They Paved Paradise?

Vacant Land and Surface Parking Lots in Downtown Areas and the Role of Regulatory Delay in Optimal Dynamic Land Use*

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Abstract

In this paper, we explore the implication for urban form, urban structure and optimal land use policy of vacant land used for downtown surface parking lots in urban areas. We develop a dynamic, spatial general equilibrium urban model to show cases where vacant land can be optimal and suboptimal depending upon its temporary use, economic and regulatory conditions as well as externalities. We show in numerical simulations how the structure of the urban economy responds to different policies and consider their implications for different types of cities. These results have important implications for cities concerned about the impacts of vacant land and in particular of surface parking lots in downtown areas.

Keywords: Urban land use, land use regulation, parking, congestion, urban growth

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1 Introduction

Vacant urban land is a common phenomenon in most cities in the world. Deliberate speculative choices related to regulatory and real estate market trends may explain why some property owners leave lots vacant in downtowns or neighborhoods despite high land values (Mills, 1981; Sinn, 1986). Planners and policymakers are often concerned when these vacant lots are either unused or are being used for low-value purposes. Vacant lots may not be a sign of market inefficiency when, given the cost of demolition, re-permitting and reconstruction land might be kept vacant to satisfy future needs. Vacant land as a byproduct of urban development processes can explain the existence of leapfrog development patterns or even development that proceeds from the outskirts inwards (Brueckner and von Rabenau, 1981; Mills, 1981; Vousden, 1980; Wheaton, 1982). Yet, temporary uses of urban vacant lots may generate externalities that, reduce the amount of land that ought to be left undeveloped, even temporarily. Instead, a greater share of this land should be left for more productive uses such as commercial and residential buildings. This misallocation also has distortionary impacts on urban form via population density and city size as well as spatial structure in terms of land uses.[1]

One such externality is traffic congestion. The problem with unpriced traffic congestion is that individuals do not take into consideration the external impact of their driving in travel and location decisions resulting in excess congestion and excessively long commute trips and a city excessively spread out (Brueckner, 2001, 2000). When vacant land is temporarily used as surface parking, it may induce additional discretionary trips, exacerbating congestion in the urban core. In the absence of policy interventions to address these externalities, land developers may leave too much land vacant, when ideally more land in central business districts (CBD) should go towards commercial or residential uses. As a result of this misallocation, new development is pushed to the outskirts of cities, resulting in additional costs of infrastructure, development of open space and environmental impacts.

In this paper, we show why temporary surface parking lots may occur in downtown areas even though land prices are extremely high for rational as well as policy-induced reasons. We demonstrate how this type of temporary land use for lots awaiting development affects urban form

[1] Vacant lots can also generate externalities when they become dumping grounds for litter and other solid wastes, and eventually health hazards for neighborhood residents if left unchecked. Vacant parcels can also increase crime in its vicinity and may be perceived as a sign of neglect which can drive down the values of nearby real estate.

and spatial structure. This result relies on the durability and non-malleability of buildings. In addition, we illