Deforestation Area 2001-2016				
	Conventional	Conventional Subset	Media NA=0	Media	CCDB Kilos SLD
	(1)	(2)	(3)	(4)	(5)
Crop	0.0518277*** (0.0117716)	-0.0413772 (0.0320491)	0.0553227*** (0.0116309)	0.0190038 (0.0207141)	0.0172797 (0.0448673)
Pasture	0.0328058*** (0.0090590)	-0.0265469* (0.0159384)	0.0358687*** (0.0089569)	0.0170182 (0.0117783)	-0.0274033 (0.0253049)
rural pop	0.0000041** (0.0000018)	0.0000032 (0.0000021)	0.0000037** (0.0000018)	0.0000034 (0.0000025)	0.0000075* (0.0000041)
precip	-0.0003474 (0.0004604)	0.0003257 (0.0006268)	-0.0004994 (0.0004552)	0.0000122 (0.0006200)	0.0001183 (0.0010627)
burned	0.0000025 (0.0000025)	0.0000012 (0.0000020)	0.0000033 (0.0000025)	0.0000015 (0.0000024)	0.0000005 (0.0000023)
GDP rate	-0.0043198 (0.0230605)	-0.0841767** (0.0337518)	0.0068179 (0.0228722)	-0.0103910 (0.0330286)	-0.0027308 (0.0568502)
media NA=0			0.0520320*** (0.0118259)		
Media				0.0317527*** (0.0113999)	
Kilos					0.0000065*** (0.0000021)
precip*burned	0.0000000 (0.0000000)	0.0000000 (0.0000000)	-0.0000000 (0.0000000)	0.0000000 (0.0000000)	0.0000000 (0.0000000)
Observations	700	196	700	292	114
R^2	0.0596537	0.1771272	0.0877306	0.1091296	0.2656159
F Statistic	5.7094260*** (df = 7; 630)	4.9816060*** (df = 7; 162)	7.5611620*** (df = 8; 629)	3.4911850*** (df = 8; 228)	3.5716420*** (df = 8; 79)
Note:					*p<0.1; **p<0.05; ***p<0.01

Country Level Models

Narcotrafficking activity has a causal effect on forest loss in Nicaragua as measured by official data, and in Honduras and Guatemala as measured by media data. Multiple drug trafficking models with media data were formed in countries with evidence of significantly correlated media temporal lags (from SI table 6 Panama= 1,2, and 4 years, Nicaragua= 4 years, Honduras= 0-4 years, Guatemala= 1-2 years). Drug trafficking models (R^2 = .20) have improved model fits compared to conventional models of forest loss (R^2 = .15) in Honduras. Note that because data are subset by country, the sample size is lower and the probability for type II error increases significantly. As a result, null results do not necessarily indicate that relationships do not exist between forest loss and narcotrafficking; a null result could have been caused due to low sample size.

Conventional model results are reported in Table SI 9. The insignificant F statistic in the official drug trafficking data models suggests little explanatory power (Table 13, robustness checks in Table SI 7). Increasing agricultural production and rainfall also showed a significantly strong positive relationship with forest loss in Nicaragua, and have a larger effect relative to narcotrafficking intensity (standardized coefficients, figure 27).

In drug trafficking models using media data, except for Costa Rica (F=1.00) and Panama (.745), all other country models had significant F-statistics (Nicaragua F=2.822). Narcotrafficking has a positive causal effect on forest loss only in Honduras (F=4.08, $p<.05$) and Guatemala (F=4.54, $p<.05$). Other countries showed no relationship between trafficking and forest loss (Table 14). Robustness checks in Honduras (Table SI 10) reveal that, as in the regional models, a one year of lag and one year of lead of forest loss also indicate a narcotrafficking intensity has a positive causal effect on forest loss. Robustness checks in Guatemala reveal narcotrafficking has a causal effect on forest loss with a 2 year lag only and after 2005. Country model subsets lagging media data elsewhere shows no significant causal effect between narcotrafficking activity and forest loss.

Significant conventional causes and factors of forest loss differ by country. Expanding crops and pasture cause forest loss in Nicaragua, and expanding crops with forest loss in Guatemala after 2005. In Costa Rica, decreasing crops and rural population growth are associated with forest loss. Causes and factors of forest loss in Guatemala differed among models. Precipitation is a significant factor in drug trafficking models with media data, but not in conventional models. Burned area is a significant factor in both conventional models and drug trafficking models with media data (SI tables 8 and 9). The relationship between burned area and forest loss effect is strongest in the Petén, Guatemala (Figure 28). In Honduras, forest loss is higher in places where rural population is decreasing, representing an unexpected effect.

Table 13. Country model comparisons with narcotrafficking variable of kilos SLD from CCDB data to predict HA of forest loss per year from 2001-2014. Guatemala and Costa Rica did not have enough units to produce model results.

Counternarcotics CCDB SLD- Country Forest Loss Models

	Dependent variable:			
	Logged Deforestation Area Fixed Effects 2001-2016			
	Nicaragua (1)	Nicaragua Conventional (2)	Honduras (3)	Panama (4)
Crop	154.9599000^{*} (64.8436400)	47.2672100 (64.7993100)	-0.4888330 (0.4601950)	0.3046132^{*} (0.1675639)
Pasture	0.4487851^{**} (0.0973608)	0.0223236 (0.1231114)	-0.0141752 (0.0690214)	0.1542720 (0.1406973)
precip	0.0108702^{*} (0.0039453)	0.0017393 (0.0066280)	-0.0018676 (0.0051104)	-0.0015584 (0.0045941)
burned	-0.0000134 (0.0000083)	0.0000020 (0.0000117)	0.0000036 (0.0000065)	-0.0000493 (0.0000435)
ruralpop	0.0000119 (0.0000085)	0.0000144 (0.0000104)	-0.0000129 (0.0000376)	0.0000235 (0.0000276)
Kilos	0.0001220^{**} (0.0000377)		0.0000055 (0.0000048)	0.0000035 (0.0000052)
precip*burned	0.0000000 (0.00000002)	-0.00000002 (0.00000003)	-0.0000000 (0.00000003)	0.0000003 (0.0000004)
Observations	23	28	30	31
R^2	0.9213336	0.2808233	0.4803714	0.4718274
F Statistic	5.0193910 (df = 7; 3)	0.4555587 (df = 6; 7)	1.0565160 (df = 7; 8)	1.2761720 (df = 7; 10)
Note:				$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 14. Country model comparisons with narcotrafficking variable of media counts to predict HA of forest loss per year from 2001-2016. NA=0 when department years with no media observations were filled with 0.

Narcoactivity in Media (NA=0) - Country Level Models

	Dependent variable:					
	Logged Deforestation Area Fixed Effects 2001-2016					
	Nicaragua (1)	Honduras (2)	Panama (3)	Costa Rica (4)	Guatemala (5)	Guatemala >2005 (6)
Crop	0.0682460*** (0.0195355)	0.0733467 (0.0561120)	0.0044822 (0.0493168)	-0.1083328* (0.0586923)	0.0417329 (0.0352465)	0.1774759* (0.0879139)
Pasture	0.0409143** (0.0188507)	0.0102132 (0.0185126)	0.0267507 (0.0303466)	-0.0387751 (0.0308481)	0.0134886 (0.0153851)	-0.0892030 (0.0629440)
precip	-0.0010421 (0.0016067)	-0.0022321 (0.0013508)	-0.0014482 (0.0012343)	-0.0012095 (0.0009274)	0.0038366** (0.0015595)	0.0022941 (0.0017719)
burned	0.0000109 (0.0000084)	0.0000009 (0.0000033)	0.0000086 (0.0000368)	-0.0000130 (0.0000294)	0.0000044 (0.0000027)	0.0000059 (0.0000045)
ruralpop	0.0000032 (0.0000044)	-0.0000090* (0.0000052)	0.0000052 (0.0000056)	0.0000132* (0.0000069)	0.0000006 (0.0000023)	0.0000045 (0.0000064)
media NA=0	0.0386568 (0.0536985)	0.0315822** (0.0126311)	0.0242298 (0.0436545)	0.0312128 (0.0494807)	-0.0005789 (0.0284689)	
media lag 2 yrs						0.0788416** (0.0368538)
precip*burned	-0.00000002 (0.00000002)	0.0000000 (0.0000000)	-0.00000005 (0.0000002)	-0.00000003 (0.0000001)	-0.0000000 (0.0000000)	-0.00000002 (0.0000000)
Observations	196	140	168	98	98	62
R^2	0.1087192	0.2044304	0.0369441	0.0897869	0.2312072	0.5144286
F Statistic	2.8229840*** (df = 7; 162)	4.0379580*** (df = 7; 110)	0.7453061 (df = 7; 136)	1.0005310 (df = 7; 71)	3.0503680*** (df = 7; 71)	4.5404110*** (df = 7; 30)
Note:						*p<0.1; **p<0.05; ***p<0.01

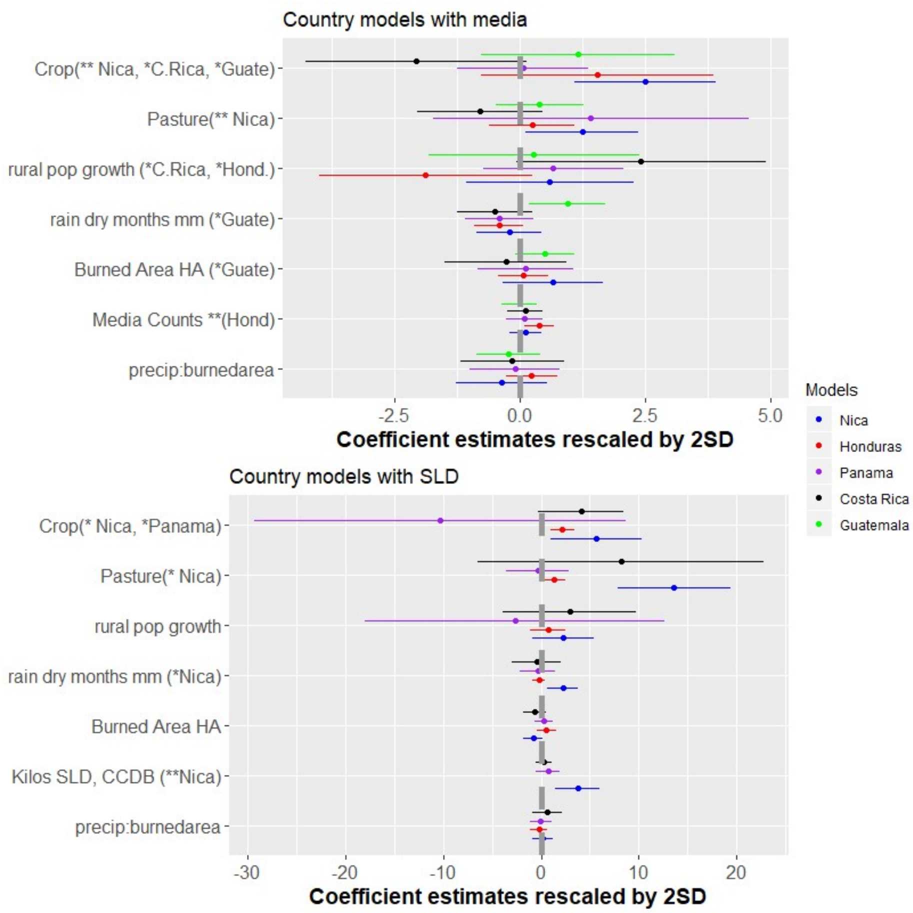

Figure 27. Coefficient plot of country models with point estimates and standard deviations. Variables that do not cross the "0" line not significant at the p<.05 level. Left axis also identifies significance, with * for p<.1, ** for p<.05, and *** for p<.001.

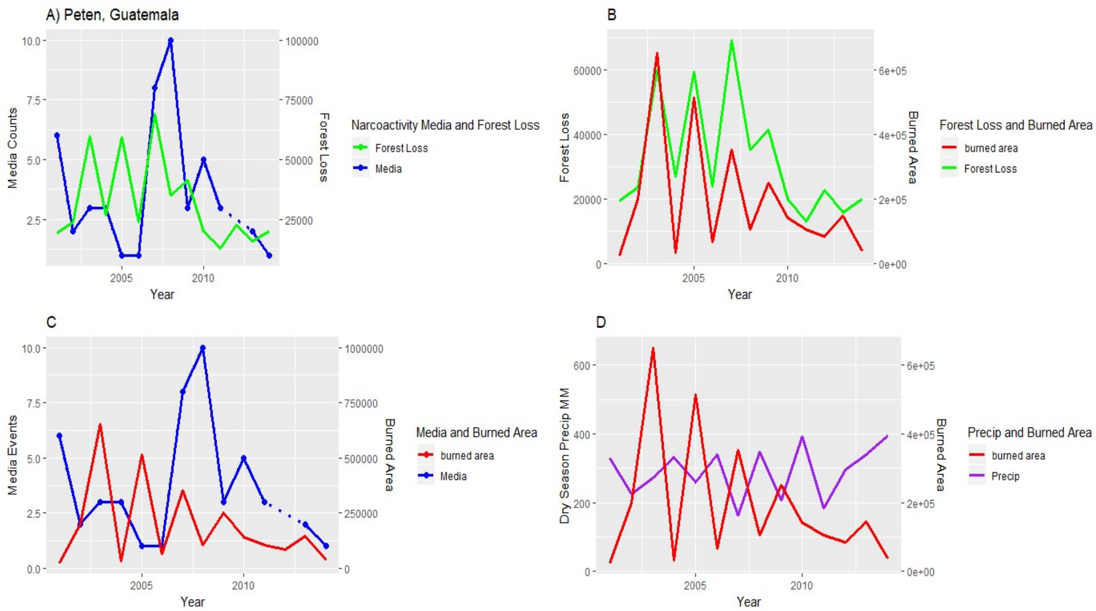

Figure 28. Peten, Guatemala time series for A) narcotrafficking measured by media and forest loss, B) forest loss and burned area, C) burned area and media, and D) burned area and dry season precipitation.

Discussion

Narcotrafficking and forest loss in Central America

Among a set of common drivers of tropical forest loss, we found a significant causal effect between narcotrafficking intensity and increased forest loss in Central America at the department scale. Panel models of forest loss explain a significantly higher amount of variation over time when narcotrafficking is added as an explanatory variable to forest loss models. Our results showed a consistent pattern between increased drug trafficking reported in official statistics within specific counties and departments, news media reports as a measure of drug trafficking intensity, and accelerated forest loss. This causal effect, complements established causal mechanisms between drug trafficking activities and forest loss in both Honduras (McSweeney et al., 2018) and Guatemala (Devine et al., 2018), providing evidence of narcotrafficking as a cause of forest loss in those two countries. While a causal effect of narcotrafficking on forest loss was also found in Nicaragua, as yet, no published studies explain a causal mechanism there.

Consistent with previous studies, we also found that increasing agricultural production, pastureland expansion, and rural population growth have a significant casual effect increasing forest loss in Central America (Aide et al., 2013; Carr et al., 2009; Graesser et al., 2015). In contrast to this regional trend, country level models in Honduras revealed a negative relationship with rural population and forest loss, explained by previous studies that outmigration that increases with drug trafficking intensity in Eastern Honduras (McSweeney et al., 2018).

Drug trafficking had no causal effect on forest loss in two countries- Costa Rica and Panama. This confirms previous studies finding no correlation between anomalous deforestation and narcotrafficking in those countries (Sesnie et al 2017). The lack of correlation has three possible explanations. First, drug trafficking generates less profit, and thus financial capital, in these two countries because cocaine accrues per kilo as it moves northward. Second, alternative country-specific transit and laundering opportunities may do away with the necessity for forest clearing. Panama uses the US dollar in its economy, making it easier to launder money in the financial sector, and Costa Rica has higher economic development, strong property rights, and more stringent forest laws compared to other countries, creating high transaction costs in forest clearing activities. These conditions provide options for laundering narco-dollars outside of forested lands. Finally, in these two countries, cocaine shipments primarily arrive by sea in small shipments scattered over multiple routes, and continue on maritime routes north or via on the Panamerican highway (Mcllwaine and Moses, 2012). These routes require less territorial control by cartels.

In contrast, in Nicaragua, Honduras, and Guatemala, cocaine moves into remote areas by air, landing in forested and often remote or indigenous territories. Cocaine supply then moves over land, along routes where DTOs require for territorial control of their supply chain and clear forest to establish usufruct ownership. Multiple studies show in both Honduras and Guatemala that drug trafficking profits are invested in forest frontiers, in pasturelands and cattle, and oil palm plantations (Devine et al., 2018; McSweeney et al., 2017).

Model results in Guatemala reveal that narcotrafficking had a causal effect on forest loss only after 2005. This could be in part because the dominant factor of forest loss in regions like the Petén in the early 2000 were forest fires (Fig. 28). Notably, in the media, forest fires have been linked to narcotraffickers. Experts in Guatemala also contend that narcotraffickers established airstrips and border territories in the Laguna del Tigre national park in the early 2000s, and only began to invest in cattle ranching and large pasturelands after amassing capital in the mid 2000s. Rival drug trafficking organizations also began to compete for territory in the mid 2000s. Future work is needed in Guatemala to better understand the relationship between narcotrafficking, fires, and forest loss.

Drug trafficking forest loss models using media data revealed that forest loss may increase up to one year before, and up to two years after narcotrafficking activity is detected and reported in the media. This indicates that either media data is temporally imprecise, or the relationship between narcotrafficking and forest loss is not immediate. It is likely that clearing forest land for money laundering would occur sometime after capital is accumulated from drug trafficking.

Guatemala, Nicaragua, and Honduras hold the only remaining intact and extensive primary moist tropical forest in Central America, which are being substantially reduced by drug trafficking. Drug trafficking is an underlying driver of forest loss in what can appear to be a business-as-usual explanation of an agricultural frontier. Illegal cattle ranching has been identified as a proximate driver of forest loss, but this study shows narcotrafficking in some cases may be the root cause in Honduras, Nicaragua, and Guatemala. This study thus reaffirms claims that drug interdiction policy is incidentally conservation policy (McSweeney 2014), because interdiction efforts influence the location and intensity of narco-trafficking (Magliocca et al., 2019) that causes forest loss in Central America. Remote regions of intact forest along major trafficking routes will continue to be vulnerable to deforestation.

Leveraging media to measure causal effects of illicit activity in the Earth System

Media data is a promising proxy of illicit activity, and can complement official statistics that suffer from coarse spatial resolution, low sample size, and the "spotlight effect." Media data, appropriately used, can provide spatial temporal data of high profile illicit activities that influence environmental change, including corruption, illegal logging, and wild life trafficking (Patel et al., 2015; Siriwat and Nijman, 2018), for which official data are unavailable or of poor quality. Media data can also illuminate processes of illicit activity not captured in official data. In our study, media capture a much richer picture of laundering strategies, conflicts between DTOs, violence, corruption, and bribes that influence environmental changes such as forest loss related to the movement of drugs. Media is already used to understand public discourse of environmental change (Cody et al., 2017; Dolšak and Houston, 2014; Le Nghiem et al., 2016), but could be leveraged to generate data about drivers of environmental change which have been previously difficult to measure, such as illicit activity.

Collecting independent measures of illicit activity at the scale of the causal inference model is critical to ensure media represent spatial and temporal dynamics.

Official data on illicit activity is fragmented and often unavailable at sub-national scales- but, as is the case with drug seizure data, availability of higher quality data exists at country and even regional scales. Obtaining these data in this study required significant effort of researchers to develop relationships with law enforcement to know what data exist, what they represent, and how to navigate transparency laws to obtain them. More transparency from policy and the military tracking interdiction activities and efforts to make these data public would allow researchers to develop more robust illicit proxies from media and other sources, echoing recommendations by the National Research Council (National Research Council, 2001). Data proxies of illicit activity independent of media on sub-national scales, such as the airstrip and cartel land holdings, were necessary in this study to ensure media accuracy captured narcotrafficking intensity this spatial specificity.

Temporal accuracy and bias in reporting must be assessed when using media data to measure illicit activity. Cross correlation analysis is important to understand the potential lag effect between media and other independent data sources. Representativeness analysis, which was developed to address sampling bias in meta-analysis for land change science (Schmill et al. 2014), was useful here to understand bias in reporting in urban and remote areas. Experts are needed to interpret the results of both representativeness and spatial and temporal correlation analyses. These expert insights explained how political and economic dynamics of media in each country explain potential difference in reporting over space and time and by media source.

Our experts were the authors on this paper with more than 10 years of field experience in each country. We considered Honduras media data to capture the temporal and spatial variability of trafficking, notwithstanding reduced reports in 2011. The decline is reports in 2011 is attributed locally to the consolidated power and stability of DTOs, lack of interdiction activity, and general destabilization and intimidation of press in the region. We note the Petén became a land-based trafficking hub in 2004, around the time narco-cattle ranching increased in the region. We note potential underreporting in western Nicaragua, and strong racial bias in the Nicaraguan media based on how indigenous peoples were represented as drug traffickers. Costa Rica, Guatemala, and Panama media both show increases in the mid-2000s of trafficking activity congruent with UNODC seizures data, but in contradiction to CCDB shipment data (Figure 24).

Using media data as a proxy for illicit activity has several limitations. For some countries in our analyses, media archives and databases were unavailable in some years (El Heraldo in Honduras and La Prensa in Guatemala) or only had partial electronic archives (e.g. Guatemala). Using multiple media sources can help fill in gaps. Media may have its own "spotlight effect", covering visible illicit activity, such as drug seizures in urban areas, ports, and border crossings spatially distant from where drugs land and money is laundered. Future studies should address spatial displacement of urban media reports from the rural social-ecological systems where the impacts of illicit activity embed. Machine learning and other artificial intelligence textual analysis may generate a larger number of articles (using databases of media such as GDELT (2018)) than this study, which relied on manual coding by analysts. Finally and most importantly, journalists covering drug trafficking in Central America are under constant threat, and often killed, by DTOs (Rafsky, 2019; Shirk, 2010). Violence and impunity influences spatio-temporal distributions of reporting, causing self-censorship (Reporters without Borders, 2018). The representativeness analyses revealed lower than expected media reports from Petén, Guatemala, for example, potentially due to DTOs intimidating journalists after coverage of a 2011 massacre of farm workers by the Zetas, hanging banners stating "Tone it down, before the war is with you." (Rafsky, 2019). These conditions reduce reports of illicit activity in the region where and when it occurs most.

Limitations

This study used a fixed-effects panel regression to measure causal effects drug trafficking on forest loss by developing proxies of illicit activity, assuming narcotrafficking would cause forest loss contemporaneously. Narcotrafficking may be an underlying cause or catalyze other activities leading to forest loss in subsequent years with reverberating effects in frontier spaces (McSweeney et al., 2017), the dynamic effects of which were not captured by the modeling approach in this study. In addition, the coefficient measure could be inaccurate because media data or official proxies or drug trafficking activity capture a signal of, but do not completely represent, the spatial and temporal intensity of narcotrafficking. These factors likely down-bias the coefficient estimate and making it difficult to estimate exactly how much forest loss can be attributed to narcotrafficking. Non-linear econometric models capable of incorporating these dynamics and Agent Based Models (ABM) could build off this study, for example by testing the conditions under which narcotraffickers clear land versus other investments for laundering.

Conclusion

Narcotrafficking constitutes a cause, as opposed to a driver, of the loss of moist tropical forests in the Central American isthmus since 2000 throughout the Mesoamerican Biological Corridor. Significant forest loss has been attributed to cycles of increased agricultural expansion and frontier development, which this study shows may be exacerbated or caused by drug trafficking. Estimating the causal effect of these relationships is important, as drug trafficking continues to increase, in spite of supply-side drug interdiction policies and the US war on drugs. This study illustrates the role of illicit and clandestine activities on land change and the need to account for them in explanations of this change. This study demonstrates a novel use of media data to partially overcome data limitations regarding these illicit activities, demonstrating its ability to capture illicit activity enabling models to measure causal effects of drug trafficking on forest loss. Creative uses of proxy data sources, such as online media, with methodological advances and interdisciplinary collaboration, should allow researchers to examine underexplored drivers of change, such as illicit and clandestine activities.

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CHAPTER 5

TOWARDS IDENTIFYING INFORMAL URBAN LAND USE PATTERNS

Abstract

Understanding how illicit and clandestine transactions influence land change is of increasing interest to land systems science, but "pixelizable" data on these activities is often unavailable. Here we employ techniques previously used in detecting illicit deforestation patterns in forest areas to the analysis of informal urbanization. We link distinct patterns of informal urban expansion observed in high-resolution satellite imagery to the associated urban institutional processes each engenders. In this way, spatial-temporal patterns of land change may identify where informal political and economic transactions--like rent-seeking, clientelism, and corruption--take place. Demonstrating causality between distinct urban spatial patterns and social-institutional processes requires not only high-resolution spatial temporal time series data of urban change, but also corresponding insights into the different social transactions that give rise to these patterns. This approach could improve urban land prediction models and aid governance in the rapidly urbanizing Global South, characterized by high informality.

Introduction[23]

Over 90% of all urban growth takes places in the Global South. A large portion if this growth[24] occurs via informal settlements, where inhabitants have little to no tenure security and lack basic services (UN Habitat, 2016). Understanding urban land systems and rapid urbanization thus requires understanding patterns of informal settlement growth. A wealth of knowledge in the social sciences has documented and described the causes and consequences of informal urbanization (see Connolly, 2009; Doshi, 2018;

[23] This chapter will be revised and later submitted with Hallie Eakin and Billie Turner
[24] 70% of urbanization in Africa is via informal settlements. 10 million people move to cities annually, with 7 million moving to slums. An estimated 30% of urban populations in Latin America, Asia, and the Caribbean live in informal settlements.

Roy, 2005; Van Gelder, 2013). Informal growth is often associated with illicit or illegal activities, because settlements outside the urban zone are often prohibited from official access to urban services, titles, and infrastructure, which politicians may facilitate in exchange for bribes or votes. Despite this knowledge, informal growth in the Global South is often assumed to have the same causes and spatial signature as formal growth patterns in the Global North, and is modeled accordingly. As a result, models of urban growth projections could be inaccurate and prove problematic for urban planning efforts.

The governance of urban land systems should be built on systematic, empirical analysis, addressing how much and what kind of land is consumed and the process at play (Solecki et al., 2013). Doing so is key to understanding what drives urban form in many cities worldwide, with implications for sustainability. Nevertheless, while most spatial urban growth models include landscape (e.g. slope or land use), location (e.g. distance to city center, road, or amenities), and zoning constraints (Irwin, 2010) as predictive variables, models do not disaggregate formal and informal growth. Urban growth models based on the conflation of informal and formal growth have mixed performance in cities in which informal growth plays a dominant role. Models perform reasonably well in Kampala, Uganda, for example (Vermeiren et al., 2012), while modeling patterns in other places of the Global South has proved challenging (Pontius et al., 2008). A recent review of the few existing informal growth models (Roy et al., 2014) found only one incorporated politics (Patel et al., 2012). No model disaggregates informal urban growth into component types. Failing to incorporate urbanization processes common in the Global South, such as informality, into land change models limits understanding of how to manage and predict urban expansion (Nagendra et al., 2018).

Urban informality is a form of land use that is challenging to study, given its association with undocumented, illegal or illicit transactions. Unsurprisingly, there is a paucity of data regarding these intentionally hidden exchanges, making them difficult to "pixelize" and thus integrate into land change models (Tellman et al in revision). The increasing availability of high resolution time series data, however, have enabled researchers to identify distinct patterns of land change and link them to illicit processes (Sesnie et al., 2017). These methodological innovations used to "socialize" pixel data aid in understanding illicit activity when social data are scarce.

Linking pattern to process, especially via Agent Based Models, has improved understanding drivers of land change in both forest (Curtis et al., 2018; De Oliveira Filho and Metzger, 2006; Manson and Evans, 2007) and urban systems (Irwin et al., 2009; Magliocca et al., 2011). There is only one example, to our knowledge, of using pattern analysis to identify illicit activity, which correlated "anomalous" patterns of forest loss in Central America to narcotrafficking activities (Sesnie et al., 2017). Sesnie and associates developed spatio-temporal forest patch metrics to represent the hypothesized process of narco-capitalized deforestation such as average patch size, time of forest loss, years to clearing. A clustering algorithm identified statistically "anomalous" patterns in Guatemala, Nicaragua, and Honduras that were correlated to drug seizure data in specific regions. This paper examines if similar methods could be leveraged to link clandestine processes to land patterns in urban systems.

Disaggregating different types of urbanization patterns is not only important for improving modeling of urbanization, but also in terms of understanding how distinct urban growth patterns generate distinct assemblages of land system architecture (Turner et al., 2013), or the spatial arrangement of heterogeneous land uses in a given landscape. These spatial patterns influence urban climate (Benson-lira et al., 2016), energy budgets and emissions (Frolking et al., 2013), flood risk (Wheater and Evans, 2009), and human heath (Ahern, 2011) among other sustainability factors. While informality plays an important role in mega-urban development worldwide, little is known about how these drivers affect urban form and the aforementioned ecosystem services (Henderson et al., 2016). As a result, existing efforts to simulate and predict patterns of urbanization in the developing world often fall short of accurately capturing the dynamics at play (Pontius et al., 2008). Moreover, the spatial patterns produced by urban informality remain unexplored, despite the importance these land patterns represent for urban socio-ecological systems. Here we examine the spatial patterns of four identified types of informal urban growth in Mexico City, and the data gaps that must be addressed to link informal pattern to process in this and other cities worldwide.

Four types of urban informality in the Mexico City Metropolitan Area

The Mexico City Metropolitan Area is one of the largest megacities in the world, with nearly 30 million people, and has the highest rate of informal urban growth (an estimated 65%) in Latin America (Connolly, 2009). Informal urbanization has characterized growth in Mexico City since the 1930s, after its lakes were fully drained and national policies encouraged urban growth (Tellman et al., 2018). Informal urban growth persists because of inadequate public housing efforts, a formal housing market inaccessible to the poor, and economic and political gains to politicians, developers, and intermediaries (informal actors who provide access to services like water or electricity) profiting from settlement expansion (Ch 2). This informal urban expansion, often characterized as chaotic and ungovernable by cities authorities and urban planners (Lerner et al., 2018), is an ordered social and institutional process with four distinct types: i) ant urbanization (direct sale of one plot to one settler), ii) illegal subdivision (one actor who buys and sells many plots of land), iii) land invasion (a group of settlers illegally squatting on land, usually facilitated by a political group), and, iv) social or public housing (city or federal subsidized housing for low or middle income populations) (Ch 2.). While this latter type of urban development is not typically considered informal in the literature, evidence from Mexico City demonstrates that this development is often deeply embedded in social transactions that deviate from stated legal norms and procedures (Ch 2).

The four types of informality are identifiable by the common type of land transactions of each and the economic and political payoffs to the actors involved (Figure 29, see Ch 2 for more details). Economic returns include cash earned through bribes and side payments, sale of land or urban services, kickbacks paid by developers to politicians to change zoning or evade regulation, and increased municipal budgets from an expanded tax base. Political returns include opportunities for politicians to advance in their party or win office by gathering loyal clienteles of voters and citizens to participate in mass mobilization.

Ant urbanization generates a small amount of economic capital to a landowner selling their plot on the informal market, and to a government official bribed by informal settlers to prevent foreclosure. Politicians come into ant urbanization areas to influence the distribution of services, provide construction materials, or encourage consolidation to garner votes. Subdivision generates larger economic returns than ant urbanization, because it is concentrated in one actor who sells dozens to thousands of lots. This actor purchases agricultural land from a member of a communally held property (called *ejidos* in Mexico- see Ch 2 for details) and who holds individual land use rights to farm a small portion of the ejido (~ 1 hectare). It is outright illegal to sell land, or expensive to sell land legally because of high transaction costs, so the *ejido* member sells it to an entrepreneur known as a “land flipper.” The land flipper buys many ejido plots, which they subdivide and sell to settlers. The political returns are often higher than ant urbanization due to larger numbers of settlers (and votes).

Land invasion generates large political returns, because settlers “pay” for rights to land and services via political participation with the group engineering the invasion. The economic returns can be higher than subdivision, depending on the size of the invasion. Social housing generates the highest economic returns, concentrated in one developer. Developers may purchase cheap agricultural land far from the urban fringe and convince the municipalities to rezone the land as urban through bribes, offering to aid in zoning plans in under resourced municipalities, or demonstrating the potential of increased tax returns. Municipalities are required to install urban services, the government facilitates the sale of these homes via a social housing program, and the developer captures the capital gains.

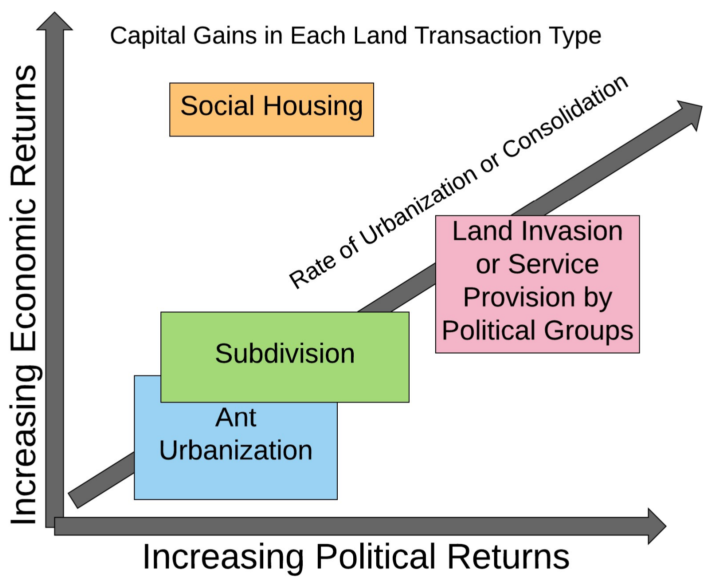

Figure 29. Economic and political capital returns in each land transaction type, and a hypothesized vector of how rate of change is orthogonally and positively correlated.

While typologies of informality for Mexico City have been developed (Ward, 1976), they have never been linked to specific spatial morphological patterns each produces on the landscape (e.g. see Bazant, 2001; Nurko et al., 2016) . Here we ask, do distinct orders of social processes driving informality produce similarly ordered spatial morphology? If so, can we identify the different underlying processes producing informality in satellite imagery?

Spatial Patterns of Informal Urban Expansion

The processes identified above for informal urban expansion display distinctive spatial attributes. Urban consolidation expands in space and accelerates in time as returns in political and economic capital increase (Fig. 29). The hypothesized spatial pattern of each informal urban type is depicted in Figure 30, with an empirical case example from Google Earth Satellite imagery provided in Figure 31. Cases were identified via GPS points taken in the field, which were uploaded into Google Earth. Screen shots were taken using the Google Earth timelapse feature, but place names are intentionally anonymous due to the sensitive nature of the topic (e.g. potentially making communities vulnerable to eviction). An explanation of the hypothesized pattern and empirical example for each urbanization type follows.

Ant urbanization appears near the urban fringe on existing agricultural or conservation lands. Ant urbanization is produced by one-off land sales in Southern Mexico City on land zoned as "conservation." Urban growth is not permitted outside areas zoned urban in local government land use plans (which began in 1997), but some agricultural activity is allowed. Farmers with land rights who no longer wish to farm or need cash with sell plots (typically 250m^2 in size) informally to settlers seeking to build a home. This distributed growth produces a slowly developing, dispersed settlement pattern (Fig. 30). Growth may accelerate or consolidate when intermediaries install urban services, making the land more valuable and increasing demand. Ant urbanization is typified by one case study community (Fig. 31) that took 15 years to develop, and is still slowly growing. In addition to the spatial pattern, ancillary data of land zones that identifies areas not permitted for urban growth are required to identify this urbanization type.

Subdivision occurs on rectangular agricultural plots (Fig 30), and the urbanization pattern is more rapid and spatially consolidated than ant urbanization. Typically, a land flipper purchases 1 ha of land of communal tenure (either *ejido* or communal rights land) and sell plots sequentially to settlers. One such community reached its development in about 10 years (Fig. 31). Subdivision and ant urbanization together represent at least 10% of all urbanization in the Mexico City Metro Area, occupying at least 3,200 ha in Mexico City's conservation land. In addition to its characteristic spatial pattern, ancillary data on land tenure is required to identify areas of collective title where subdivision typically occurs.

Land invasion generates the most rapid and consolidated urban pattern. These communities construct many homes rapidly in interstitial urban areas or immediately adjacent to the urban fringe (Fig. 30). Urban plots are built next to one another with little undeveloped space, and the community (~100-1,000 homes) is completed within a two month period (see example in Fig. 31). Although often receiving significant media attention, this process represents the smallest proportion of informal growth in Mexico City. The two most common invasion groups in Mexico City, Antorcha Campesina and the Pancho Villas, have together urbanized 600 ha of land, representing only 2% of the city's growth since 2000. In addition to its distinctive pattern, media reports could be used to identify approximate neighborhoods where an invasion process may have taken place.

Social housing is constructed on cheap agricultural land, often far from the urban fringe. Social housing areas are large, and develop within two to four years (Fig. 30). This pattern represents at least 11,000 ha of urban growth, around 30% of new urban land in

Mexico City from 2000-2010. Social housing has slightly smaller rates of consolidation compared to land invasion (Fig. 31) but the area urbanized is much larger. Ancillary data on permits for social housing construction could be used to identify the names and municipality of construction, but specific data on the polygon associated with these permits is not publicly available. Sometimes, the name of the developer appears in Google Earth, which can help identify a social housing complex.

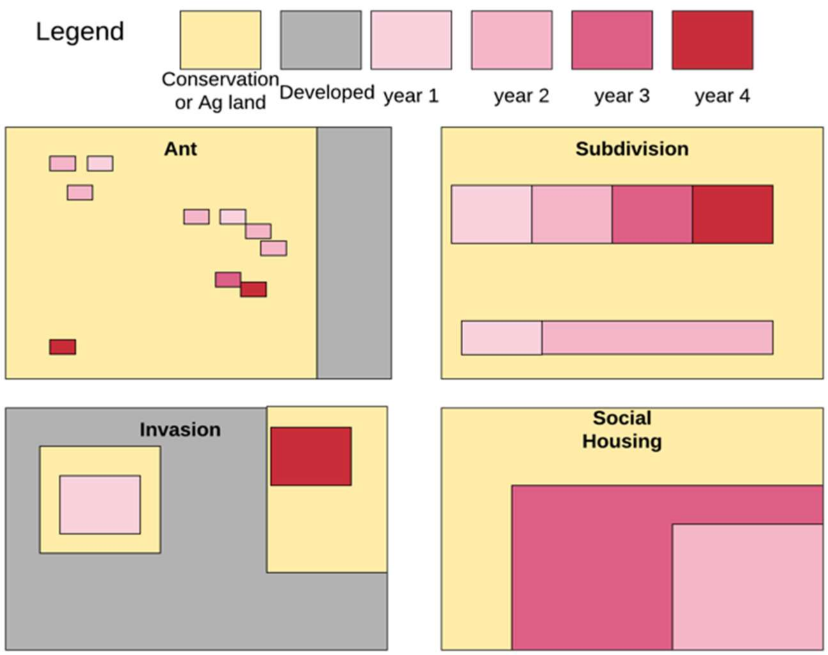

Figure 30. Hypothesized spatial patterns of informal urban development, illustrated from textual interview analysis (Ch 2). Yellow represents existing undeveloped land, grey is existing urban land cover. New informal urban settlement is displayed in pink to red, with shades representing year of development.

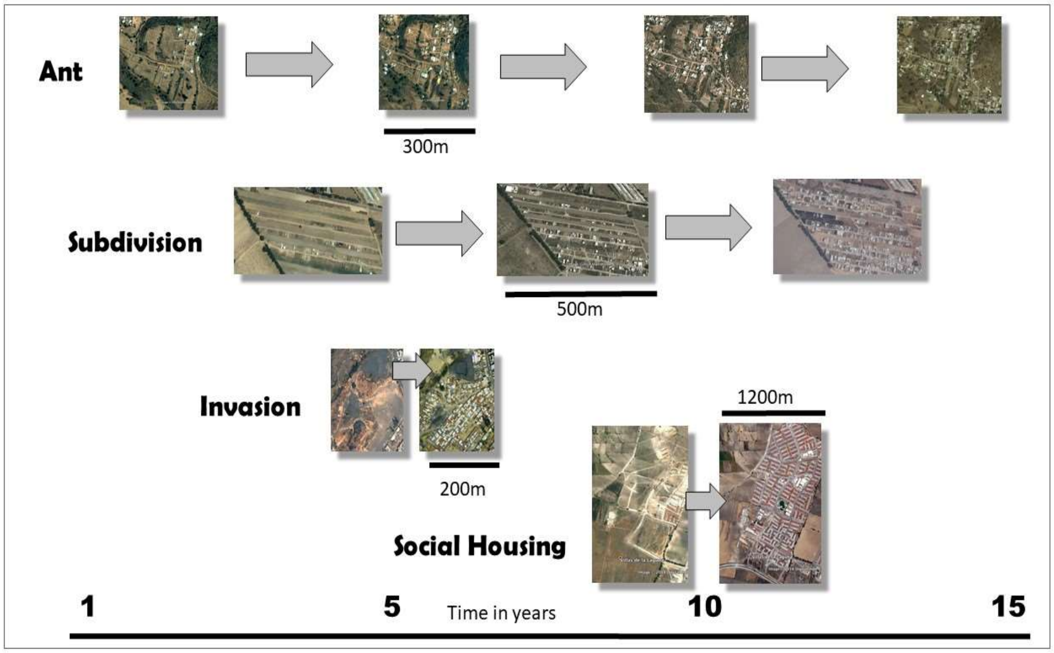

Figure 31. Empirical examples of each informal urbanization type by hypothesized spatial pattern and speed of development.

Identifying informal land change patterns in urban areas requires higher resolution time series

Mapping informal settlements requires very high resolution satellite data (Kuffer et al., 2016). Thus, while a set of hypothesized spatial-temporal patterns for informal urbanization types was developed for Mexico City, it could not be empirically tested. Sesnie et al (2017) leveraged a 30 m resolution annual time series of forest change to identify anomalous growth patterns linked to narcotrafficking operations and laundering. The average forest patch size ranged from 100ha in Honduras (~ 1,000 Landsat pixels) to over 1000 ha in Guatemala. The average land invasion, in contrast, in Mexico City, was 1.9 ha, which is equivalent to only 20 Landsat pixels.

Public satellites from 2000-2015 available to map annual urban expansion (MODIS and Landsat) are not at resolution sufficient to capture growth patterns such as ant urbanization[25]. Efforts to map informal growth at 5m in Mexico City have been successful (see (Rodriguez Lopez et al., 2017b), but no time series are available. Time series are required to differentiate, for example, a consolidated ant urbanization community from a subdivision (Fig.31). Other studies that have examined patterns in land system architecture rely on 1m resolution image (Li et al., 2017). While we were unable to take advantage of the data for the analysis here, the availability of Sentinel-2 data (10m resolution, available starting 2015) could help identify distinct informal urban land patterns in Mexico City and elsewhere in the future.

High-resolution urban time series data would facilitate pattern analysis to address several key questions to understand informal urban land systems and aid their governance. First, while consolidation likely increases with economic and political returns to informal urban growth (Fig 1), what is the shape of this relationship? Do economic versus political incentives influence urban land consolidation differently? If so, what does this imply about the appropriate institutional mechanisms to govern such growth? Second, do formal versus informal urban development produce distinct and identifiable patterns? Can distinct types of informal growth be differentiated across a metropolitan area? If so, do these differentiated patterns indicate distinct environmental and social consequences? Finally, it is difficult to identify where intentionally hidden activities, such as corruption and rent-seeking, occur on the landscape. Could urban pattern analysis reveal, for example, specific locations where illegal urban services have been installed and facilitated unusually rapid consolidated growth in Mexico City's conservation land? Together these data could aid impact evaluation of policies such as land titling and regularization, eviction, payments for environmental services, and other interventions designed to curb urban growth.

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[25] The average roof size for homes in ant urbanization is $60m^2$, and these homes are dispersed, this pattern was not resolvable with Landsat data.

Disaggregating urban informality links institutions to landscape patterns and environmental consequences

Not all urbanization is driven by the same mechanisms or produces the same patterns. At first glance, this diversity appears seemingly chaotic, that which has overwhelmed attempts to model the pattern in the Global South robustly (Pontius et al., 2008). In Mexico City, we identified explicit and distinct sets of actors and rules characterizing different types of informal urbanization, each with its unique spatial footprint. This effort allows us to demonstrate potential links between processes and patterns for one metropolitan area. On this basis, we posit that codifying and translating rule sets into urban growth models could improve their accuracy. To improve urban growth models, however, a series of such studies should be made across the Global South to enable meta-analyses. The outcomes may point to common patterns associated with the general type of processes involved or by regional context. Connecting institutional and social patterns to spatial footprints, as demonstrated here for Mexico City, provides a framework that could be replicated in other cases and lead to informal urban pattern meta-analyses. Understanding the spatial patterns of informal could lead to more robust modeling approaches and assessment of consequences for the environment.

Informal urbanization is a social-ecological process that produces diverse but potentially predictable patterns with measurable environmental outcomes. Each pattern is driven by institutional arrangements that produce distinct land system architecture with implications for environmental services (Turner II, 2017). In Mexico City, for example, land system architecture of small areas of slow, distributed ant urbanization on conservation land versus the large areas of rapid, consolidated social housing on agricultural land could have different consequences for hydrologic ecosystem services, such as water filtration, aquifer recharge, and flood mitigation. Yet, public discourse in

Mexico City assumes ant urbanization and invasion as the primary cause of reducing environmental services and increasing water scarcity and flood risk (Lerner et al., 2018). This assumption leaves other types of informal urbanization and their spatial and environmental consequences unexamined. Disaggregating informal urbanization based on institutional arrangements and landscape patterns could provide a new avenue to analyze tradeoffs based on environmental costs of informal growth in Mexico City and elsewhere. A better understanding of these environmental service impacts generated by distinct types of informal growth could aid urban planning efforts to improve urban sustainability. Yet these differentiated ecosystem service assessment are predicated on the ability to identify the process, spatial pattern, and local of informal settlement types, which is currently a challenge for the land change community.

In conclusion, land system science has yet to fully engage with the range and nuances of institutional contexts that shape informal or illicit transactions. These transactions may result in unique landscape signatures, urban or non-urban in kind. Linking institutional rules and social relations to the distinct spatial footprints they engender requires bringing together disparate knowledge communities which have focused almost exclusively on either informal urban processes or urban land cover patterns. Bridging the pattern to process gap represents an exciting frontier for land systems scientists, and a necessary step to understanding urbanization in the Global South.

CHAPTER 6

CONCLUSION

This dissertation calls for Land System Science (LSS) and affiliated research communities to incorporate illicit and clandestine activities affecting land change into their portfolio of research. This dissertation demonstrates various ways in which land change understanding is enhanced by doing so. It identified clandestine drivers of land change by either their unique spatial patterns of change or through correlations with proxies of illicit activity through case studies involving urbanization in Mexico City and deforestation in Central America. The methods included examples of both "pixelizing the social" and "socializing the pixel", efforts that have undergirded LSS. Attempts to "socialize the pixel" by understanding social processes and linking them to land use patterns include the institutional analysis and examination of satellite imagery in chapters 2 and 5. Fieldwork informed typologies of informality identifiable in high-resolution satellite imagery in Mexico City. An effort to "pixelize the social" by digitizing social data linked to administrative units at which land change data could be aggregated, included fixed effects regressions used in chapters 3 and 4, which developed proxies of clientelism and narcotrafficking activities, respectively, to associate them with respective land use outcomes of urbanization and deforestation. Media data on narcotrafficking indicated a causal effect on forest loss, while the timing and distribution of voting data in Mexico City explained the variance of land titling and urban expansion. In a general sense, the aim of identifying drivers of land change in each of the two cases was achieved. Nonetheless, estimating the true magnitude of these drivers on land change outcomes remains elusive. Here, I summarize the progress made in pixelizing and socializing clandestine activity from this dissertation, with an extensive focus on the pros and cons of the LSS approaches employed in this study, reflections on the ethical implications of studying illicit activity for the communities affected and as “the researcher”, and the research agenda for future LSS to expand on this promising work.

Objective 1:

Can clandestine drivers of land-use intensity be identified either by unique spatial patterns of change or through correlations with proxies of illicit activity?

This dissertation demonstrated that the influence of illicit activity and political transactions can be studied quantitatively by leveraging existing statistical methods common to land system science. Existing data from media reports, government archives, and elsewhere can and should be digitized (pixelized) and used in land system studies to expand the range of causal factors studied, albeit with caveats explored below. Interpreting the results of these studies, and developing appropriate hypothesis regarding illicit phenomena requires an understanding of the complex social processes involved. Understanding these processes can be developed by either collaborating with other researchers with long histories of field work, or preferably, for the researcher to spend extensive time in the field building appropriate relationships with the actors and organizations in question. The importance of fieldwork goes beyond the practical need for the researcher to understand social phenomena. Time spent in the field with the people involved in, and the places where, illicit activity occurs is critical to developing a grounded perspective of the ethical and sometimes troubling implications of studying illicit activity and the risks to both the researcher and communities implicated in the research.

<u>Pixelzing social data: straight forward but time consuming</u>

A plethora of information indicating political and illicit economic transactions exist in the digital age of increasing transparency, but significant effort to georeference data and assess their quality are necessary to transform the data into variables in land system models. Chapters 3 and 4 used fixed effects panel regressions and attempted to "pixelize" proxies of illicit and political transactions to estimate their respective causes on forest loss in Central America and urban change in Mexico City. Turning information about clandestine activity into georeferenced proxies that can be used for causal inference is relatively straight forward, but the required manual labor and financial resources to gain strict quality control are difficult, especially if the research involves much more than this effort alone. The large amount of digitized and georeferenced information and number of observations required for statistical analysis and causal inference required a research team of students I trained and supervised. I had to make dozens of decisions and update data digitization protocols, noticing new errors in data collection as it was delivered, and requiring my research team to redo the work. In this dissertation, at least $10,000 were required to digitize and georeference data on land titles and electoral outcomes for Mexico City. Another $37,000 was spent to code about 3,000 media articles with the help of collaborations who hired over students to develop a narcotrafficking proxy for Central America across a 15 year time period. These data were proxies intended to "scale up" anecdotal evidence, for example, on clientelistic exchange in a given informal settlement to the ubiquity of this type of exchange across Mexico City. These data were also intended to extend the geographical scale of analysis, for example, beyond official records of narcotrafficking activities by interdiction authorities, which was only available in a few Central American departments.

In each case, triangulating the data proxies of illicit activity required either quantitative or qualitative comparisons to other empirical data. Quantitative comparisons were used, for example, for the media data with narcotrafficking with official interdiction data. Qualitative comparisons between electoral data and empirical observations were made in my own fieldwork (e.g., Chapter 2) or via conversations with other political scientists. These comparisons revealed both the feasibility and potential limitations of the proxy data, paving the way for future work.

Pixelizing existing social data is likely the lowest hanging fruit for researchers seeking to identify a new driver of land change using a causal inference framework. It requires generating enough proxy data and collecting control variables such that that "signal" of illicit and clandestine transactions can be ascertained through frequentist statistics. Well-established methods in causal inference, especially those methods used in econometrics, and associated computation software (R and STATA), can be used to study drivers in land systems. Some methodological limitations persist, however, owing to low sample sizes in terms of temporal or geographic specificity of measuring clandestine activity, and the zero-inflated distribution of sporadic land changes like informal settlements.

<u>Identifying drivers of change and estimating effects: pixelizing clandestine proxies, the challenges of micronumerosity, and type II errors</u>

It is easiest to estimate the causal effect of a driver in any social-ecological system, including land systems, when sample sizes are large and land changes follow a linear (or even a log-linear) distribution. In this dissertation, as is common to land change studies, neither forest loss nor urban expansion were linearly distributed. Forest loss, however, was log-linearly distributed, and could be easily log transformed, allowing for estimation with linear models. Normal distributions and linear models are more computationally efficient and with coefficients that are easy to interpret (e.g., a one unit change in X [illicit activity] = a one unit change in Y [land use]).

In contexts where land change is more "sporadic" than forest loss, such as informal settlements in conservation land, time series cannot be log-linear transformed. In Mexico City, neither land titles nor informal urban expansion are linearly distributed, and the majority of observations contain a "0" (e.g., no land titles or urban expansion observed in unit i for time j), preventing logarithmic transformation. A nonlinear distribution was required for regression, meaning that the coefficients had to be estimated through maximum likelihood instead of least squares. Nonlinear models limit interpretability of coefficients as the "effect" of X on Y, are less computationally efficient, and may fail to converge with low sample sizes. Furthermore, non-linear time-series panel regression models are an area of active research with fewer estimation methods in R and Stata. For example, there were no options in either software to incorporate spatial error or lags, or even cluster robust standard errors by geographic sections of the city with non-linear fixed effects models, making it challenging to deal with spatial autocorrelation. There was no ideal distribution to fit urban growth data. The distribution that best fit the data (if we treat urban growth as count data), negative binomial, also fails to meet assumptions of fixed effect hypothesis testing (Allison and Waterman, 2002; Guimarães, 2008). Typical solutions, such as including a dummy variable for unit, were not implementable because models failed to converge with such a low sample size. These issues limit hypothesis testing we had to compromise in the "right" distribution versus the ability to control for unit variation with fixed effects.

The second challenge in estimating spatial variation of causal effects is low sample size. This is referred to in microeconomics as "micronumerosity", a term indicating the number of parameters required to specify a model often exceeds the sample size in empirical economics (Goldberger, 1991). This causes type II error, and forces researchers to accept a null result because the ratio of the mean to the standard error in a sample is small. In socio-ecological systems with high variance, where institutional context, spatial location, and other factors condition a response, this problem is even more pronounced (Franzese and Hays, 2007; Franzese and Kam, 2009).

These “contextual factors” must either be measured, a dummy variable (yet another parameter) added, sub models attempted for each region (further reducing sample size), or coefficient spatial variance explored through geographic weighted regression (not advised in small sample sizes and has no causal inference) or the even newer geographically temporally weighted regression (Fotheringham et al., 2015).

The problems of context conditionality and micronumerisotiy were apparent in chapters 3 and 4. While narcotrafficking has a mean effect on forest loss in Central America, submodels per country revealed a significant relationship between drugs and deforestation only in Honduras. It was not possible to ascertain if this relationship is limited to that country or if the lower sample sizes of Nicaragua and Guatemala precluded inference and caused type II error (i.e., failure to reject a false null hypothesis). Likewise, in Mexico City, examining the relationship between patronage and electoral competition for urban expansion differed across boroughs and election processes. This variance made it difficult to answer the research question clearly, which was set up to test whether electoral competition versus patronage (two opposing mechanisms) caused urban expansion. The empirical results revealed, confusingly, that both cause urban expansion in different elections and different regions. Resolving these problems requires a larger sample size, which is infeasible because of the difficulty of developing spatially and temporally specific data proxies of illicit activity. Additional modeling techniques to account for endogeneity and feedbacks between the urban growth process and electoral dynamics could help tease apart this complexity in future work. Notwithstanding this challenge, some ideas of how to increasing sample size for illicit transactions are discussed in recommendations.

<u>Socializing pixel data- pattern analysis remains elusive in urban systems</u>

Pixelizing social data commonly requires large investment for digitization, but socializing pixel data requires another expensive investment—fieldwork. Due to equifinality (i.e., multiple processes giving rise to the same pattern), linking pattern to process requires a deep understanding of process. The only way of arriving at processual understanding regarding illicit activity is by personal, one-on-one discussions with many people involved in and affected by these transactions. Due to the large amount of variance and secrecy involved in illicit exchanges, the researcher must gain multiple perspectives around the same "type" of exchange until data saturation (i.e., no new information is discovered) is reached. Initially I had hoped to code previously published studies via the QCA (Qualitative Comparative Analysis (Basurto and Speer, 2012) method as Ostrom (1990) had done to develop a typology of informal land-use change. This was infeasible because so few studies of Mexico City describe the pattern of land-use change in spatial terms (except for a few pioneering architects such as Bazant 2001; Nurko, Ruiz Durazo, and Gonzalez Rodriguez 2016). The only way to link spatial pattern to social mechanisms was through my own empirical fieldwork presented in Chapter 2.

Socializing pixelized patterns attempted in Chapter 5 was based on a heuristic typology of informality developed in Chapter 2. While the patterns of informality appear distinct in high resolution Google Earth imagery, testing these hypotheses across the landscape requires developing a high-resolution dataset currently inexistent for Mexico City (or any urban area in a developing country). Another approach would be using machine learning techniques to separate patterns on Google Earth, which proved successful for developing a deforestation typology of commodity loss, shifting agriculture, forestry, and wildfire (Curtis et al., 2018).

Pattern analysis unfortunately proved infeasible with the Landsat urban detection algorithm attempted in this thesis (Goldblatt et al., 2018), because urban detections were inconsistent overtime and the pixel size was too large to detect some types of informal expansion in Mexico City, like ant urbanization and land invasions. Socializing pixel patterns was feasible to link narcotrafficking to forest loss using publicly available data (Sesnie et al., 2017), but in urban systems, commercial imagery or new machine learning methods on Google Imagery must be developed. Perhaps other larger scale or incremental land-use changes, such as land grabbing or pasture, could also be assessed via pattern analysis with public satellite imagery.

Another successful approach to socializing the pixel is to use agent-based models (ABM) to mimic land-use patterns as an outcome of rules between agents. ABMs have never been used, to my knowledge, to model illicit transactions for land outcomes, but they have been successfully used to model illicit behavior. Magliocca and associates (2019) successfully modeled the behavior of cocaine cartels in Central America based on decades of field work from an interdisciplinary team of place based researchers (Devine et al., 2018; Mcsweeney et al., 2017; McSweeney et al., 2018). This again underscores that socializing the pixel requires a depth of understanding only available through fieldwork and qualitative analysis. Likewise, the institutional analysis, payoff surfaces, and typology from chapters 2 and 5, based on my own extensive fieldwork, could enable formalization of complex social interactions into equations to undergird an ABM of informal land change.

<u>Limits to "scaling up" insights from political ecology and political science: context dependence and middle range theories</u>

A major intent of this dissertation was to take phenomena typically assessed in political science, political ecology, and affiliated research communities that study power and politics and place them into the post-positivist framework of LSS. While this dissertation made progress, it also suffered from inadequate data on social process and context conditionality that has long plagued theoretical development in LSS (Meyfroidt et al., 2018). LSS has dealt with this challenge by focusing on "middle-range theories," or contextual generalizations of causal explanation of delimited phenomenon (Merton 1968 in Meyfroidt et al. 2018). LSS middle-range theories have incorporated some important factors involving land change as gleaned from political science and political ecology, such as the institutional analysis in Ostrom's (2011) design principles, neoliberal frontiers, and recessions in urban areas. As this introduction argues, however, LSS continues to ignore illicit and clandestine activity in middle-range theories of land use change.

Using a post-positivist approach, foremost hypothesis testing, this dissertation required developing data proxies to represent illicit and clandestine transactions. Ideally, these proxies are good enough to use in fixed effects models where administrative units represent their own control while "exposed" to the illicit activity over time. If the proxy is a reasonable representation of illicit activity and a causal mechanism exists, ideally the proxy shows a statistically significant relationship on the land use outcome.

Chapter 3 used voting records, land titling, and urban expansion data from 2000 to 2015 to study clientelism in Mexico City elections. With those data, I could not determine the directionality of X and Y (e.g., do expanding formal settlements attract political transactions, or do political transactions create or consolidate informal settlements). Most studies of clientelism either rely on time series of electoral records with a large sample size across a country (e.g., Albertus et al., 2016; Castañeda Dower and Pfutze, 2015) or use ethnographic and field based surveys (Berenschot, 2018; Hagene, 2015; Hicken, 2011; Martinez-bravo, 2014; Paller, 2014; Post, 2018). Voting records are an indirect way to measure the activity politicians engage in on the ground and for which no public data exist, such as connecting electrical grids, bribes to bureaucrats in the water department to "look the other way" when a pipe is installed, paving a road with campaign money from the party and so on. A more direct way to measure this relationship is through surveys, which limit the geographic scope of analysis and generalizability of the results across the Mexico City metro area.

Likewise, Chapter 4 relied on counting media events to represent narcotrafficking activity. This could problematically induce media bias in understandings of trafficking activity. Although we attempted to quantify media representation, it provided no means of transforming the data proxy to address the bias.

Political ecologists are correct to caution LSS's approaches to "quantify" power and illicit activity. Quantification implies a reductionist approach. Data proxies will always be an incomplete representation of nuanced and complex processes. Yet, if Political Ecology were to reject the methods used in LSS as reductionist, it would result in minimal inclusion of power and politics in LSS models, which can have significant consequences. Failing to incorporate power and politics into LSS models could result in urban growth projections that are inaccurate for cities with informal growth, for example. Ignoring illicit activity in assessments of land change risks conclusions that fail to identify root causes of frontiers of deforestation that are narcocapitalized (and continue to blame, and attempt to govern, rural population growth and marginalized peoples as if they were the drivers of change instead of a proximate cause). Importantly, land change models are the bases for other assessments of ecosystem services and climate change projections. Incorporating illicit activity in models of land change could be critical to differentiating the drivers of land change and associated impacts for the marginalized populations, addressing power issues that political ecologists emphasize.

The intent of "pixelizing social data" in this dissertation was for the data proxies to represent a treatment effect on a unit of a land system. This required measuring land change outcomes before the treatment effect was present, or including similar land units where the treatment effect of the illicit variable of interest was not present. An alternative way to estimate the causal effect of illicit transactions in land systems would be in a "natural" experiment, defined in the social science as when the treatment variable is haphazard and possibly random (Sekhon and Titiunik, 2012). In social-ecological systems, natural experiments are rare historical accidents. Illicit and clandestine activity such as corruption, clientelism, and narcotrafficking is rarely random and often arise in places with specific historical contexts (Devine et al., 2018). Methods such as matching, which estimates differences in units similar in every way except the treatment variable, can help simulate natural experiments and have been used in LSS and political science (Heilmayr and Lambin, 2016; Keele et al., 2015). Matching was not used in this dissertation but could be explored in future work.

Despite using time series data, or matching land units in a quasi-natural experiment, causality can be very difficult to estimate when endogeneity is present between dependent and independent variables. For example, in Mexico City, urban growth is potentially an outcome and a cause of electoral competition, because political parties may be attracted to rapidly growing settlements. Methods using instrumental variables could help tease apart these differences. Even with a natural experiment and causal effects measurement framework, outlining the causal mechanism remains essential to identify illicit activity as a "cause" in LSS (Meyfroidt, 2016).

Abductive approaches, qualitative methods, and field-based studies in both political ecology and LSS have an irreplaceable role in informing LSS model design and interpreting the results of LSS modeling efforts, explaining detailed mechanisms that cannot yet be modeled. More importantly, understanding the intangible, hidden transactions in illicit activity require disentangling social processes. Understanding these processes is achieved by understanding political ecology and political science theories about how power works, and spending time in the field gleaning information and trust about informal transactions that are “invisible” in existing quantitative data.

This dissertation demonstrated LSS type methods can be used to begin to “scale up” and test political ecology (as well as political science and political economy) based descriptions and theories of informal and illicit transactions and mechanisms. Methodological approaches from political ecology and LSS need and should continue to build from each other to improve processual understanding and estimated impacts of power and politics in land systems (Turner and Robbins, 2008).

The ethical implications of studying illicit activity

Scientists studying social-environmental change have an ethical obligation under the social contract of science to study problems of importance and communicate their findings to the public to aid decision making (Lubchenco, 1998). Illicit and clandestine activity, however, has unique ethical and social justice implications, both in the collection and dissemination of data. Illicit transactions tend to involve an unequal exchange and distribution of benefits between an actor with power and an actor with relatively less agency. The role of the researcher is to document this exchange safely and anonymously, and not to “name names”, feed a rumor mill, or compromise the safety of any actor involved. The role of the researcher is to study a generalizable phenomenon and pattern, and in the case of this dissertation, expand the knowledge base of how land systems work. All data collection and production in this context, is unavoidably political, because the actors involved in the system of study have political aims that they may attempt to further via the research results and even the relationship to the researcher. This research is also political by definition, because it is about power, access to resources, and asymmetries in information and control. Making illicit activity more “legible” by quantifying it, as well as making the data collection in research open access versus restricted access is a political act because it can affect the relationships the researcher studies.

In Mexico City, my identity as a North American women provided me special privilege and access to data with political groups, government, official, and informal settlements because I was viewed as an outsider. This status, for example, took many months of fieldwork to gain the trust of a community leader of an informal settlement, but resulted in the gracious offer of social capital—introducing me as a trusted ally to residents who allowed me to interview them. Critically, this leader accompanied me to many interviews, which helped ensure my safety. My interviews also represented some risk for the residents, who bravely discussed their difficulties and exploitation by the intermediaries in their community who had threatened them with eviction. There were many moments of turning off the recorder, and tearful off-the-record admissions of the fear and anxiety under which the interviewee lived. As a researcher I could only offer access to information about their land zone and legal status, to help them understand the process to get title to their land, and to listen earnestly to their story and maintain complete confidentiality.

I was also able to interview leaders of political groups who led "land invasions" in Mexico City. They provided access to interview residents in these squatter settlements, where many government officials are not allowed to enter (but often observe via drone). They provided me this access in part to increase their legitimacy and recruit new members to their political movement from other informal settlements via association with a North American researcher. These organizations depicted themselves as protagonists providing homes for people the government could not, which is not discussed in the public discourse of informal growth.

Making informal settlements “more visible” may be important for land system scientists, but it is also desirable for the State that wishes to govern them (Scott, 1998). Making data transparent and public could harm communities in informal settlements, for example, if the government uses it to plan evictions or cut services. Likewise in Central America, identifying specific locations of deforestation that are likely related to narcotrafficking is of great interest to law enforcement because it could aid interdiction activities. Drug interdiction, however, can have adverse consequences on communities in Central America where narcotraffickers are operating, and even push trafficking activities into more remote areas and move cartels around the isthmus. Paradoxically, interdiction has not reduced the volume of cocaine reaching the United States (Magliocca et al., 2019). My understanding of drug trafficking was facilitated by researchers who had built trusted relationships with community leaders, just as I had done in Mexico City. I relied on their understanding and relationships both in the field, and interpreting the media data in each Central American country. Other stakeholders in the field, including environmental NGOs and national and international governments, had contested visions of how to address narcotrafficking, including pro-militarization and interdiction. With this ethical dimension in mind, only portions of my dissertation data will be made public, with coarser spatial resolution such that it cannot be linked to specific locations or communities and used by actors who could cause harm or violence to local residents.

Making illicit activity salient to environmental change, beyond specific names and places, has important implications for social justice. The unequal exchanges and power dynamics involved in land changes in both Mexico City and Central America included elements of coercion, social exclusion, and even violence against marginalized populations. Paradoxically, these same marginalized populations are often blamed as the root cause of environmental change. Public discourse in Mexico City, especially among many government officials, blames informal settlers as the cause of hydrologic risk (Lerner et al., 2018). Likewise, deforestation in protected areas in Central America has often been blamed on rural peasants or settlers in frontier areas (Devine et al., 2018). My research identified these marginalized populations as both victims and agents, acting to meeting their needs, while focusing on the economic and politically powerful actors that shape land use and the conditions of exchange. This dissertation reframes corruption beyond a normative discussion of good and bad actors, and instead focuses on the rules, payoffs, and institutional contexts that incentive particular social relationships (Ch 2). In some cases, the actors involved in illicit land change are those in government charged with regulating it. Studying illicit activity and understanding the social processes involved, leaves the researcher with ethical obligation: providing insights about the problem at hand without causing harm.

Objective 2: What is the role of illicit activities in urbanization in Mexico City and deforestation in Central America?

This dissertation identified the presence of a causal effect of narcotrafficking on forest loss in Central America and identified both the causal mechanism and associated effects of political rent seeking on informal urban expansion in Mexico City. As both case studies used a fixed effects approach to test hypotheses, the identifying a causal effect (or mere association in Mexico City) could be confirmed, but the estimated area of land change these clandestine transactions cause could not be estimated. This dissertation took an important first step in establishing causal effects for these phenomena, but future work must seek to measure the magnitude of its effects.

Political and economic rent seeking and urban expansion in Mexico City

Titles and regularization

Chapters 2 and 3 found that politicians and other intermediaries manipulate the distribution of land titles for personal and political party gain, but only in private property titling. Chapter 2 found that titling efforts were more rapid in invasion urbanization, but often lagged in subdivisions and ant urbanization unless an intermediary who could accrue political gains was present. Chapter 3 also demonstrated the influence of the political business cycle of titling in private property: more titles were extended in the month leading up to elections. Titles to informal settlers in *ejido* lands, however, must rely on a presidential decree to initiate the titling process. These decrees exhibited no relationship to the timing of presidential elections, in contrast to claims in qualitative studies that decrees follow electoral cycles (Herrera, 2005; C. E. Salazar, 2012). A larger number of private property titles were distributed to core voters of the PRD (which has held the mayoral seat in Mexico City since elections began in 2000), but not to informal settlements that ephemerally increased support for the PRD party. Core voter preferences explained a small portion of variance (3-4%) of titles extended. This indicates that while titles are politically timed, their spatial distribution is only somewhat dependent on political or clientelistic relationships. Titling timing is likely part of a larger strategy of the party to demonstrate effectiveness to voters across the city, not just informal settlement constituencies.

Public discourse in Mexico City often claims land titles should not be given to settlers because it will increase urbanization in sensitive conservation land. Yet, this dissertation finds less than 25% of land titles have been extended in conservation lands. This indicates titles are not extended to ant urbanization settlements, but rather to well-consolidated urban communities (and potentially, land invasions) that are not in conservation land. Future work is needed to determine the rates of titling among the four urbanization types identified in Chapter 2.

Urban Growth

Chapter 3 tested the relationship between electoral politics and urban growth in conservation land in Mexico City since 2005, which is largely where ant urbanization has taken place. This limitation means the results only apply to one of the four informal growth types identified in chapters 2 and 5: ant urbanization. There is a correlation between political relationships and ant urbanization, but the direction of causality remained elusive in Chapter 3. Electoral competition increases with urban expansion but it is unclear if the effect is causal, or merely correlative in places like Xochimilco. More work is needed disentangle the context conditionality of these results. In sum, while political party strategies have a significant influence on informal urban growth, exactly where and how this occurs, and in what elections, remains unclear.

The effect of clientelism and political relationships on the three other types of informal urban growth remains untested. This requires a “socializing the pixel” approach explained in Chapter 5. To achieve this, first a pattern analysis would be required based on a very high resolution annual time-series data of urban growth in the Mexico City Metro Area addressing the four types informal settlements. Ideally, with a high spatial and temporal resolution urban patch pattern metrics of consolidation, such as those used in gerrymandering studies to assess shape (Fan et al. 2015), could be applied. Other metrics from land system architecture to measure feature of urban patterns could also be used (Li et al., 2017; Turner, 2017). If informality types could be successfully identified based on these patterns and associated zoning data, and unique “patches” of urban growth could be identified, these patches or its characteristics could be the outcome variable of a regression. The independent variable could be time series electoral data for the State of Mexico for each district, which would need to be constructed.

Due to the lack of a monthly or even an annual high-resolution urban time-series for Mexico City, we could not test the significance of the political business cycle for urban growth as we did for land titling. This is an important research domain left for future research.

<u>Does titling increase urban growth?</u>

Land titles may improve livelihood of informal settlers by granting them services and security. On the other hand, many government officials fear titles will induce further urban growth on sensitive conservation lands by giving settlers confidence that if they weight long enough, they can always gain access to land. Evaluating the effect of titling on urban growth could inform this policy debate. Unfortunately, both the lack of specificity in titling locations (approximate neighborhoods, instead of polygons or exact points) and limited time series of urban growth (starting in ~2000 and limited to conservation land) made it infeasible to estimate the causal effect of titling on urbanization growth. A matched difference in difference strategy may allow for estimation of these effects, but geographically expanded higher resolution temporal urban change data are required. Most titled areas were consolidated (e.g. fully urbanized with services) before the 1992 designation of Mexico City's conservation zone. The urban time series available for this dissertation was limited to conservation land 2005 and later. As indicated in Chapter 5, an annual time series of urban change at a very high resolution is likely required to estimate the effect of titling on urban growth in Mexico City.

Decentralizing and democratizing urban decision-making: what does it mean for urban form?

Chapter 3 notes a global trend in democratizing urban decision making through direct elections of local officials with increasing jurisdiction. A similar trend exists in forest systems (Agrawal et al., 2008). While decentralization may improve forest outcomes and decrease deforestation under some conditions (Wright et al., 2016), the effect of decentralization on preventing land conversion may not be generalizable to urban land systems. Mexico City could represent an interesting case to answer a larger question: Does decentralization of urban decision making exacerbate informal or environmentally damaging urban growth? Mexico City could be one of many "natural experiments" of cities that have decentralized and democratized urban regulation over the last decade. Regression discontinuity analysis, for example, could examine both growth and land titling patterns before and after Mexico City's first election in 2000 to answer new questions. Does decentralized democracy accelerate and increase the number of land titles because of electoral pressure? Alternatively, do elections only influence when these titles are given, and concentrate distribution of titles near elections?

Can or should informal urban expansion be "depoliticized?"

How and where urban growth occurs has implications for the socio-ecological system. Urban growth in Mexico City influences hydrologic services of a city struggling to manage water vulnerability in terms of both scarcity and flooding since its inception as the urban center of Tenochtitlan in 1325 (Tellman et al., 2018). Results from Chapter 2 question the assumption that informal urban expansion is a significant hydrologic problem in many cases. What at the social and environmental consequences that titles are given to core voters just before the election or that the most socially and economically marginalized populations receive support from political parties to consolidate their communities and improve living conditions? Research regarding these questions, which could contribute to the larger environmental policy debate in Mexico City, were not answered in this dissertation.

Increasing access to information regarding the application, timing, and process of land titles could help identify if, when, and where this administrative process is politically manipulated. Providing detailed locations of land titles (with coordinates in a common georeferenced system) would facilitate analysis of these data, rather than the attempt to digitize public records without geographic protocols. Reducing opacity of the land titling process and making it accessible and legible to residents and the public could lead to more informed governance. Any increase in transparency, however, may privilege some actors over other who can leverage this information to achieve their political or social goals.

Regardless of the directionality, Chapter 3 revealed political parties have a relationship with ant urbanization settlements. Chapter 2 indicates, however, that this urban growth represents a relatively small portion of Mexico City. Ultimately, assessing the political influence of any one type of urban growth may only be as important as the associated social and environmental impacts. Future research should assess the impacts of each urbanization type, which could inform public debates about what type of urban growth requires "depoliticizing" and how to regulate it.

Aside from the normative discussion of if and how to depoliticize urban growth and titling, future research of urban expansion in Mexico City, and perhaps all cities, should consider politics as part-and-parcel of the urban process. Land system science has long noted that long-term projections of land change are inherently difficult because of the non-stationarity of the factors at play, which include policies and politics around, for example, zoning (Turner et al., 1995). This dissertation echoes this claim and those of others who indicate ignoring this dimension of cities means failing to study a major component of this social-ecological system (Eakin et al., 2017).

Drug trafficking and deforestation in Central America

Chapter 4 demonstrated not only that drug trafficking has a causal effect of forest loss in the region, but that this signal can be detected through media data. Yet because Chapter 4 used a fixed effects model, and the proxy of narcotrafficking was media data, assessing the total deforested area was not possible. Interpreting the coefficient relationships are difficult because, although the model may estimate the relationship between one additional media report of narcotrafficking and forest loss, the error and variance are subsumed in the year and unit fixed effects. A model that could predict forest vulnerability as cocaine trafficking increases would be more useful for policy assessments. Such a model, however, would require collecting data on difficult to measure conditions, such as the amount of money needed for laundering, competition with other cartels, the likelihood of interdiction, and the local economic conditions of each department and country. If these variables were available, a model of cocaine trafficking and forest vulnerability could be constructed in future work.

Chapter 4, together with recent research on the complex adaptive nature of cartels because of the interdiction policy employed by the United States (Magliocca et al., 2019), raises questions about the ecological consequences of the current war on drugs. Future work to build an agent based model (ABM) to examine cartel decision making of where and how much to clear forested lands in response to this interdiction could examine this relationship. My dissertation research and the previous published efforts noted inform my hypothesis that increasingly militarization against cartels forces their activities into more remote and forested regions, and has an indirect causal effect on forest loss. This hypothesis, with policy implications beyond those of my dissertation, should be tested in future work.

Recommendations and a research agenda

This dissertation informs a research agenda for the study of clandestine activities in forest and urban systems. Recommendations for future work include efforts to improve spatial and temporal resolution of pixelizable social and land-use data, cumulating additional case studies to facilitate middle-range theory building, and studying the feedback loops between economic and political rent seeking.

Discussions in chapters 3-5 and this conclusion, like most quantitative research, call for more data to explore additional findings. Specifically, an annual urban time series (but at very high spatial resolution, ca. 2m or less), akin to the Hansen's (2013) annual forest loss data, is needed to support both socializing and pixelizing efforts. In Mexico City, such a dataset could allow for the many aforementioned research questions, including pattern analysis, ecosystem service assessments, the political business cycle of urban expansion, and more. A second data effort would require developing a methodology of automating spatial-temporal time series of media data, to create proxies of narcotrafficking and other illicit activity. This automation would increase sample size, save time and money, and is possible as increasing amounts of media are aggregated into databases such as GDELT (GDELT, 2018). Finally, increasing the sample size and estimating other variables that influence land change in these regions could facilitate multi-level or geographically weighted regression models to could better estimate the effects of clandestine activity on land outcomes.

To develop the middle-range theory on which LSS is based (Chowdhury and Turner II, 2019; Meyfroidt et al., 2018), the incorporation of electoral politics relating to inform settlements and urban land systems requires studying a wide range of cities, especially in the Global South where informality is commonplace. For example, experts in each city could identify the types of informality (similar to Chapter 2) and develop ABMs (preferably a standardized model) to simulate land patterns. Methods to synthesize cases to develop process based land change models have already been developed and could be applied to informal urban land systems (Magliocca et al., 2015; 2014). These case studies could also be used to test new rules of thumb for urban simulation models, like SLUETH (Chaudhuri and Clarke, 2013), that struggle to capture patterns of growth in cities in the Global South (Pontius et al., 2008). Comparisons of hindcast model simulations of urban growth with and without political relationships or rules of informal growth would reveal if quantifying informal transaction patterns improve model fit.

Middle-range theory to understand the role of illicit economies in land-use change requires building case studies of drug flows in other regions, and studies of other illicit commodities in frontiers. Some of comparative and theoretical work has already begun in political ecology to compare drug frontiers in Burma, West Africa, Colombia, and Central America (Ballvé, 2018). Equivalent work is needed to synthesize land system studies and cumulative knowledge on the role of drugs and other illicit economies in land outcomes (Magliocca, 2015; Magliocca et al., 2018, 2014). Better estimation of the influence of such activities on land change requires more complex models to explore synergies, spillovers, and lagged spatial and temporal effects in emerging land markets.

A final needed area of research is to understand the feedback loops between land and illicit activity. This dissertation studied illicit economic activity and clandestine political activity in separate case studies. As narcotrafficking activities increase in Central America, it may reshape political institutions and land regulation that may further encourage narcotrafficking or expand legal commodity frontiers. Likewise, in Mexico

City, the political actors who reinforce and engineer land invasions used their status to increase political power, and in some cases, became the appointed regulator of environmental conservation areas. This dissertation only examined the unidirectional "grey arrow" in Figure 1 (introduction) that connects the social system to land change outcomes. The next step is to examine the blue arrows to determine how land change mediates the power or resources of actors and organizations with power or the needs and externalities for organizations and actors with needs. Analyzing these feedbacks will require new methods to simulate or estimate the influence of land system change on actors in the action arena.

Significance of the dissertation

This dissertation contributes to LSS, political ecology, and sustainable urbanism, resource management, urban studies, and global environmental change and sustainability science. It does so by providing new analytical methods to detect and quantify the relative significance of clandestine drivers of land change not otherwise examined or heretofore detectable as well as their consumption of critical conservation land. This dissertation integrated conceptual insights from political ecology, political science, new institutional economics, and urban planning on clientelism and corruption into formal approaches to land system science, and demonstrated salience of such concepts for urbanization and deforestation. The methods employed move analysis of clandestine activity from the narrative and case observation to an analytically stronger empirical analysis.

The Mexico City case study assessed how clandestine transactions shape urban form, and in this case, serve to change conservation land and its environmental services. The results extend the important work of Mexican scholars by connecting theories about the economics and politics informal land markets (Duhau and Giglia, 2008; Flores Peña and Soto Alva, 2010; Rodríguez, 2001; C. E. Salazar, 2012; Schteingart and Salazar, 2005) with efforts to map and quantify informal settlements in Mexico City (Aguilar, 2008; Aguilar and Santos, 2011). The regression analyses yields insight into the political role of regularization that have become common in Latin America cities. The methods employed and findings have applications in many other cities globally where clandestine activities are thought to be significant drivers of urban change.

The Central American case provides a crucial step forward in understanding the links between cocaine and deforestation, recently termed narcodeforestation (Mcsweeney et al., 2014) by estimating for the first time the causal effect of narcotrafficking on forest loss. These findings may help bring together diverse actors in drug interdiction and conservation policy to work together to protect forests and the rural communities that depend on them. The methodological development of using media data to estimate causal effects of illicit activity on land use outcomes contributes to future students of other land systems.

This dissertation sheds new light on clandestine activity and bridges gaps between disciplines in ways that break new ground for the future of land systems science. In the process, it provides insights for governmental officials, non-governmental organizations, community groups, and urban residents to better understand and respond to environmental threats posed by clandestine activities.

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APPENDIX A

SUPPLEMENTARY INFORMATION, CHAPTER 2

Institutional Matrices

Table SI 1. Institutional Matrix, Ant Urbanization. Benefits in green, losses in red, and neutral or mixed outcomes in yellow. Low information/control in white, and higher information and control in darker grey

Institutional Entrepreneurs	Information	Control	Payoff in Urbanization	Payoffs in Services	Payoffs in Regularization	Payoffs in Mitigating Urbanization
Land Seller	medium	medium	pesos	none	none	violence or violating social norms
Political Group	medium or varied	medium to high	pesos, votes	pesos, votes	votes	lose constituents/money
Intermediary Service Providers	high	high	pesos	pesos	lose money, control	neutral
Government Entrepreneurs	high	high	pesos, votes	pesos, votes	lose control	lost rent-seeking opportunity
Other Actors						
Residents	low	low	affordable land	fulfills need	tenure security, formal services	decrease access to affordable land
Local Government	medium	high	votes, taxes	votes	lose control	lose votes, pesos
Other Community/Ejido Members	medium	medium	lose communal land	neutral	mixed	break familial ties
Ministry of Environment	high	medium	lose conservation land	lose conservation land	mixed	political prestige

Table SI 2. Institutional Matrix, Subdivision. Benefits in green, losses in red, and neutral or mixed outcomes in yellow. Low information/control in white, and higher information and control in darker grey. *indicates assumed from other evidence (media or literature, not directly stated in interviews). No evidence states where no sources are available.

Institutional Entrepreneurs	Information	Control	Payoff in Urbanization	Payoffs in Services	Payoffs in Regularization	Payoffs in Mitigating Urbanization
Land owner	varies, medium	varies, medium	pesos	neutral	pesos	neutral
Land Purchaser/Flipper	high	high	pesos	neutral	neutral	can go to jail- buts its rare
Political Group	medium	high	mostly votes, some pesos	mostly votes, some pesos	votes	mixed (can use as a tool against others)
Government Entrepreneurs	no evidence	medium	mostly votes	pesos, votes	pesos	pesos
Other Actors						
Residents	low	low	affordable land- (or because of access to credit) but opportunity cost sometimes to political org	fulfills need	tenure security, formal services, increase land value	lost home, anxiety/stress, having to move
Local Government	low	medium	votes, taxes	votes	mixed- can help get more taxes	lose votes
Community/Ejido Members	medium	medium	mixed- those who sell make some money. many others lose	neutral	neutral	lose money
Ministry of Environment	high	medium	lose conservation land*	lose conservation land*	no evidence	political prestige*

Table SI 3. Institutional Matrix, Invasion. Benefits in green, losses in red, and neutral or mixed outcomes in yellow. Low information/control in white, and higher information and control in darker grey. *indicates assumed from other evidence (media or literature, not directly stated in interviews). No evidence states where no sources are available.

Institutional Entrepreneurs	Information	Control	Payoff in Urbanization	Payoffs in Services	Payoffs in Regularization	Payoffs in Mitigating Urbanization
Land Owner	low	low	loses money	neutral	potential payment	keeps land*
Political Group	high	high	mainly votes	votes and control	neutral, some votes	mixed lose constituents/money- but can gain new ones
Inf. Service Providers	high	high	pesos	pesos	no evidence	no evidence
Government Entrepreneurs	high	high	votes, party power/advancement	pesos, votes	votes and political power	lost votes
Residents	medium	low	affordable land, but high opportunity cost	fulfills need, cheaper	tenure security, formal	decrease access to affordable land

					services, ownership	
Other actors						
Local Government	medium*	medium*	votes, taxes	votes	mixed	mixed (some use as a tool against rival parties)
Neighbors	no evidence	no evidence	reduce service provision	no evidence	neutral	mixed (some not in informal settlements think eviction should occur)
Ministry of Environment	high to medium	medium to low	lose conservation land	lose conservation land	mixed (some thinks it encourages growth)	political prestige, fulfilling mission*

Table SI 4. Institutional Matrix, Public and Social Housing. Benefits in green, losses in red, and neutral or mixed outcomes in yellow. Low information/control in white, and higher information and control in darker grey. *indicates assumed from other evidence (media or literature, not directly stated in interviews). No evidence states where no sources are available.

Institutional Entrepreneurs	Information	Control	Payoff in Urbanization	Payoffs in Services	Payoffs in Regularization (ALREADY REGULAR)
Developer	high	high	big profits	capital gains	bigger profits
Ejido President* (sometimes involved)	low	medium	some pesos, sometimes a house	land speculation- increased value	land speculation- increased value
Government Entrepreneurs	medium	high	pesos, votes, and a new municipal land use plan	no evidence	pesos
Residents	medium	medium	mixed- access to a home but house may be too far or poorly built- or owe political favors to group (time cost)	no evidence (services come with the house=neutral)	no evidence (title comes with the house= neutral)
Other Actors					
Local Government (municipalities for edomex, city for cdmx (INVI)	medium	medium	mixed- some new taxes, municipal plan, but now have burden on services	burden on services	could attract developers
Public	low	low	doesn't meeting housing demand for poor*	uses lots of resources*	neutral*
State/Federal Government?	medium	medium	mixed. political prestige for solving housing problem, but lose tax dollars because they pay developers even when house is not occupied	neutral	no evidence
Ministry of Housing	high	high	? fulfills their mission?	neutral	no evidence

Survey Instrument

This survey was approved under IRB ID STUDY00001785 for DDRI 1657773. English translation in orange text.

Para actores sociales comprando tierra: For social actors buying land:

- *Porque y cuando se mudó a esta comunidad? Why and when did you move to this community?*
- *Como se accesó a los servicios y la regularización? Cuanto tiempo se tardó? How did you access services and regularization? How long did it take?*
- *Que tan rápido creció la comunidad? How quickly did the community grow?*
- *(Si es posible) que era el precio de esta terreno? Recibió un crédito? (if it's posible) what was the Price of this parcel? Did you get credit?*
- *Es importante para ti tener una escritura legal? Is it important for you to have a legal title?*
- *Que información tenia disponible sobre este tierra antes de que se asentó aquí? Que entendió sobre el proceso de regularización? What information did you have available about this land before you settled here? What did you understand about the process of regularization?*
- *Que capital se ocupó para comprar este tierra? (social, político, o económico)? What capital did you have to buy this land? (social, political, economic)?*
- *Que instituciones te ayudó o obstaculizó el proceso de transacciones de la tierra? What institutions helped you or were an obstacle in the transactions process of the land?*
- *Que haría si fuese desalojado? What would you do if you were removed from the land?*
- *Que es su relación con los actores que vende terrenos? What is your relationship with the actors who sell parcels?*

Para actores sociales vendiendo tierra: For social actors selling land:

- *Porque se vendió este terreno? Why did you sell your land?*
- *En cuanto lo vendió? Que otros costos están asociados con este proceso? How much did you sell it for? What other costs were associated with this process?*
- *Ha sido involucrado en regularización o provisión de servicios para esta área? Cuanto tiempo se tardó? Have you been involved with regularization or provision of services for this área?*
- *Que capital se ocupó para vender/regularizar/producir los servicios aquí? What capital did you use to sell/regularize/produce services here?*
- *Cuales instituciones te ayudó o estorbó el proceso de transacciones de tierra? What institutions helped you or hindered you in the transactions process of land?*
- *Que es su relación con actores comprando terreno? What is your relation with actors buying land?*

A instituciones de gobierno formales: To formal government institutions:

- *Que es la relación de tu institución al proceso de urbanización, regularización, or provisión de servicios urbanos? What is the relationship of your institution to the process of urbanization, regularization, or provision of urban services?*
- *Como los asentamientos informales logran regularización, agua, drenaje, luz, o materiales de construcción? Cuanto tiempo tarda? How do informal settlements achieve regularization, water, drainage, electuricity, or construction materials? How long does it take?*
- *Los comunidades que aceden a servicios y regularización mas rápido- porque será? The communities that access services and regularization more quickly, why is that?*
- *Como disuade la urbanización el gobierno? (Si sí, porque?) Es el desalojo una opción? Porque sí o porque no? How does the government disuade urbanization? (if yes, why?). Is removal an option? Why or why not?*

APPENDIX B

SUPPLEMENTARY INFORMATION, CHAPTER 3

SI Table 1. Electoral timing: ejido land area. 95% Confidence intervals in brackets.

	(1) ejido area
Area expropriated	
Months til election	-0.000349
	[-0.0115,0.0108]
Alvaro Obregon	0
	[0,0]
Azcapotzalco	1.376
	[-0.277,3.028]
Coyoacan	-14.48
	[-1823.5,1794.6]
Cuajimalpa	0.703
	[-1.189,2.595]
Gustavo Madero	1.362
	[-0.240,2.963]
Iztapalapa	1.679*
	[0.114,3.243]
Magdalena Contreras	1.093
	[-0.549,2.735]
Milpa Alta	-14.99
	[-2410.4,2380.5]
Tlahuac	2.090**
	[0.545,3.636]
Tlalpan	1.404
	[-0.221,3.029]
Xochimilco	-0.0641
	[-2.099,1.971]
_cons	-4.970***
	[-6.474,-3.466]
N	616
AIC	1159.2

SI Table 2. Electoral timing private property parcels: lags and leads (in month increments) of dependent variable for robustness checks. 95% Confidence intervals in brackets.

	(1) Titles	(2) Titles lag 2	(3) Titles lead 1	(4) Titles lead 2	(5) Titles lead 3	(6) Titles lead 4
Months til Election	-0.0352***	0.0110	0.0317***	-0.0332***	0.0183*	-0.00613
	[-0.0548,-0.0156]	[-0.00898,0.0310]	[0.0136,0.0499]	[-0.0526,-0.0137]	[0.00155,0.0351]	[-0.0271,0.0149]
1997	0	0	0	0	0	0
	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]
1998	-1.113	-1.148	1.298	-1.597	1.131*	-1.870
	[-2.702,0.477]	[-2.504,0.208]	[-0.201,2.798]	[-3.764,0.569]	[0.0921,2.169]	[-3.971,0.230]

1999	-1.819* [-3.278,-0.360]	-2.472** [-4.105,-0.840]	1.212 [-0.193,2.617]	-0.109 [-1.316,1.097]	0.383 [-0.693,1.460]	0.194 [-0.908,1.295]
2000	-1.359* [-2.490,-0.228]	-1.225* [-2.223,-0.226]	0.737 [-0.523,1.997]	-0.554 [-1.752,0.644]	0.859 [-0.0928,1.811]	0.100 [-0.851,1.052]
2001	-0.962 [-1.979,0.0544]	-0.780 [-1.676,0.115]	0.743 [-0.437,1.924]	-0.165 [-1.230,0.899]	0.196 [-0.676,1.068]	-0.157 [-1.052,0.738]
2002	-1.382* [-2.625,-0.140]	-1.737* [-3.131,-0.342]	1.641* [0.334,2.948]	0.309 [-0.879,1.497]	-1.405 [-3.008,0.199]	-0.981 [-2.270,0.308]
2003	-0.706 [-1.747,0.335]	-1.297* [-2.292,-0.302]	1.612** [0.488,2.736]	0.133 [-0.941,1.207]	-0.0311 [-0.903,0.841]	-0.922 [-1.978,0.133]
2004	-0.274 [-1.246,0.698]	-0.978 [-2.036,0.0796]	0.923 [-0.252,2.099]	-0.544 [-1.692,0.604]	-0.104 [-1.048,0.840]	0.0307 [-0.897,0.958]
2005	-0.475 [-1.419,0.469]	-1.205* [-2.126,-0.284]	1.722** [0.585,2.859]	-0.505 [-1.575,0.565]	-0.514 [-1.444,0.416]	-0.246 [-1.167,0.676]
2006	-0.449 [-1.392,0.493]	-1.344** [-2.267,-0.421]	0.942 [-0.160,2.045]	-0.796 [-1.903,0.312]	0.429 [-0.438,1.296]	-1.352* [-2.430,-0.274]
2007	-0.207 [-1.132,0.718]	-0.885 [-1.788,0.0189]	0.475 [-0.726,1.675]	-0.542 [-1.653,0.570]	-0.286 [-1.211,0.638]	-0.317 [-1.215,0.582]
2008	-2.015** [-3.242,-0.788]	-0.323 [-1.232,0.586]	1.503* [0.321,2.686]	-0.778 [-1.929,0.374]	-0.810 [-1.924,0.305]	-0.464 [-1.467,0.539]
2009	-0.565 [-2.112,0.982]	-2.764** [-4.860,-0.668]	-0.928 [-3.119,1.263]	-1.310 [-3.454,0.834]	-0.493 [-2.013,1.027]	-1.613 [-3.688,0.463]
2010	-1.554** [-2.730,-0.378]	-0.388 [-1.291,0.515]	0.181 [-1.106,1.468]	-0.411 [-1.726,0.905]	-0.238 [-1.302,0.825]	-0.479 [-1.599,0.641]
2011	-1.875* [-3.303,-0.447]	-1.221* [-2.402,-0.0396]	1.591* [0.312,2.870]	-0.0764 [-1.279,1.127]	-0.495 [-1.738,0.748]	-0.538 [-1.669,0.593]
2012	-1.115* [-2.204,-0.0255]	-1.407** [-2.412,-0.401]	1.135 [-0.0644,2.335]	-0.288 [-1.594,1.019]	-0.501 [-1.601,0.600]	0.795 [-0.0689,1.658]
Alvaro Obregon	0 [0,0]	0 [0,0]	0 [0,0]	0 [0,0]	0 [0,0]	0 [0,0]
Cuajimalpa	-1.055** [-1.789,-0.320]	-1.105** [-1.852,-0.358]	-1.068** [-1.796,-0.341]	-1.000** [-1.736,-0.265]	-1.095** [-1.835,-0.356]	-0.872* [-1.607,-0.137]
Gustavo Madero	-0.602 [-1.244,0.0396]	-0.606 [-1.255,0.0427]	-0.634 [-1.279,0.0107]	-0.546 [-1.197,0.104]	-0.579 [-1.242,0.0840]	-0.428 [-1.092,0.236]
Iztapalapa	-1.523*** [-2.293,-0.753]	-1.585*** [-2.374,-0.797]	-1.546*** [-2.310,-0.782]	-1.488*** [-2.260,-0.716]	-1.734*** [-2.529,-0.938]	-1.466*** [-2.255,-0.676]
Magdalena Contreras	-1.131** [-1.857,-0.405]	-1.119** [-1.843,-0.394]	-1.156** [-1.876,-0.436]	-1.164** [-1.908,-0.420]	-1.330*** [-2.074,-0.587]	-1.099** [-1.839,-0.358]
Tlahuac	-1.369*** [-2.174,-0.564]	-1.326** [-2.135,-0.517]	-1.425*** [-2.225,-0.626]	-1.501*** [-2.333,-0.668]	-1.620*** [-2.456,-0.783]	-1.348** [-2.180,-0.515]
Tlalpan	-1.263*** [-1.985,-0.541]	-1.378*** [-2.107,-0.649]	-1.334*** [-2.046,-0.622]	-1.222*** [-1.942,-0.502]	-1.425*** [-2.145,-0.705]	-1.078** [-1.801,-0.355]
Xochimilco	0.166 [-0.450,0.783]	0.232 [-0.394,0.857]	0.204 [-0.422,0.829]	0.211 [-0.412,0.833]	0.149 [-0.479,0.778]	0.251 [-0.372,0.873]

_cons	-0.106 [-1.213,1.001]	-0.678 [-1.735,0.378]	-3.224*** [-4.501,-1.946]	-0.595 [-1.810,0.620]	-1.723*** [-2.729,-0.717]	-1.147* [-2.258,-0.0360]
N	438	422	430	422	414	406
AIC	2026.8	1994.1	2033.9	1988.9	1969.3	1940.5

*note model did not converge for lag1

SI Table 3. Electoral timing private property, area: lags and leads (in months increments) of dependent variable for robustness checks. 95% Confidence intervals in brackets.

	(1) Titles	(2) Titles lag 2	(3) Titles lead 1	(4) Titles lead 2	(5) Titles lead 3	(6) Titles lead 5	(7) Titles lead 6
Months til Election	-0.0354***	-0.00499	0.0349***	-0.0349***	0.0234**	0.0264**	0.0122
	[-0.0555,-0.0153]	[-0.0240,0.0140]	[0.0167,0.0530]	[-0.0549,-0.0150]	[0.00618,0.0406]	[0.00762,0.0451]	[-0.00869,0.0331]
1997	0	0	0	0	0	0	0
	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]
1998	-1.406	1.356	1.359	-1.878	1.328*	1.413**	-0.119
	[-3.020,0.208]	[-0.917,3.629]	[-0.166,2.885]	[-4.023,0.268]	[0.241,2.415]	[0.366,2.461]	[-2.408,2.171]
1999	-2.193**	1.616	1.449*	-0.249	0.554	-1.256	1.593
	[-3.683,-0.703]	[-0.519,3.751]	[0.0852,2.812]	[-1.427,0.929]	[-0.545,1.654]	[-2.633,0.121]	[-0.0984,3.285]
2000	-1.638**	0.491	0.840	-0.879	0.925	-0.443	0.874
	[-2.800,-0.477]	[-1.675,2.657]	[-0.427,2.108]	[-2.049,0.291]	[-0.0550,1.905]	[-1.407,0.522]	[-0.554,2.301]
2001	-1.356*	1.172	0.764	-0.340	0.183	-1.734**	1.436*
	[-2.393,-0.319]	[-0.888,3.232]	[-0.424,1.951]	[-1.345,0.666]	[-0.709,1.076]	[-2.823,-0.645]	[0.148,2.724]
2002	-1.622*	1.505	1.671*	-0.0742	-1.378	-0.356	1.963**
	[-2.893,-0.351]	[-0.625,3.635]	[0.355,2.986]	[-1.244,1.096]	[-2.993,0.237]	[-1.450,0.737]	[0.549,3.377]
2003	-1.050	1.285	1.678**	-0.146	0.202	-0.296	0.568
	[-2.134,0.0343]	[-0.768,3.338]	[0.548,2.808]	[-1.177,0.885]	[-0.692,1.097]	[-1.133,0.542]	[-0.800,1.937]
2004	-0.444	0.721	0.952	-0.621	0.0851	-1.983*	1.289
	[-1.427,0.540]	[-1.431,2.872]	[-0.230,2.133]	[-1.725,0.483]	[-0.877,1.047]	[-3.506,-0.460]	[-0.0755,2.653]
2005	-0.758	1.334	1.760**	-0.714	-0.460	-0.487	1.709**
	[-1.735,0.220]	[-0.698,3.365]	[0.619,2.900]	[-1.738,0.310]	[-1.408,0.489]	[-1.354,0.380]	[0.415,3.003]
2006	-0.786	1.931	1.157*	-1.066	0.627	-0.0372	1.394*
	[-1.763,0.191]	[-0.0898,3.951]	[0.0442,2.269]	[-2.137,0.00511]	[-0.276,1.531]	[-0.881,0.806]	[0.102,2.686]
2007	-0.545	1.615	0.491	-0.763	-0.278	0.00698	1.017
	[-1.495,0.406]	[-0.425,3.655]	[-0.715,1.697]	[-1.826,0.300]	[-1.220,0.665]	[-0.792,0.806]	[-0.302,2.336]
2008	-2.363***	2.272*	1.491*	-0.957	-0.617	-0.320	0.869
	[-3.614,-1.113]	[0.240,4.304]	[0.302,2.679]	[-2.070,0.155]	[-1.708,0.475]	[-1.253,0.612]	[-0.519,2.257]
2009	-0.853	0.180	-0.909	-1.501	-0.645	-0.691	1.776*
	[-2.422,0.716]	[-2.594,2.954]	[-3.103,1.285]	[-3.619,0.618]	[-2.195,0.904]	[-1.973,0.590]	[0.340,3.212]
2010	-1.761**	0.935	0.310	-0.697	-0.285	0.498	2.061**
	[-2.950,-0.572]	[-1.188,3.057]	[-0.984,1.604]	[-1.982,0.588]	[-1.366,0.797]	[-0.372,1.369]	[0.737,3.385]
2011	-2.203**	-0.115	1.653*	-0.417	-0.421	0.502	0.376
	[-3.651,-0.755]	[-2.536,2.306]	[0.359,2.947]	[-1.587,0.754]	[-1.684,0.841]	[-0.462,1.466]	[-1.292,2.044]
2012	-1.295*	1.903	1.384*	-0.529	-0.318	-1.451*	1.884**

	[-2.394,-0.196]	[-0.137,3.943]	[0.178,2.591]	[-1.799,0.740]	[-1.378,0.743]	[-2.609,-0.292]	[0.575,3.192]
Alvaro Obregon	0	0	0	0	0	0	0
	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]
Cuajimalpa	-1.145***	-1.101**	-1.248***	-1.082**	-1.285***	-1.095**	-1.054**
	[-1.815,-0.475]	[-1.773,-0.429]	[-1.917,-0.579]	[-1.755,-0.410]	[-1.965,-0.606]	[-1.792,-0.399]	[-1.766,-0.342]
Gustavo Madero	-0.695*	-0.686*	-0.697*	-0.501	-0.578	-0.583	-0.236
	[-1.281,-0.109]	[-1.273,-0.100]	[-1.297,-0.0972]	[-1.098,0.0958]	[-1.192,0.0352]	[-1.226,0.0606]	[-0.864,0.392]
Iztapalapa	-1.420***	-1.556***	-1.562***	-1.418***	-1.738***	-1.406***	-1.410***
	[-2.119,-0.722]	[-2.272,-0.840]	[-2.262,-0.861]	[-2.120,-0.716]	[-2.467,-1.009]	[-2.134,-0.677]	[-2.157,-0.663]
Magdalena Contreras	-1.051**	-1.075**	-1.189***	-1.155***	-1.335***	-1.249***	-1.168**
	[-1.719,-0.382]	[-1.745,-0.406]	[-1.858,-0.521]	[-1.841,-0.468]	[-2.028,-0.642]	[-1.963,-0.535]	[-1.899,-0.437]
Tlahuac	-1.376***	-1.360***	-1.553***	-1.513***	-1.744***	-1.650***	-1.515***
	[-2.089,-0.662]	[-2.074,-0.646]	[-2.273,-0.834]	[-2.254,-0.772]	[-2.497,-0.990]	[-2.430,-0.871]	[-2.322,-0.709]
Tlalpan	-1.158***	-1.351***	-1.352***	-1.122**	-1.428***	-1.095**	-1.064**
	[-1.831,-0.485]	[-2.033,-0.669]	[-2.024,-0.681]	[-1.796,-0.449]	[-2.107,-0.748]	[-1.779,-0.410]	[-1.760,-0.368]
Xochimilco	0.0866	-0.00488	-0.0672	0.0586	-0.0543	0.265	0.302
	[-0.468,0.641]	[-0.562,0.552]	[-0.629,0.495]	[-0.504,0.621]	[-0.627,0.518]	[-0.325,0.856]	[-0.290,0.895]
_cons	-0.569	-3.579***	-3.991***	-1.059	-2.559***	-2.376***	-3.892***
	[-1.698,0.561]	[-5.656,-1.502]	[-5.246,-2.736]	[-2.227,0.109]	[-3.563,-1.555]	[-3.352,-1.401]	[-5.316,-2.468]
N	440	432	432	424	416	400	392
AIC	4045.6	4006.4	4020.0	3940.9	3893.1	3702.9	3548.8

*note model did not converge for lead 4

SI Table 4. Private property title distribution: patronage, competition? borough election lags and leads (in election increments) of dependent variable for robustness checks. 95% Confidence intervals in brackets.

	(1) # lots	(2) # lots	(3) # lots lead 1	(4) # lag 1	(5) area titled m2	(6) area titled lag1
main support for prd	1.603					
	[-0.618,3.825]					
2000 election	0	0	0		0	
	[0,0]	[0,0]	[0,0]		[0,0]	
2003 election	0.474	0.356	1.016***	0	0.338	0
	[-0.0414,0.989]	[-0.189,0.902]	[0.586,1.446]	[0,0]	[-0.206,0.882]	[0,0]
2006 election	1.490***	1.375***	0.0485	0.574*	1.353***	0.553*
	[0.944,2.036]	[0.808,1.942]	[-0.517,0.614]	[0.0562,1.091]	[0.792,1.914]	[0.0364,1.070]
2009 election	0.746**	0.732**	-1.956***	1.741***	0.733**	1.741***
	[0.255,1.236]	[0.246,1.218]	[-2.764,-1.148]	[1.288,2.194]	[0.248,1.219]	[1.288,2.193]
2012 election	-1.551***	-1.402**		0.862***	-1.403**	0.876***
	[-2.454,-0.649]	[-2.246,-0.559]		[0.364,1.359]	[-2.246,-0.559]	[0.380,1.372]

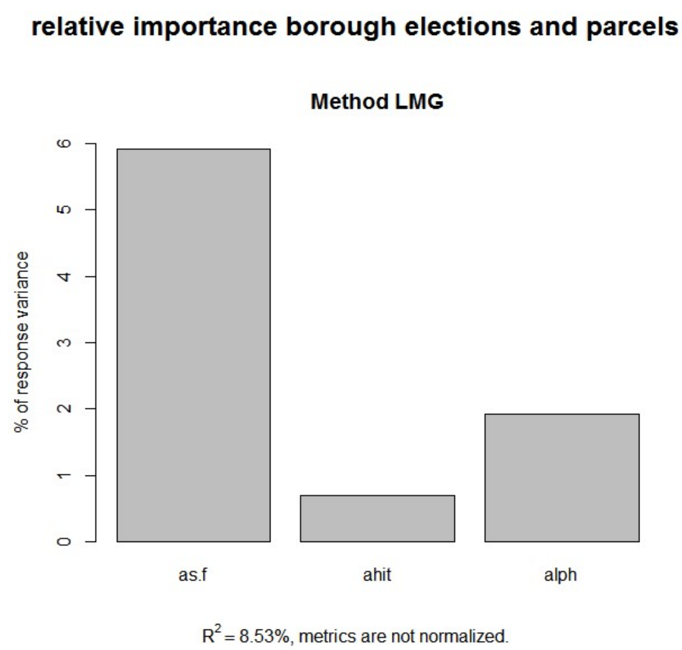
Cuajimalpa	0 [0,0]	0 [0,0]	0 [0,0]	0 [0,0]	0 [0,0]	0 [0,0]
Gustavo Madero	-2.385* [-4.486,-0.284]	-2.508* [-4.595,-0.421]	-14.87 [-1094.3,1064.6]	-2.571* [-4.664,-0.478]	-2.508* [-4.569,-0.447]	-2.665* [-4.731,-0.600]
Iztapalapa	-0.901 [-1.969,0.167]	-0.990 [-2.066,0.0858]	-0.454 [-1.576,0.669]	-1.557* [-2.897,-0.216]	-0.830 [-1.857,0.197]	-1.467* [-2.770,-0.164]
Magdalena Contreras	-15.08 [-1279.2,1249.1]	-14.89 [-1187.3,1157.5]	-22.43 [-62795.4,62750.5]	-16.73 [-3043.0,3009.5]	-28.24 [-943930.5,943874.0]	-17.67 [-4684.8,4649.5]
Alvaro Obregon	-0.903 [-2.256,0.450]	-0.953 [-2.306,0.400]	-1.031 [-2.645,0.583]	-0.945 [-2.299,0.408]	-1.135 [-2.434,0.164]	-1.151 [-2.451,0.149]
Tlahuac	-31.23 [-4206444.1,4206381.6]	-16.47 [-2550.9,2518.0]	-20.29 [-20043.9,20003.3]	-30.13 [-2395428.0,2395367.8]	-38.12 [-97363918.4,97363842.1]	-28.56 [-955021.8,954964.7]
Tlalpan	-1.739* [-3.071,-0.406]	-1.804** [-3.139,-0.469]	-1.785* [-3.376,-0.195]	-1.743* [-3.077,-0.409]	-1.776** [-3.075,-0.476]	-1.757** [-3.056,-0.459]
Xochimilco	-0.547 [-1.362,0.268]	-0.629 [-1.455,0.197]	-0.561 [-1.495,0.374]	-0.512 [-1.330,0.307]	-0.711 [-1.489,0.0662]	-0.701 [-1.472,0.0709]
margin of win		1.429 [-0.0449,2.903]	0.804 [-0.754,2.361]	0.128 [-1.545,1.802]	1.469* [0.0209,2.918]	0.218 [-1.432,1.868]
_cons	-4.254*** [-5.494,-3.015]	-3.681*** [-4.450,-2.912]	-3.122*** [-3.934,-2.310]	-3.537*** [-4.415,-2.660]	-4.795*** [-5.528,-4.061]	-4.571*** [-5.414,-3.729]
N	1060	1060	796	832	1065	836
AIC	1100.2	1098.5	826.3	1004.7	1677.4	1544.8

SI Table 5. Private Property Title Distribution: patronage, competition? Legislature Lags and leads. 95% Confidence intervals in brackets.

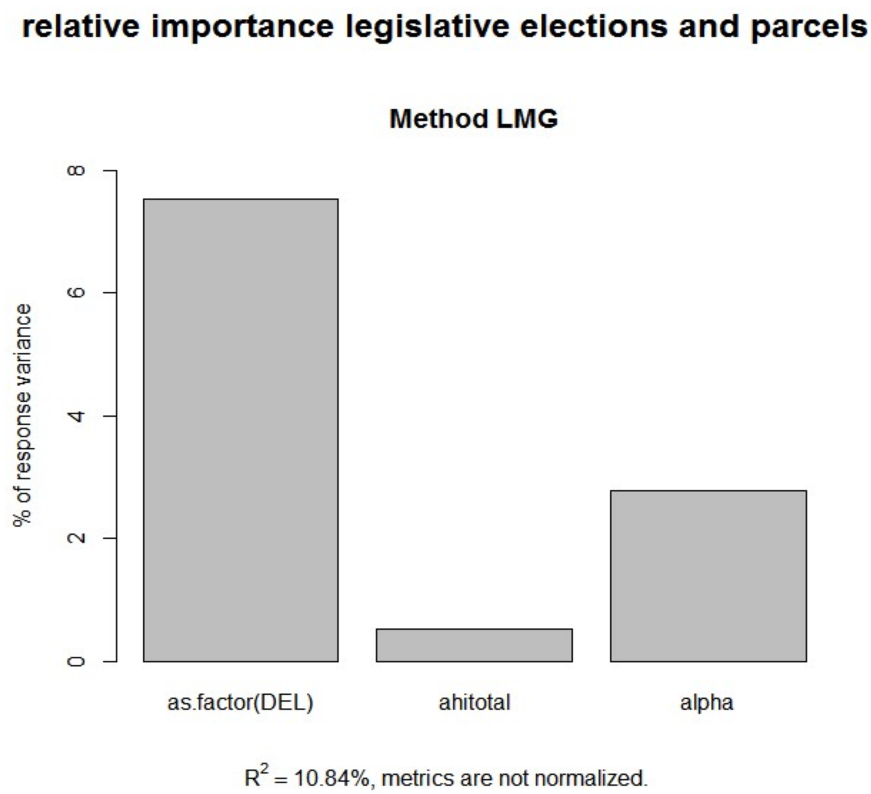
	(1) number of lots
parcelsum_0	
support for prd	-0.416 [-5.280,4.447]
2000 election	0 [0,0]
2006 election	2.246*** [1.014,3.477]
2009 election	1.112** [0.295,1.929]
2012 election	-2.234* [-4.302,-0.165]

Cuajimalpa	0
	[0,0]
Gustavo Madero	-0.965
	[-3.516,1.586]
Iztapalapa	-13.79
	[-4013.6,3986.0]
Magdalena Contreras	-13.91
	[-2927.9,2900.1]
Alvaro Obregon	-0.351
	[-2.852,2.149]
Tlahuac	-18.57
	[-15486.3,15449.1]
Tlalpan	-20.47
	[-32690.8,32649.9]
Xochimilco	0.568
	[-1.045,2.181]
_cons	-4.108**
	[-6.704,-1.513]
N	348
AIC	323.4

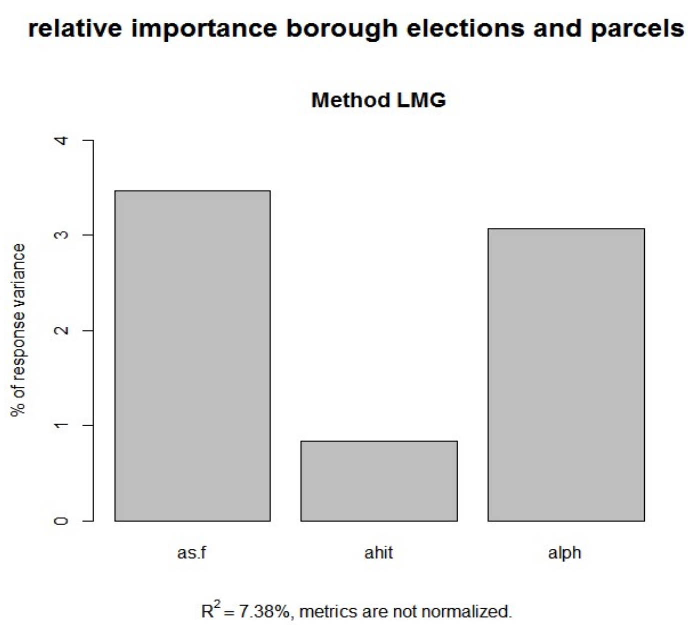
95% confidence intervals in brackets
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$



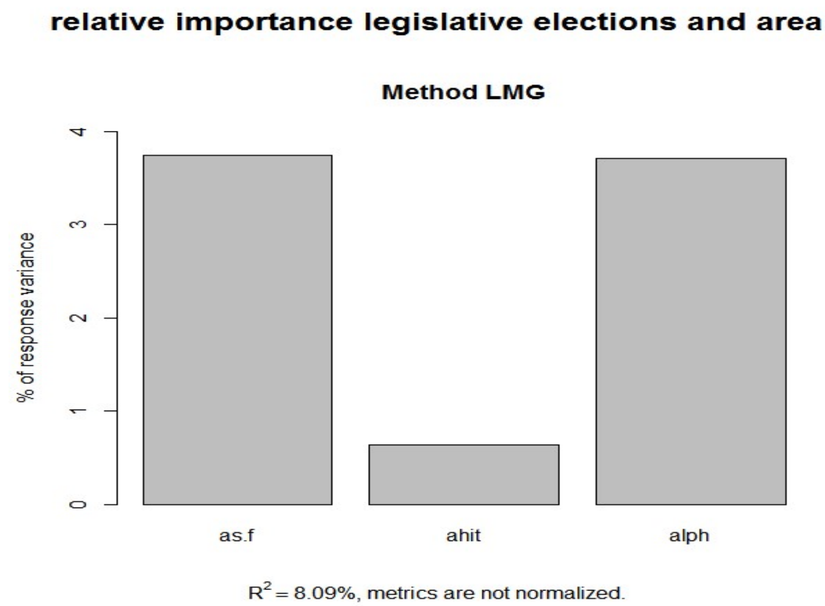
SI Figure 1. Variable importance plots, Core voter models, borough elections and # of titles. As.f= borough. Ahit= area of irregular settlement. Alph=alpha



SI Figure 2. Variable importance plots, Core voter models, legislative elections and # of titles**.** As.factor(DEL)= borough. Ahitotal= area of irregular settlement. Alpha=alpha



SI Figure 3. Variable importance plots, Core voter models, borough elections and area. As.f= borough. Ahi= area of irregular settlement. Alph=alpha



SI Figure 4. Variable importance plots, Core voter models, legislative elections and area**.** As.f= borough. Ahi= area of irregular settlement. Alph=alpha.

SI Table 6. Informal Urban Expansion: patronage or competition? Borough Lags and leads, negative binomial distribution. 95% confidence interval in brackets.

	(1) Expansion	(2) Expansion lag 1	(3) Expansion lead 1	(4) Expansion
Margin of Win	-0.997**	0.559	-0.562	
	[-1.598,-0.397]	[-0.247,1.365]	[-1.404,0.280]	
2006 election	0		0	0
	[0,0]		[0,0]	[0,0]
2009 election	-1.109***	0	0.314**	-0.903***
	[-1.306,-0.913]	[0,0]	[0.0874,0.540]	[-1.091,-0.715]
2012 election	-0.767***	-1.021***	0.0438	-0.558***
	[-0.966,-0.567]	[-1.188,-0.854]	[-0.200,0.288]	[-0.720,-0.396]
2015 election	-1.107***	-0.602***		-0.749***
	[-1.333,-0.881]	[-0.772,-0.431]		[-1.089,-0.409]
Cuajimalpa	0	0	0	0
	[0,0]	[0,0]	[0,0]	[0,0]
Gustavo Madero	0.805**	0.638*	1.267***	0.796**
	[0.312,1.297]	[0.0513,1.225]	[0.638,1.897]	[0.298,1.294]
Iztapalapa	-1.147**	-1.670***	-1.612*	-1.387***
	[-1.900,-0.394]	[-2.564,-0.775]	[-2.861,-0.362]	[-2.150,-0.624]
Magdalena Contreras	-1.052***	-1.534***	-0.614	-1.235***
	[-1.625,-0.478]	[-2.226,-0.841]	[-1.380,0.151]	[-1.829,-0.641]
Milpa Alta	0.719*	0.669	0.903*	0.619*
	[0.147,1.292]	[-0.0484,1.387]	[0.191,1.615]	[0.0421,1.196]

Alvaro Obregon	0.820***	0.981***	0.873**	0.907***
	[0.377,1.263]	[0.452,1.510]	[0.317,1.429]	[0.459,1.355]
Tlahuac	1.028***	1.033***	1.219***	1.047***
	[0.581,1.476]	[0.503,1.564]	[0.655,1.782]	[0.599,1.495]
Tlalpan	0.181	0.441	0.449	0.0718
	[-0.267,0.628]	[-0.0986,0.981]	[-0.113,1.011]	[-0.385,0.528]
Xochimilco	0.777***	0.494	1.130***	0.628**
	[0.351,1.203]	[-0.00489,0.993]	[0.578,1.681]	[0.196,1.061]
PRD vote				0.319
				[-0.536,1.175]
_cons	-0.501*	-0.643**	-1.753***	-1.032***
	[-0.942,-0.0604]	[-1.110,-0.177]	[-2.339,-1.167]	[-1.641,-0.423]
N	1092	798	759	1092
AIC	12908.2	8575.1	7982.8	12918.3

95% confidence intervals in brackets
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

SI Table 7. Informal Urban Expansion: patronage or competition? Legislature. Lags and leads, negative binomial distribution. 95% confidence interval in brackets.

	(1) Expansion	(2) Expansion	(3) Expansion lag 1	(4) Expansion lead 1	(5) Expansion lead2
Margin of Win	-0.0878				
	[-0.745,0.570]				
2006 election	0	0		0	0
	[0,0]	[0,0]		[0,0]	[0,0]
2009 election	-0.957***	-0.430**	0	0.812***	-0.00730
	[-1.190,-0.723]	[-0.750,-0.109]	[0,0]	[0.406,1.219]	[-0.502,0.488]
2012 election	-0.579***	-0.205	-1.094***	0.435*	
	[-0.769,-0.389]	[-0.460,0.0494]	[-1.278,-0.909]	[0.104,0.766]	
2015 election	-0.882***	-0.114	-0.527***		
	[-1.140,-0.625]	[-0.552,0.325]	[-0.751,-0.303]		
Cuajimalpa	0	0	0	0	0
	[0,0]	[0,0]	[0,0]	[0,0]	[0,0]
Gustavo Madero	0.796**	0.948***	0.751*	1.555***	1.140*
	[0.300,1.291]	[0.445,1.450]	[0.147,1.355]	[0.918,2.192]	[0.148,2.132]
Iztapalapa	-1.287***	-1.585***	-1.665***	-1.847**	-0.658
	[-2.040,-0.534]	[-2.348,-0.822]	[-2.569,-0.761]	[-3.105,-0.589]	[-2.312,0.997]
Magdalena Contreras	-1.137***	-1.344***	-1.524***	-0.753	-0.347
	[-1.711,-0.563]	[-1.927,-0.761]	[-2.227,-0.822]	[-1.523,0.0174]	[-1.450,0.757]
Milpa Alta	0.682*	0.530	0.700	0.823*	0.567
	[0.106,1.259]	[-0.0508,1.110]	[-0.0252,1.426]	[0.0955,1.550]	[-0.539,1.673]
Alvaro Obregon	0.909***	0.952***	0.966***	0.982***	0.588
	[0.464,1.355]	[0.503,1.401]	[0.433,1.499]	[0.423,1.540]	[-0.294,1.469]
Tlahuac	1.075***	1.073***	1.067***	1.316***	1.563***
	[0.625,1.526]	[0.619,1.527]	[0.529,1.606]	[0.745,1.887]	[0.666,2.461]
Tlalpan	0.141	-0.0159	0.419	0.390	0.432

	[-0.311,0.593]	[-0.475,0.443]	[-0.140,0.978]	[-0.182,0.962]	[-0.471,1.336]
Xochimilco	0.701**	0.576**	0.520*	1.001***	1.442**
	[0.270,1.132]	[0.144,1.009]	[0.0118,1.028]	[0.446,1.555]	[0.572,2.312]
PRD vote		1.926***	0.828	1.614*	0.549
		[0.880,2.971]	[-0.292,1.949]	[0.159,3.069]	[-1.196,2.294]
_cons	-0.852***	-1.964***	-0.825**	-2.920***	-2.031**
	[-1.310,-0.394]	[-2.679,-1.249]	[-1.393,-0.257]	[-3.894,-1.945]	[-3.405,-0.656]
N	1091	1091	797	758	478
AIC	12898.9	12885.9	8554.7	7959.4	3912.0

SI Table 8. Informal Urban Expansion: patronage or competition? Legislature. Lags and leads, Poisson distribution with standard error correction. 95% confidence interval in brackets.

	(1) lag1	(2) lead1	(3) lag1	(4) lead1
Margin of Win	0.723***	-1.097***		
	[0.714,0.732]	[-1.110,-1.085]		
2009 election	0	0.160***	0	0.432***
	[0,0]	[0.157,0.164]	[0,0]	[0.427,0.438]
2012 election	-1.238***	0.408***	-1.190***	0.608***
	[-1.240,-1.236]	[0.406,0.411]	[-1.192,-1.188]	[0.603,0.612]
2015 election	-0.699***		-0.800***	
	[-0.701,-0.697]		[-0.802,-0.797]	
PRD vote			-0.187***	0.0586
			[-0.203,-0.171]	[0.0386,0.0786]
N	797	758	797	758
AIC	2193480.3	3764476.4	2219483.7	3794288.5

SI Table 9. Informal Urban Expansion: patronage or competition? Legislature. Lags and leads, Poisson distribution with standard error correction. 95% confidence interval in brackets.

	(1) lag1	(2) lead1	(3) lag1	(4) lead1
main				
Margin of Win	-0.378***	-0.654***		

	[-0.387,-0.369]	[-0.665,-0.643]		
2009.year	0	0.305***	0	0.670***
	[0,0]	[0.302,0.308]	[0,0]	[0.667,0.672]
2012.year	-1.224***	0.437***	-1.165***	0.668***
	[-1.226,-1.222]	[0.434,0.440]	[-1.167,-1.164]	[0.666,0.670]
2015.year	-0.820***		-0.924***	
	[-0.821,-0.818]		[-0.928,-0.920]	
2006.year		0		0
		[0,0]		[0,0]
PRD vote			-0.553***	2.526***
			[-0.567,-0.539]	[2.507,2.545]
N	798	759	798	759
AIC	2217653.0	3782360.0	2218531.2	3730045.3

APPENDIX C

SUPPLEMENTARY INFORMATION, CHAPTER 4

Methods

General Approach, Country Media Analysis Method:

Articles were selected and coded using the following steps.

1) Find search engines in leading national newspapers (see table 1) and using the Bribes, Bullets and Intimidation book.
2) Search using keywords from list below
3) For each keyword combination include a year (2000-2017) and repeat the keyword search using each individual year.
4) Repeat for each year with the keyword
5) In separate meta search spreadsheet record the number of search results for the keyword and year combination.
6) For each article, key attributes of each discrete event are recorded in a spreadsheet. One entry is recorded for each place and time mentioned in the article. For example, one article that mentions a drug landing in three locations will have three separate entries. The article date, event date, and locations including: country, department/province, municipality, aldea/canton/village are recorded. GADM administrate level 1 was coded for each department and level 2 for each municipality per country.
7) Additional attributes including the names of any narco traffickers or drug trafficking organizations listed in the article, X, Y, and Z are recorded.
8) Additional notes about the article are also captured (including if the event contained violence, the size of cocaine reported, if the movement was land, air, or marine based, the name of the cartels or individuals involved, and other ancillary data)

Key words:

Narco pista Narcopista, Pista Clandestina[26]*, Narco avioneta, Narco ganad* (Narco ganadería, Narco ganadero, Narco ganado), Narco Incauta* (incautado or incuatan), Narco Soborno* o Coima Droga, Narco lancha, Narco playa, Narco barco, *Narco submarino,* Narco lavado, Narco minería, Narco vida silvestre, Narco Palma Africana, Narco Incauta (incautado or incuatan should both get picked up by this abbreviated verb), Cocaína decomisada , Cocaína incauta, Narco lavado. , Narco Blanqueo. , Narco Legitimación de capitales, Narco Bodega, Narco Mar , Narco Océano, Narco Costa, Narco Puerto, Pesca con narco o cocaína

Duplicate check

No duplicate articles were added, and a 2nd analyst reviewed all entries and removed any redundancies.

Guatemala Media Database Notes

No online newspaper database exists for Guatemala. The country's leading paper, *The Prensa Libre,* has a complete online searchable database from 2015 to the present, and incomplete archived entries before then. Therefore, the Guatemalan search is comprised of a a) digital online search for 2015 (and includes incomplete records for other years as well) and b) a manual search in the archives of the National Library of Guatemala for 2000-2014. A Guatemalan consultant was hired to access the hemeroteca of the National Library in Guatemala to obtain hardcopies of the *Prensa Libre*. The consultant used the key words to identify articles of interest and:

[26] *For landing strip key words, convention for the local newspaper was used once common usage in the country was identified*

1. took photographs of those articles containing narco-events to create a digital database of articles. There are a total of 1014 entries.
2. Analyzed and entered information into the database for these narco – events *that had a listed amount of incautaciones,* n = 576.

News articles indicating less than 1 kg of cocaine seized, a focus on heroin or crack cocaine, or other indications that an event was "street level" drug dealing were removed from the database for this analysis.

Representation Analysis

Media reporting has a potential for a strong spatial bias towards urban areas, and the potential for underreporting an illicit activity. Journalists have been targeted in particular by narcotrafficking organizations in Central America, and may be hesitant to report if they are threatened. Some newspapers are also controlled by elite political or economic families who are involved in narcotrafficking themselves, which could bias reporting away from some areas.

To address this, the spatial distribution of media data was compared to an expected probability of narcotrafficking based on the GLOBE method to analyze representativeness (Schmill et al., 2014). The GLOBE method is aimed at understanding sampling bias to ensure the sample is representative of a global phenomenon by testing if the sample is drawn from the same distribution. The sample (in our case, media counts per location) is compared to an expected probability based on an independent dataset of the expected distribution. The probability data is then discretized into bins, and the histogram of this distribution compared to the histogram of the sample. chi-squared, f-divergence, and the Kolomogorov-Smirnov test can then be used to compare distributions or reweight the sample data. However, given that we do not know the expected distribution of narcotrafficking to narcosuitability- other than that we expect it to be positively correlated- we do not make use of statistical tests or outputs to reweight the media data. However, the graphs comparing distributions are useful for a better qualitative understanding of the bias in the media data for each country.

Narcosuitability

This narcosuitability surface- which we expect to predict increased narcotrafficking activity- was used previously in the agent based model in Magliocca et al (2019). It is a combination of 30 meter raster data layers, based on assumptions of conditions for narcotrafficking from the authors of that paper. Narcosuitability ranges from 0-1 and is assumed to be a function of proximity to country borders, remoteness, tree cover, market access, slope, protected area status, and suitability of existing land use (Table S1). Risk of interdiction and increase in cocaine value were highest at border crossings, making these strategic locations for trafficking nodes (i.e., high suitability). In general, remote locations (using population density and market access as proxies) and locations with more tree cover were more suitable because of reduced risk of detection. Slope negatively influenced the suitability of the location for a given land-use (licit or illicit) and/or airstrips. Protected areas were considered suitable because detection risk is low and/or governance is often weak. Finally, land cover types classified as shrubs, trees, and pasture were rated highly suitable, whereas all other land uses (e.g., built-up areas, row crops, established plantations) were deemed unsuitable.

The 30m resolution narcosuitability surface scores were aggregated using the mean at the municipal level for each country (using GADM). Departments were too large in area- and the mean narcosuitability scores were quite similar. Smaller municipalities had a larger variation in mean narcosuitability scores in the aggregation process. The distribution of mean municipal narcosuitability was then discretized into 15 data bins for each country using equal frequency. The sum of media accounts per municipality (note that this represents a smaller subset of the media data, since many articles did not contain municipal information) were then aggregated into the 15 narcosuitability bins. We plotted the histogram of the narcosuitability bins and corresponding number of articles for each country (below) to aid interpretation of the media data quality and understand bias. Note that the line represents the number of media articles per bin. The width of the bins represents the range of narcosuitability scores to calculate the number of municipalities in that bin for that country.

CCDB Seizures Data

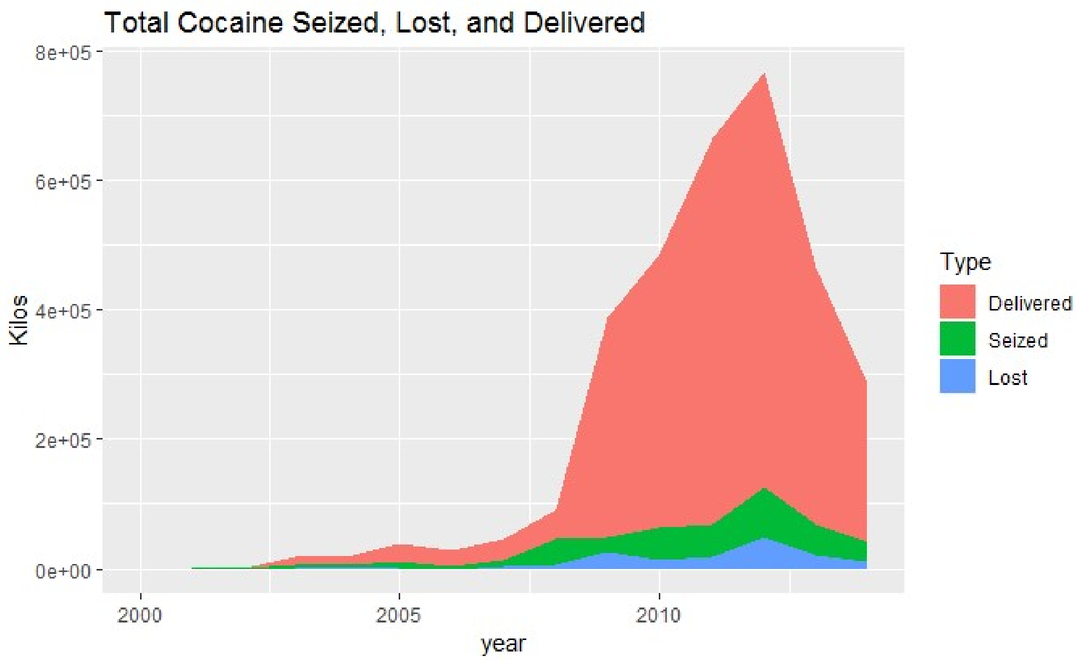


Figure S1. Kilos of cocaine total seized, lost, and delivered from 2001-2014 in Central America.

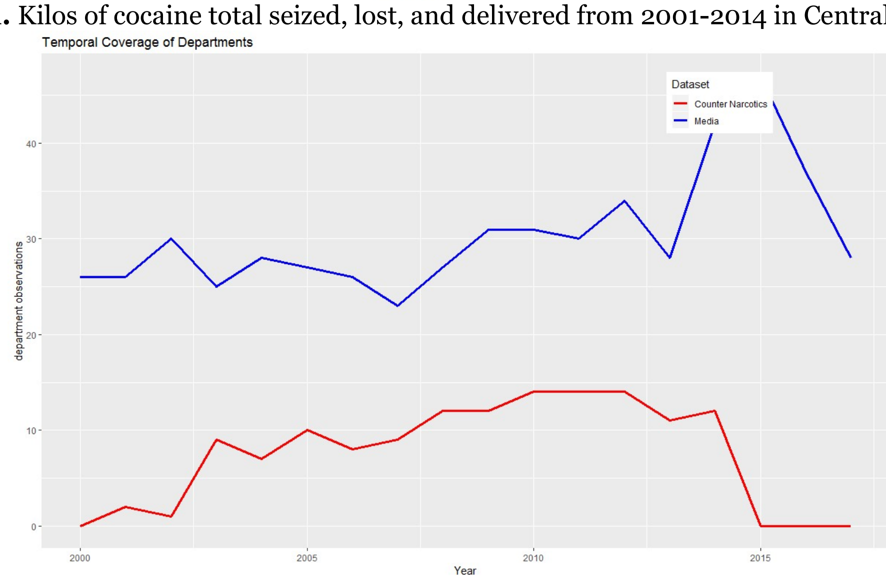


Figure S2. Temporal coverage and completeness for CCDB and media data. Temporal coverage calculates the number of departments per year that have a valid observation.

Table S1. Summary of Sources: 2000-2017 for media events

Country	Sources Consulted	N Total Unique Events (N with department level data)	N used in this analysis (number of events per department)	Special Notes
Honduras	Proceso, La Prensa, La Tribuna, Bribes, Bullets, and Intimidation, El Heraldo,	406 (385)	826	Multiple sources used because La Prensa had no data before 2007
Costa Rica	La Nacion	114 (90)	124	
Guatemala	Prensa Libre	570 (516)	566	La Prensa has no online data before 2015 so paper archives were used. Under reporting possible. Large urban bias towards Guatemala City. All articles with 1 kilo or less of cocaine, crack, or heroin, were removed
Panama	Prensa, Panamaamerica, Bribes Bullets and Intimidation, imprensa, el siglo	283 (247)	327	Potential decrease in 2009 and 2014 because of elections. Increase from 2005-2008 not supported by ethnography.
Nicaragua	La Prensa	100 (101)	165	Racism + Sandinista gov means over reporting in Caribbean and underreporting in pacific

Table S2. Variables for Narcosuitability

Attribute	Description
Proximity to Country Border	Country borders are strategic locations for trafficking nodes. Nodes closer to a country border are more attractive than those further away. Derived in ArcGIS 10.2 from the Global Administrative Boundaries (GADM) dataset (GADM, 2015).
Proximity to Coast (Dcoast)	Interdiction risk increased with distance from coastline. Derived from global coastlines in ArcMap 10.2.
Population Density (PDen)	Probability of detection decreases with population density. Population density is used as a proxy for and is inversely related to remoteness. Derived from Landscan 2000 data product.
Tree Cover	Greater tree cover reduces the probability of detection and increases attractiveness for money laundering via land improvement through deforestation. Tree cover data in the year 2000 from Hansen et al. (2013).
Market Access	Travel time along roads to cities of 50,000 or more (Verburg et al., 2011). Market access is another proxy for and is inversely related to remoteness.
Slope	Contributes to suitability for agriculture. Derived from ASTER GDEM (NASA & METI)
Protected Area Status	Areas designated as conversation areas or indigenous lands (IUCN)
Existing Land Use	Some land uses are easier for node establishment (e.g., shrubs, trees, pasture) than others (e.g., built-up areas, row crops). Classified land-use data from (Aide et al., 2013).

Ancillary Data

Narcotrafficking Airstrips, Caribbean Honduras

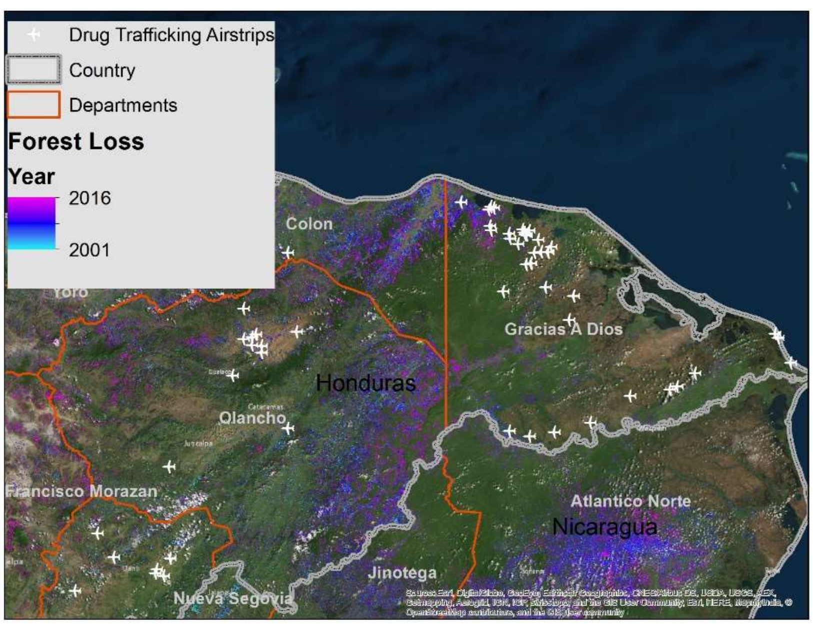


Figure SI.3: Narcotrafficking Airstrips in Honduras. Green circles are in protected areas, and white circles are outside protected areas.

Cartel Land Holdings, Peten, Guatemala
In 2011, Insight Crime published a report called "Grupos de Poder en el Peten." They identified networks for six cartels operating in the region, and used network analysis to outline the full legal names of everyone associated with the cartel. Search through cadastral records enabled the ability to link land holdings of people working for the cartel from 2004-2011. This only includes areas where legal land title is possible, expressly outside of protected areas. We georeferenced these pdf maps (Figure S1 4) and calculated the area of forest loss per year in these polygons (Figure 25, main text).

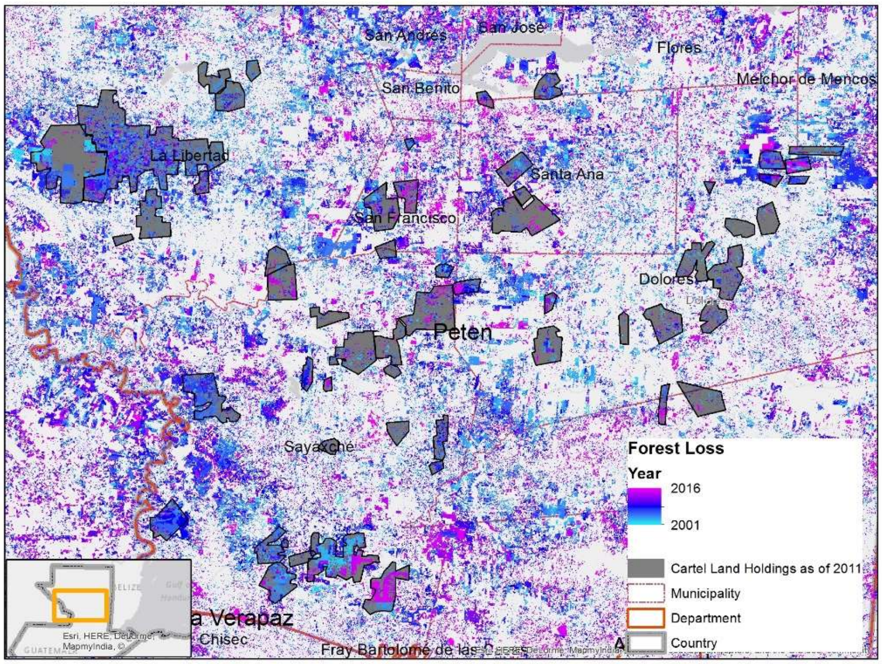


Figure S1 4. Cartel Land holdings recorded by Insight Crime as of 2011 and forest loss, Petén, Guatemala. Orange box shows inset.
Land Seizures in Guatemala

Land seizures were obtained by request to the Ministerio Public under Guatemalan Transparency of Information Laws. The .pdf data was digitized into an excel. These data represent accusations of "ursurpacion" or illegal land seizures in protected areas from the Guatemala Public Ministry. Each crime is reported to the ministry and recorded by municipality and by year. Many of these are reported by the Guatemalan National Commission of Protected Areas (CONAP). Interviews with CONAP revealed that many of these cases are narcotraffickers, but could not give us access to case specific data as that information is not public except for a few "emblematic" closed cases listed below in table SI 4. SI Figure 5 shows a time series of number of reports of land seizures per Guatemalan Department. This could be an indicator of narcoactivity in protected areas. These data are compared to the media in figure 25 of the main text.

Table SI 4. Emblematic cases of narcotraffickers and illegal land seizures in the Peten

Name	Location	Year	Area
Rodolfo Antonio Guerra Cameros	San Miguel	2012	1507 ha.
José Sanabria Roldan	Carmelita y Cruce a la Colorada	2016	64.5 ha.
Carlos Marroquin Contreras	Carmelita	2016	154 ha.
Mynor Estuardo Palma Melgar	Cruce a la Colorada	2016	675 ha.
Luis Carabantes	San Miguel	2017	135 ha.
Laguna Larga	Triangulo Candelaria	2017	74 ha.

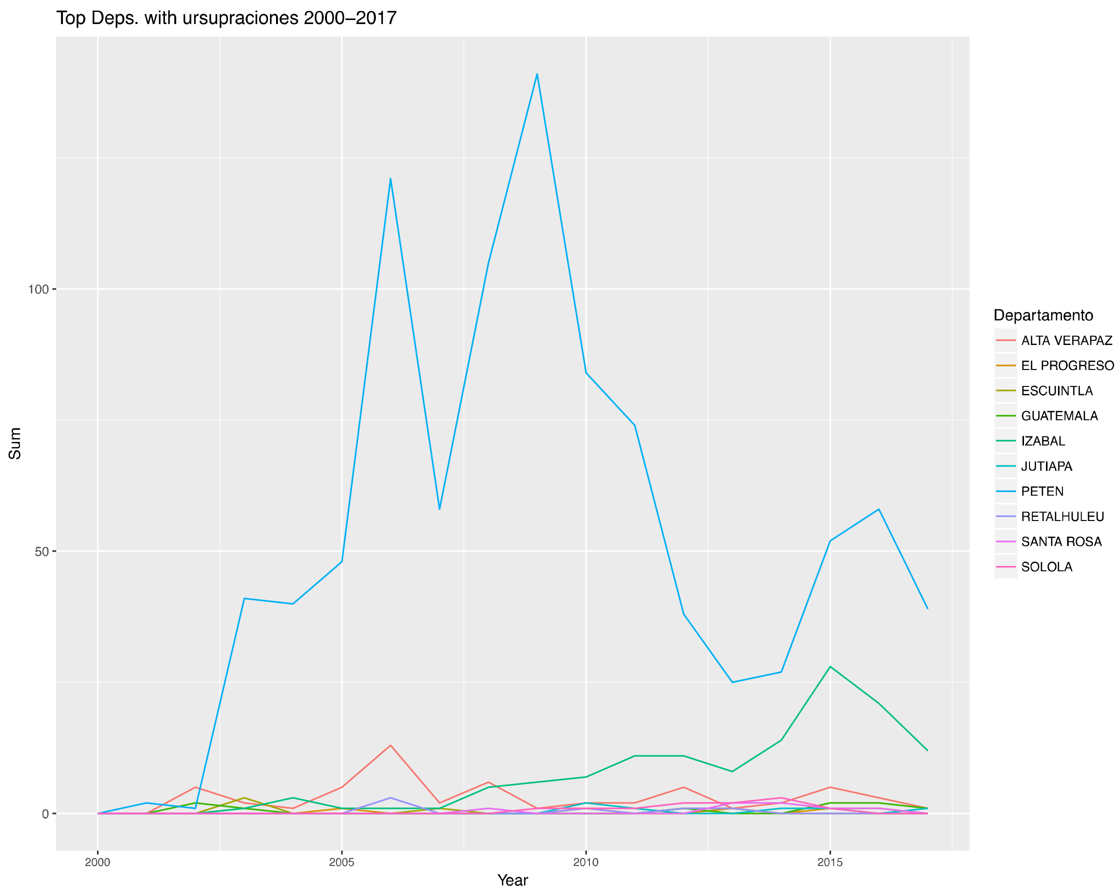


Figure SI 5. Land seizures accusations in protected areas, Guatemala (top 10 departments)

Representativeness Analyses

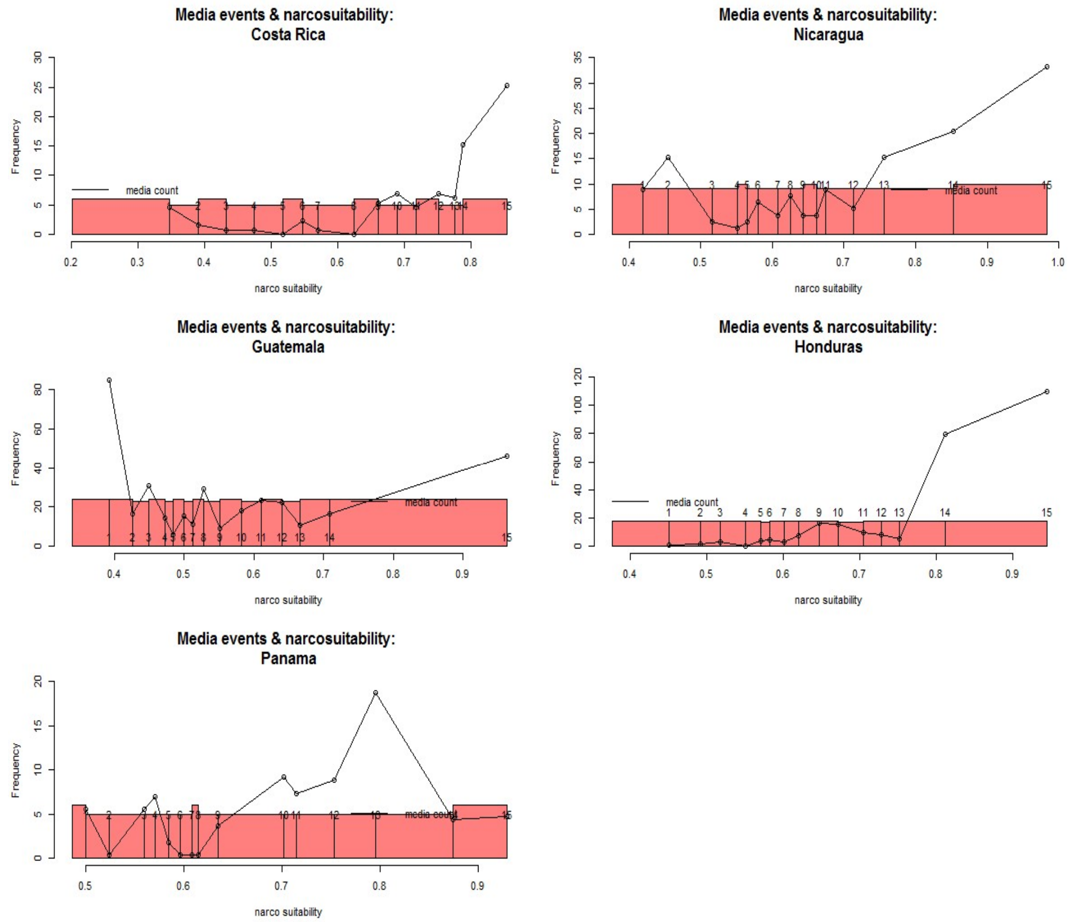


Figure SI. 6. Distribution of media events and municipal narcosuitability for each country in Central America. Each country has 15 narcosuitability bins defined by equal frequency of mean narcosuitability per department. As the bin number and narcosuitability increases (to the right), we expect to see more narcoactivity. Guatemala, N=497 media events; Costa Rica, N=106 media events; Honduras, N=426 media events; Nicaragua, N=106 media events; Panama, N=213 media events.

Guatemala Media Database
While the Guatemala database had the highest total number of events, there is a strong bias towards Guatemala City (the municipalities of which are in bins 1,3-4 and 8), where there are much more media articles than would be expected for these low suitability surfaces that would predict reduced narcotrafficking activity. Bin 15 contains mostly municipalities in the Petén, which we know to have high activity from the CCDB data. Bin 1 contains the Guatemala City airport, where there are over 35 articles alone representing large interdictions of cocaine in the hundreds to thousands of kilos. No other country showed such a strong urban bias. This could be related to unique methods required - articles prior to 2015 in Guatemala were hard copies instead of identified through an online media database. It could also be related to repression by DTOs and self censorship.

Nicaragua Media Database

Nicaragua had the lowest number of total events. While media coverage does increase with narcosuitability, there is an over representation of narcoactivitites in Matagalpa and Managua (bin 3). Ethnographers in this region note an apparent under reporting of trafficking in western Nicaragua that may be related to racism, or to the government protecting routes on the western side of the country

Panama Media Database

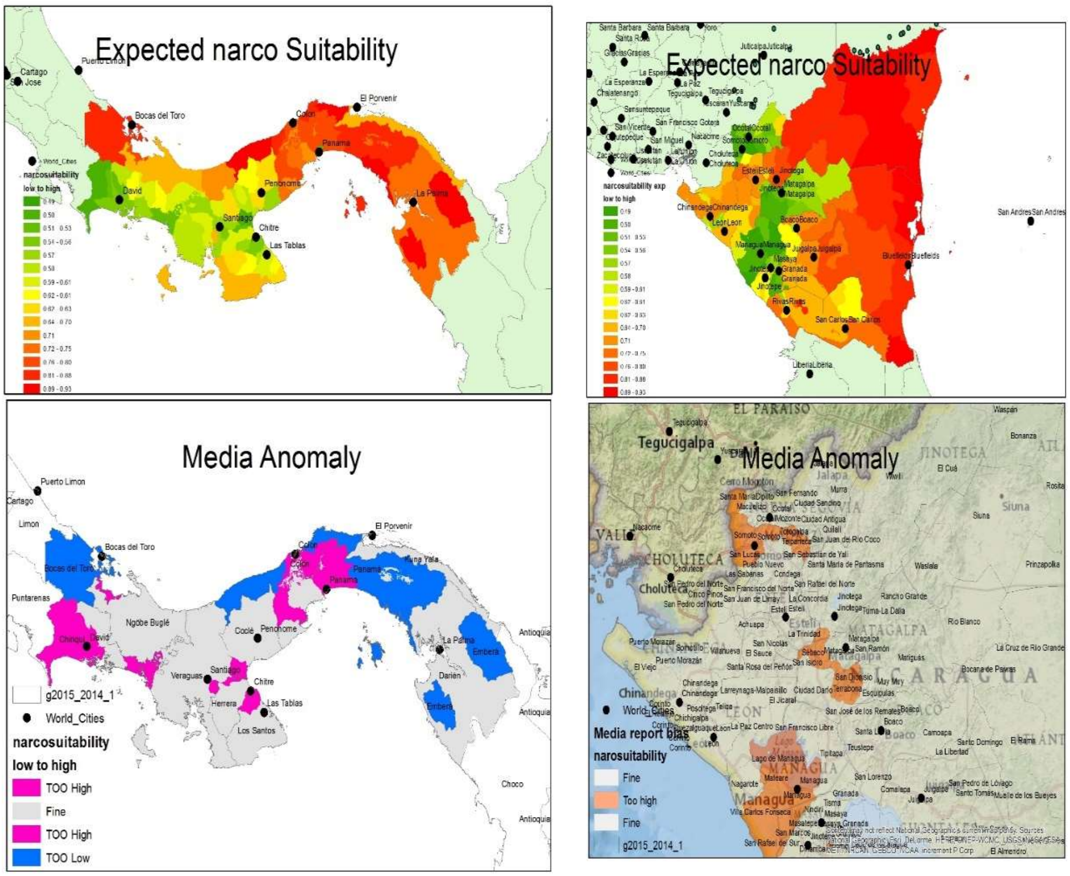


Figure SI 7. Top map shows the mean narcosuitability score for each municipality from low (green) to high (red) for Nicaragua and Panama. Bottom map then compared the expected media distribution (which should increase as narcosuitability increases) to the narcosuitability. For Panama Areas in blue are places with very low media reports, but high narcosuitability- and indicate potential under reporting. Areas in pink are places with higher than expected media reports given its low or medium narcosuitability- this either indicates that our expected narcosuitability is incorrect, or that media is over reporting narcotrafficking (as often occurs in urban areas, like panama city).

There are many media events reported in northwestern Panama, in bins 3 and 4, which are of low narcosuitability because of its medium population density, access to market, and agricultural land cover. However this location is strategically near the Costa Rican border, and has moderate activity reported in the media. Bins 11 and 12 are alone the Western panama coast, and have higher activity than the forest border regions like the Darien, Panama, like Guatemala, has a strong urban bias. Bin 13 has Panama City, which has a very large number of media reports of narcotrafficking activity.

The time series of media in Panama (see figure 3 main text) has an unexplainable increase in activity from 2005-2008 that cannot be corroborated with ethnographic insight. The media in Panama may poorly represent the temporal distribution of narcoactivity.

Honduras Media Database
The Honduras media data most closely resembles the CCDB data both spatially and temporally. It also demonstrates many media reports in the high suitability areas of Honduras. High correlation with CCDB could imply improved sampling efforts there by the US government. Honduras was also cooperative with the US government especially after the 2009 coup. Honduras, the media accounts drop off just as cocaine flows ratchet up, ca. 2011. This could have to do with the fact that this is when murder rates for journalists, lawyers, and activists started to rise, when repression increased, and when the media climate in Honduras, therefore, was not very friendly to talking about narcotrafficking.

Costa Rica Media Database
The spatial distribution of narcotrafficking activity in Costa Rica follows a distribution similar to Honduras- where areas of high suitability have many media reports. The temporal distribution however is perplexing- the increase in media reports in 2007 and 2008- and no increase in the recent period of 2013-2015- does not follow ethnographic insight. The Costa Rica data may not capture temporal trends well.

Country Level Regressions for Media and Counter Narcotics Data

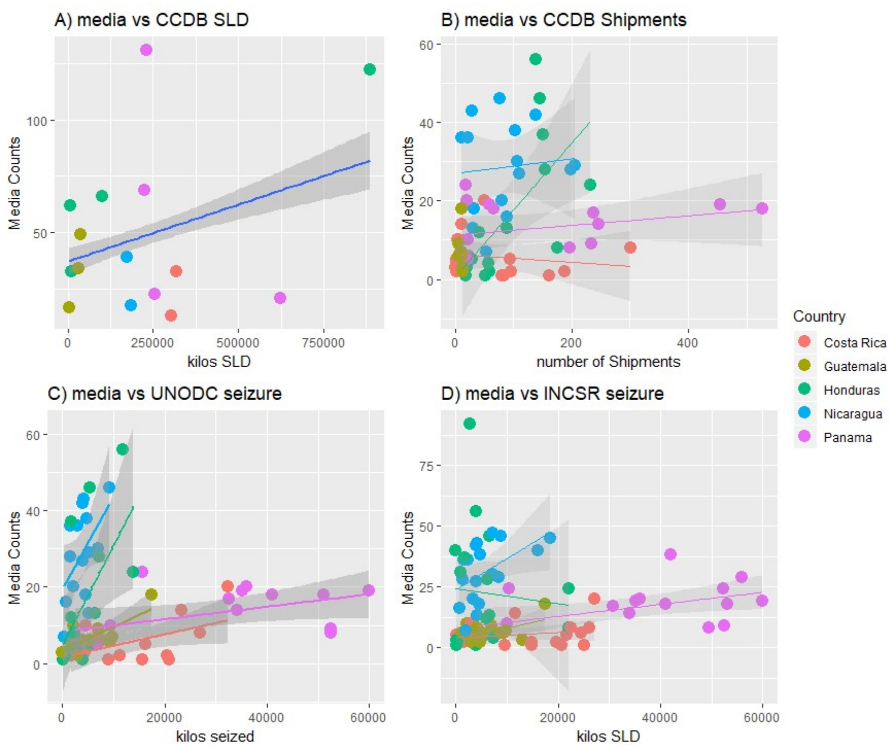


Figure SI 8. Scatterplots of media events compared to counter narcotics data (kilos seized). A) CCDB kilos SLD (with trend line for all data, not for each country.); B) CCDB shipments (with trend line per country); C) kilos seized from INCSR; and D) UNODC (with trend lines per country, and 95% confidence interval).

SI Table 5. Correlations between Media and Counter Narcotics Data. *indicates interaction with counternarcotics variable. Country names with no start indicate dummy variable to control for media variation by country. Linear regressions were used to predict media counts per country-year.

Counternarcotics data compared to media events

	Dependent variable:				
		media counts		media counts	media counts
	CCDB Shipments	UNODC Seizures	INCSR Seizures	UNODC-INCSR comparison	CCDB kilos
	(1)	(2)	(3)	(4)	(5)
Shipment	-0.0102 (0.0288)				
UNODC_Seizure		0.0003 (0.0003)		0.8868^{***} (0.1046)	
incsr			0.0001 (0.0003)		
SLDsum					0.0014 (0.0034)
CountryNicaragua	-0.4111 (6.9221)	1.5812 (5.6731)	-0.7613 (8.1443)	2,316.6710 (2,279.0960)	774.9961 (1,330.5790)
CountryHonduras	-5.7743 (5.2387)	3.2269 (5.4087)	20.1872^{***} (6.9835)	2,439.0240 (2,234.6790)	457.3337 (1,063.8890)
CountryGuatemala	20.6127^{***} (5.3849)	17.8065^{***} (6.1218)	19.8127^{***} (7.5001)	408.4091 (2,529.3150)	419.1480 (1,064.4550)
CountryPanama	4.9049 (4.5751)	6.6351 (5.9236)	3.8559 (8.3216)	65.6906 (2,447.4390)	517.4949 (1,064.3870)
Shipment:CountryNicaragua	0.0960 (0.6804)				
Shipment:CountryHonduras	0.1811^{***} (0.0467)				
Shipment:CountryGuatemala	0.0287 (0.0508)				
Shipment:CountryPanama	0.0224 (0.0325)				
UNODC_Seizure:CountryNicaragua		0.0003 (0.0006)		-0.0920 (0.2008)	
UNODC_Seizure:CountryHonduras		0.0023^{***} (0.0006)		-0.0413 (0.2652)	
UNODC_Seizure:CountryGuatemala		0.0021^{**} (0.0011)		0.0473 (0.4339)	
UNODC_Seizure:CountryPanama		-0.0001 (0.0003)		0.0987 (0.1158)	
incsr:CountryNicaragua			0.0004 (0.0008)		
incsr:CountryHonduras			-0.0004 (0.0006)		
incsr:CountryGuatemala			0.0012 (0.0007)		
incsr:CountryPanama			0.0001 (0.0004)		
SLDsum:CountryGuatemala					-0.0005 (0.0037)
SLDsum:CountryHonduras					-0.0013 (0.0034)
SLDsum:CountryNicaragua					-0.0033 (0.0056)
SLDsum:CountryPanama					-0.0015 (0.0034)
Constant	6.4039^{*} (3.2110)	1.6314 (4.1442)	4.0383 (5.6521)	125.8604 (1,712.2450)	-407.1385 (1,063.6780)
Observations	73	73	88	75	15
R^2	0.5555	0.5899	0.4106	0.9350	0.6694
Adjusted R^2	0.4920	0.5313	0.3426	0.9260	0.0743
Residual Std. Error	9.4603 (df = 63)	9.0874 (df = 63)	13.2902 (df = 78)	3,754.5840 (df = 65)	34.9623 (df = 5)
F Statistic	8.7492^{***} (df = 9; 63)	10.0683^{***} (df = 9; 63)	6.0383^{***} (df = 9; 78)	103.8594^{***} (df = 9; 65)	1.1249 (df = 9; 5)
Note:					$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Cross correlation analyses

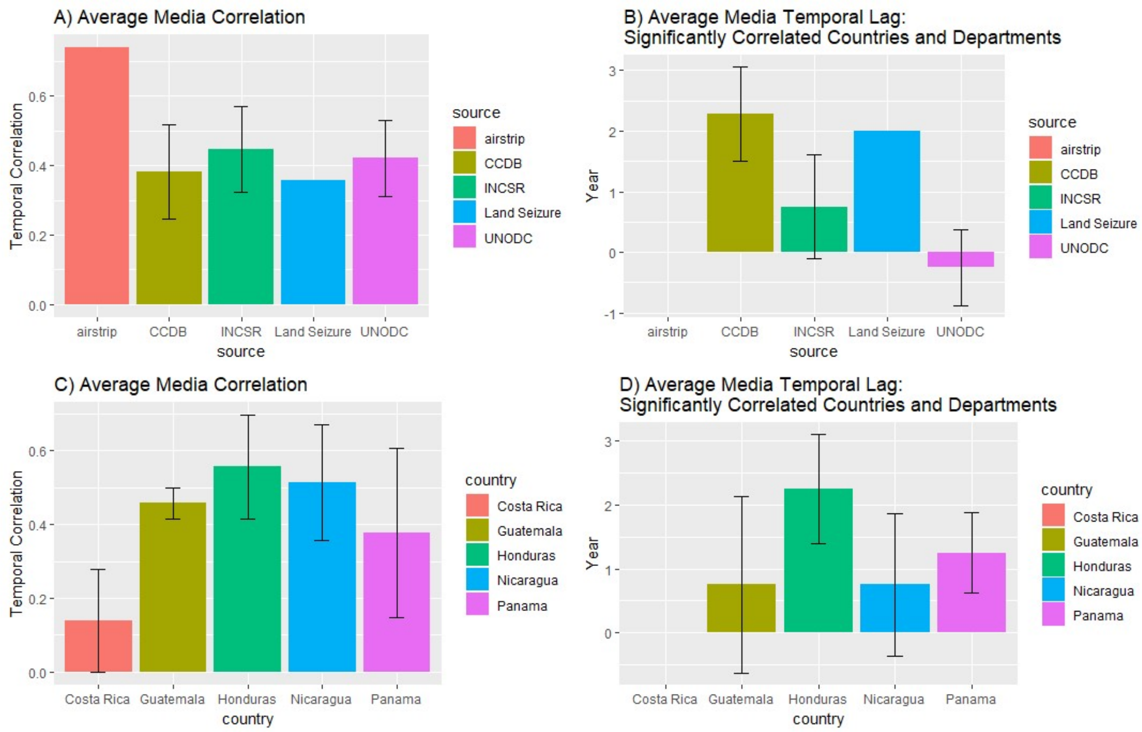


Figure SI 9. Average and standard errors for correlation between media, seizure, and ancillary datasets by A) data source and C) country. B) Average lag times for each data source and D) countries compares to media data. See Table 3 in the SI for details.

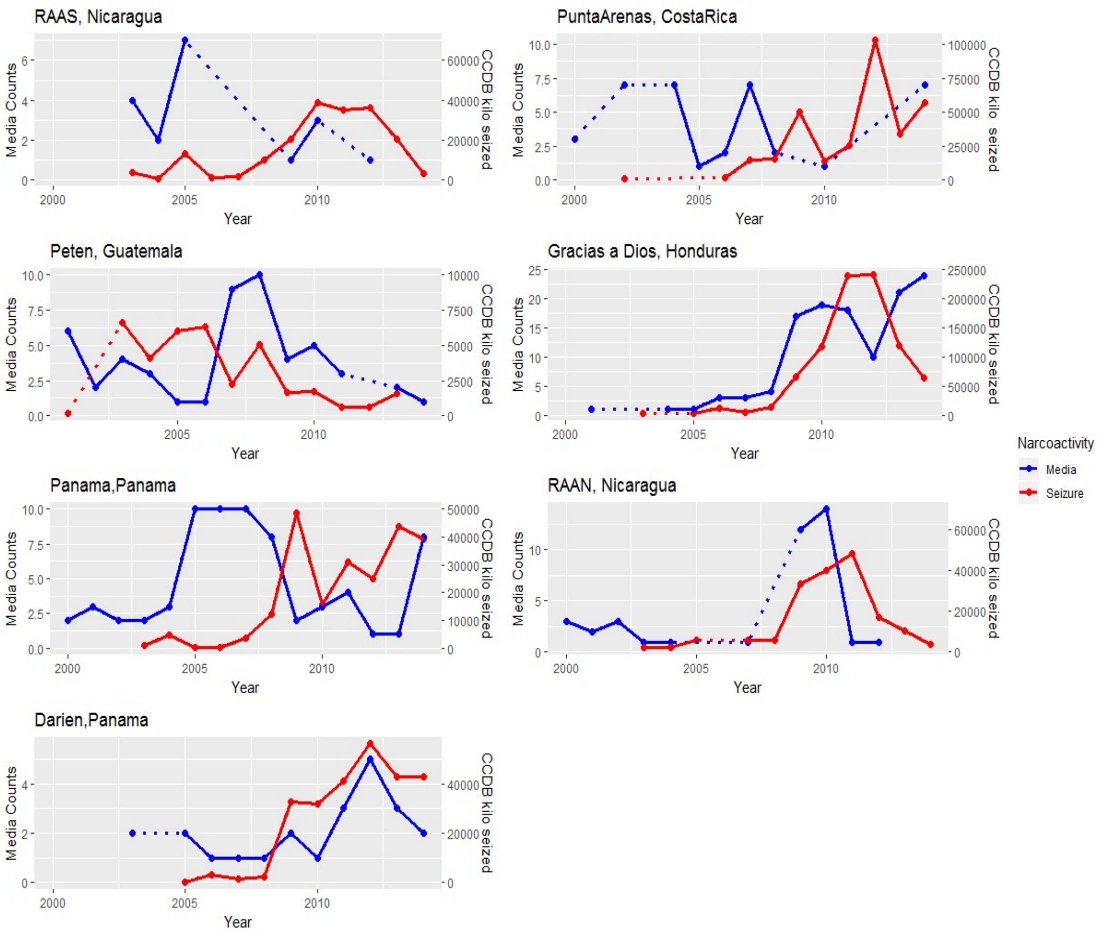


Figure SI 10. CCDB kilos SLD versus media event counts in 7 10 years or more of CCDB data per department. Red lines are kilos SLD of cocaine, blue line is number of media events per year. Dotted lines interpolate between years of no data.

Figure S11. INCSR to UNDOC seizure data time series plots

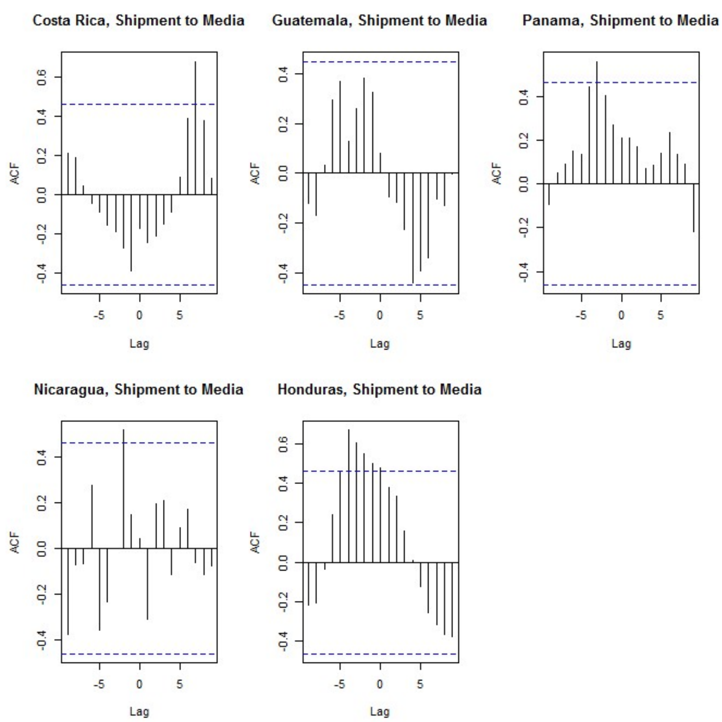


Figure SI 12. Corrolelograms between CCDB Shipment and media data by country. Blue line indicates significant correlation (p<.05).

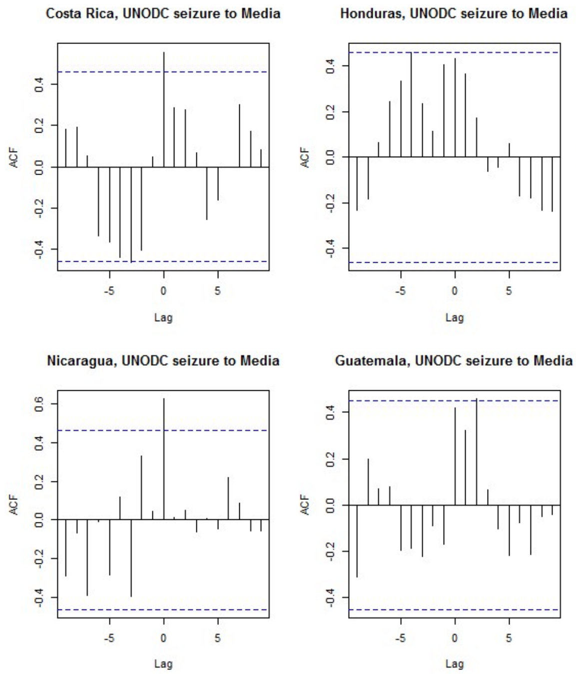


Figure SI 13. Corrolelograms between UNODC kilos seized data and media data by country. Blue line indicate significant correlation (p<.05).

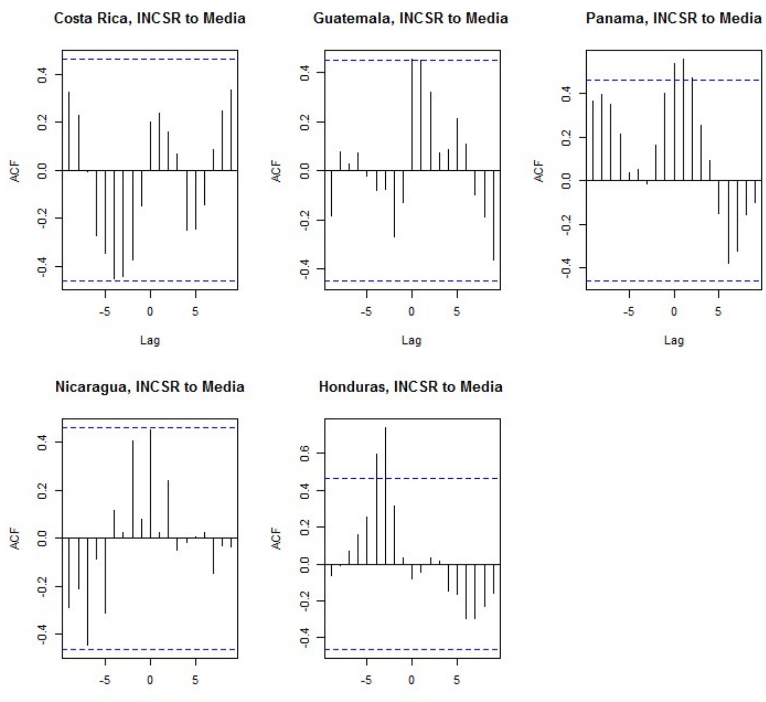


Figure SI 14. Corrolelograms between INCSR kilos seized data and Media data by country. Blue line indicate significant correlation (p<.05).

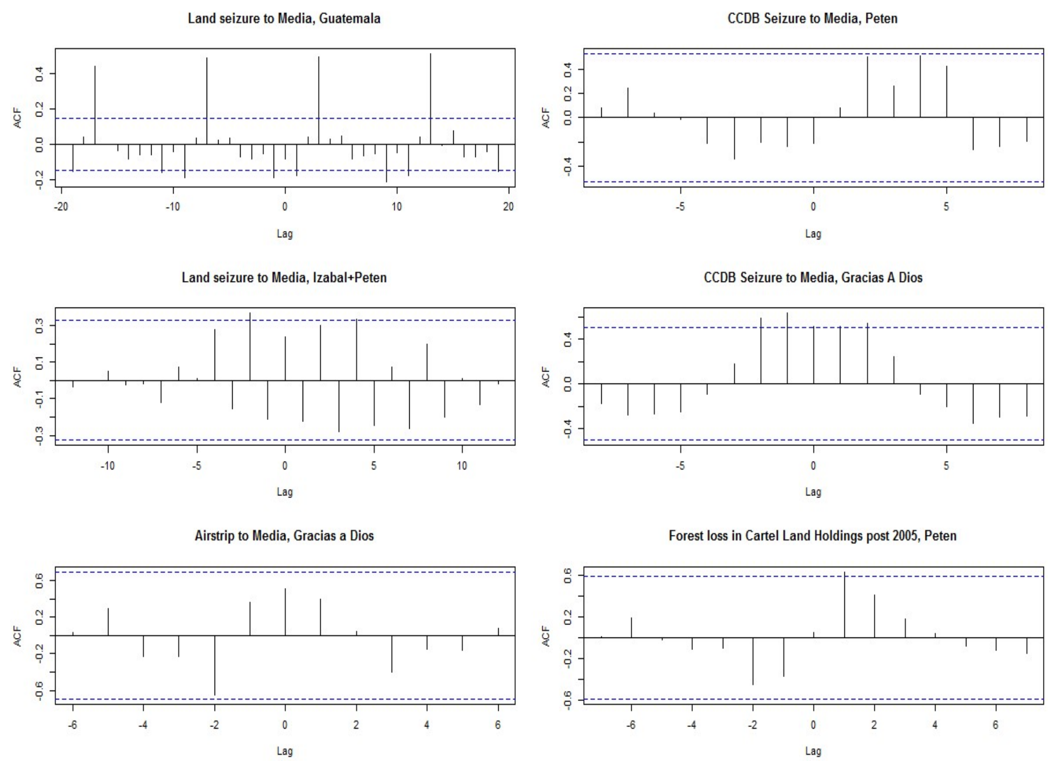


Figure SI 15. Corrolelograms between Ancillary data and Media data by country. Blue line indicates significant correlation (p<.05).

Table SI 6. Results of Correlation Coefficients and Lags reported per country and department dataset as compared to the media.

Scale	Location	Variable	Source	Significant Correlation?	Lag or Lead	Correlation Coefficient(s)
		Shipment	CCDB	no		
			INCSR	no		
	Costa Rica	Kilos Seized	UNODC	yes	no lag	0.558
		Shipment	CCDB	yes	shipments lagged by 4 years	0.386
			INCSR	yes	media leads 1,2,0	.538,.557,.471
	Panama	Kilos Seized	UNODC	yes	media lagged by 0,1,2 years	.538,.478,.216
		Shipment	CCDB	yes	shipments lagged by 4 years	0.518
			INCSR	yes	no lag	0.453
	Nicaragua	Kilos Seized	UNODC	yes	no lag	0.625
		Shipment	CCDB	yes	shipments lagged by 0-4 years	.476,.5,.551,.606,.669
			INCSR	yes	shipments lag 3,4 years	.739,.596
	Honduras	Kilos Seized	UNODC	no		
		Shipment	CCDB	no		
Country	Guatemala	Kilos Seized	INCSR	yes	media lagged by one year	0.452

			UNODC	yes	media lagged by 2 years	0.458
	Gracias a Dios, Honduras	Airstrip Construction	Authors, Honduran Military	no		
	Gracias a Dios, Honduras	Kilos Seized	CCDB	yes	seizures lead 1,2, lag, 1,2, and 0	.513,.541,.513 ,.635,.586
	Petén, Guatemala	Cartel Land Holding Forest Loss	Insight Crime and Hansen et al 2013	yes	Media lags by 1 year	.634
	Petén and Izabal, Guatemala			yes	seizures lagged by 2 years	0.357
	All departments, Guatemala	Land Seizure Accusations	Ministerio Publico, Guatemala Government	yes	seizures lagged by 1-2 years, media lag by 3	.17,.16, .433
	Petén, Guatemala			Yes	seizures lag 4 years	0.563
	RAAN, Nicaragua			Yes	media lags seizures 1 and 0 years	.973,.77
	RAAS, Nicaragua			No		
	PuntaArenas, Costa Rica			No		
	Panama, Panama			yes, but negative!	no lag	-0.511
Department	Darien, Panama	Kilos Seized	CCDB	Yes	media lags 1, 0 years	.794, .631

Robustness Checks for Regression Models

Table SI 7. Robustness checks for regional models, lagging and leading dependent variable.

Narcoactivity Robustness Checks- Regional Forest Loss Models

	Dependent variable:						
	Logged Deforestation Area lag 1 Media (1)	Logged Deforestation Area lag 2 Media (2)	Logged Deforestation Area lead 1 Media (3)	Logged Deforestation Area lead 2 Media (4)	Logged Deforestation Area lead 3 Media (5)	Logged Deforestation Area lag 1 SLD (6)	Logged Deforestation Area lag 1 SLD (7)
Crop	0.0704072*** (0.0227270)	0.0361866 (0.0270812)	-0.0410885** (0.0207326)	-0.0690869*** (0.0251607)	-0.1533603*** (0.0305435)	-0.0279286 (0.0519163)	-0.0697201 (0.0442179)
Pasture	0.0159649 (0.0134333)	0.0288272* (0.0159480)	0.0224654* (0.0117888)	-0.0156161 (0.0143067)	-0.0091177 (0.0143121)	0.0078655 (0.0292805)	-0.0397061 (0.0249386)
ruralpop	0.0000020 (0.0000029)	0.0000010 (0.0000036)	-0.0000002 (0.0000025)	0.0000054* (0.0000031)	0.0000033 (0.0000030)	0.0000023 (0.0000047)	0.0000054 (0.0000040)
precip	-0.0002871 (0.0006679)	0.0015011** (0.0007573)	0.0017599*** (0.0006206)	-0.0000112 (0.0007531)	-0.0006692 (0.0007195)	-0.0002344 (0.0012296)	0.0027359** (0.0010473)
burned	-0.0000006 (0.0000026)	0.0000079*** (0.0000029)	0.0000009 (0.0000024)	0.0000028 (0.0000030)	0.0000005 (0.0000029)	-0.0000010 (0.0000026)	0.0000005 (0.0000022)
GDP rate	0.0065377 (0.0377220)	-0.0210243 (0.0474180)	0.0262768 (0.0330582)	-0.0194708 (0.0401187)	-0.0468245 (0.0374469)	-0.0202146 (0.0657818)	-0.1037544* (0.0560273)
Media	0.0315581** (0.0123474)	0.0192374 (0.0135187)	0.0488915*** (0.0114101)	0.0177812 (0.0138471)	-0.0053014 (0.0147374)		
Kilos						0.0000029 (0.0000025)	-0.0000008 (0.0000021)
precip*burned	0.0000000 (0.0000000)	-0.00000003*** (0.0000000)	-0.0000000 (0.0000000)	-0.0000000 (0.0000000)	-0.0000000 (0.0000000)	0.0000000 (0.0000000)	-0.0000000 (0.0000000)
Observations	276	258	292	292	266	114	114
R^2	0.0704466	0.0736347	0.1627680	0.0686739	0.1500531	0.0337479	0.1452595
F Statistic	2.0272600** (df = 8; 214)	1.9573870* (df = 8; 197)	5.5407420*** (df = 8; 228)	2.1015270** (df = 8; 228)	4.4798050*** (df = 8; 203)	0.3448998 (df = 8; 79)	1.6782140 (df = 8; 79)

Note: *p<0.1; **p<0.05; ***p<0.01

Table SI 8. Country models with media with NO NA=0 fill

Narcoactivity in Media- Country Level Models

	Dependent variable:				
	Logged Deforestation Area Fixed Effects 2001-2016				
	Nicaragua	Honduras	Panama	Costa Rica	Guatemala
	(1)	(2)	(3)	(4)	(5)
Crop	0.0575929** (0.0260671)	0.2353246** (0.0974608)	0.0322663 (0.0757363)	-0.1241238 (0.1381259)	0.0756911 (0.0537781)
Pasture	0.0588961** (0.0250606)	-0.0148183 (0.0209520)	0.0259479 (0.0452263)	-0.0516434 (0.0939401)	-0.0081935 (0.0182386)
precip	-0.0045449*** (0.0015661)	-0.0010477 (0.0018613)	-0.0024070 (0.0019338)	0.0011310 (0.0016545)	0.0022270 (0.0018364)
burned	-0.0000086 (0.0000113)	0.0000019 (0.0000040)	-0.0000184 (0.0000423)	-0.0001293 (0.0000714)	0.0000050* (0.0000027)
ruralpop	-0.0000032 (0.0000060)	-0.0000116 (0.0000082)	0.0000211 (0.0000130)	0.0000226 (0.0000309)	-0.0000053 (0.0000031)
media	-0.0202339 (0.0510510)	0.0134169 (0.0137110)	0.0153345 (0.0464454)	-0.1376997 (0.1185748)	0.0143976 (0.0314255)
precip*burned	0.00000003 (0.00000003)	0.0000000 (0.0000000)	-0.0000001 (0.0000003)	0.0000004 (0.0000002)	-0.0000000 (0.0000000)
Observations	59	76	84	35	52
R^2	0.4343773	0.2942162	0.1252203	0.4242406	0.4376660
F Statistic	2.8524340** (df = 7; 26)	2.7989470** (df = 7; 47)	1.1042620 (df = 7; 54)	1.0526230 (df = 7; 10)	2.8908380** (df = 7; 26)
Note:					*p<0.1; **p<0.05; ***p<0.01

Table SI. 9. Country level conventional only models

Convential Variables Only- Country Level Models

	Dependent variable:				
	Logged Deforestation Area Fixed Effects 2001-2016				
	Nicaragua	Honduras	Panama	Costa Rica	Guatemala
	(1)	(2)	(3)	(4)	(5)
Crop	0.0682164*** (0.0195065)	0.0693076 (0.0574003)	0.0056307 (0.0491488)	-0.1069265* (0.0584042)	0.0417794 (0.0349273)
Pasture	0.0407448** (0.0188213)	0.0173032 (0.0187220)	0.0275911 (0.0302321)	-0.0403493 (0.0306182)	0.0135364 (0.0150991)
precip	-0.0010628 (0.0016041)	-0.0024747* (0.0013788)	-0.0014561 (0.0012311)	-0.0012894 (0.0009149)	0.0038339** (0.0015427)
burned	0.0000085 (0.0000076)	-0.0000001 (0.0000034)	0.0000051 (0.0000362)	-0.0000137 (0.0000293)	0.0000044* (0.0000026)
ruralpop	0.0000034 (0.0000044)	-0.0000110** (0.0000053)	0.0000051 (0.0000056)	0.0000126* (0.0000068)	0.0000006 (0.0000023)
precip*burned	-0.0000000 (0.00000002)	0.00000002 (0.0000000)	-0.00000003 (0.0000002)	-0.00000003 (0.0000001)	-0.0000000 (0.0000000)
Observations	196	140	168	98	98
R^2	0.1058680	0.1592146	0.0347626	0.0846857	0.2312027
F Statistic	3.2166160*** (df = 6; 163)	3.5032370*** (df = 6; 111)	0.8223327 (df = 6; 137)	1.1102500 (df = 6; 72)	3.6087950*** (df = 6; 72)
Note:					*p<0.1; **p<0.05; ***p<0.01

Table SI 10. Robustness check, media+ Honduras country model, lagging and leading dependent variable

Narcoactivity Media Robustness Checks- Honduras

	Dependent variable:			
	Logged Deforestation Area lag 1 yr	Logged Deforestation Area lag 2 yr	Logged Deforestation Area lead 1 yr	Logged Deforestation Area lead 2 yr
	Honduras	Honduras	Honduras	Honduras
	(1)	(2)	(3)	(4)
Crop	0.1199671* (0.0620572)	0.1102008 (0.0880442)	0.0859509 (0.0544584)	0.1498319** (0.0626934)
Pasture	0.0138989 (0.0201140)	0.0416625* (0.0216387)	0.0085284 (0.0179671)	-0.0255854 (0.0206840)
precip	0.0013082 (0.0014193)	0.0033577** (0.0015674)	0.0013385 (0.0013109)	-0.0030634** (0.0015092)
burned	-0.0000010 (0.0000035)	0.0000044 (0.0000037)	-0.0000053 (0.0000032)	-0.0000016 (0.0000037)
ruralpop	-0.0000077 (0.0000062)	-0.0000113 (0.0000069)	-0.0000052 (0.0000051)	0.0000006 (0.0000058)
media count NA=0	0.0420200*** (0.0132572)	0.0148243 (0.0139559)	0.0371501*** (0.0122589)	-0.0057646 (0.0141126)
precip*burned	-0.0000000 (0.0000000)	-0.00000002 (0.0000000)	0.00000002* (0.0000000)	0.0000000 (0.0000000)
Observations	130	120	140	140
R^2	0.1865880	0.1553137	0.1751288	0.0806005
F Statistic	3.3097600*** (df = 7; 101)	2.4165960** (df = 7; 92)	3.3363070*** (df = 7; 110)	1.3776170 (df = 7; 110)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table SI 11. Robustness check, SLD+ Nicaragua country model, lagging and leading dependent variable

Counternarcotics CCDB SLD- Nicaragua Robustness Check

	Dependent variable:			
	Logged Deforestation Area		Forest loss 1 year lag	Forest loss 1 year Lead
	Nicaragua	Nicaragua Conventional	Nica lag 1 yr	Nica lead 1 year
	(1)	(2)	(3)	(4)
Crop	154.9599000* (64.8436400)	47.2672100 (64.7993100)	170.5611000 (154.7595000)	-81.8599000 (74.7284600)
Pasture	0.4487851** (0.0973608)	0.0223236 (0.1231114)	-0.1058732 (0.2323669)	-0.0977603 (0.1122026)
precip	0.0108702* (0.0039453)	0.0017393 (0.0066280)	0.0058405 (0.0094160)	-0.0026872 (0.0045467)
burned	-0.0000134 (0.0000083)	0.0000020 (0.0000117)	0.0000247 (0.0000198)	-0.0000068 (0.0000096)
ruralpop	0.0000119 (0.0000085)	0.0000144 (0.0000104)	0.0000116 (0.0000203)	-0.0000014 (0.0000098)
Kilos	0.0001220** (0.0000377)		-0.0001743 (0.0000900)	-0.0000027 (0.0000435)
precip*burned	0.0000000 (0.00000002)	-0.00000002 (0.00000003)	-0.0000001 (0.0000001)	0.00000004 (0.00000003)
Observations	23	28	23	23
R^2	0.9213336	0.2808233	0.6106761	0.8333659
F Statistic	5.0193910 (df = 7; 3)	0.4555587 (df = 6; 7)	0.6722381 (df = 7; 3)	2.1433590 (df = 7; 3)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table SI 12. Robustness check, media and Guatemala country model, lagging and leading dependent variable

Narcoactivity Media Robustness checks, Guatemala, Forest Loss 2005-2016

	Dependent variable:			
	Logged Deforestation Area			
	Guatemala	Guatemala media lag 1	Guatemala media lag 2	Guatemala media lag 3
	(1)	(2)	(3)	(4)
Crop	-0.1571066* (0.0903966)	0.1451976* (0.0755948)	0.1774759* (0.0879139)	0.2410346** (0.0894121)
Pasture	-0.2052914** (0.0815390)	0.0217751 (0.0593450)	-0.0892030 (0.0629440)	-0.0842389 (0.0588048)
precip	0.0001435 (0.0019441)	0.0013340 (0.0015748)	0.0022941 (0.0017719)	0.0011493 (0.0014478)
burned	0.0000079* (0.0000047)	0.0000016 (0.0000030)	0.0000059 (0.0000045)	0.0000033 (0.0000038)
ruralpop	0.0000154 (0.0000093)	-0.0000078 (0.0000060)	0.0000045 (0.0000064)	-0.0000075 (0.0000081)
media count	-0.0183559 (0.0467904)			
precip*burned		0.0296698 (0.0321424)		
plm::lag(countsum.y, k = 2)			0.0788416** (0.0368538)	
plm::lag(countsum.y, k = 3)				-0.0037935 (0.0298211)
precip:burnedarea	-0.00000002 (0.00000002)	-0.0000000 (0.0000000)	-0.00000002 (0.0000000)	-0.0000000 (0.0000000)
Observations	83	70	62	49
R^2	0.2119579	0.2534747	0.5144286	0.5845516
F Statistic	1.8443510 (df = 7; 48)	1.7947080 (df = 7; 37)	4.5404110*** (df = 7; 30)	4.2211130*** (df = 7; 21)
Note:				*p<0.1; **p<0.05; ***p<0.01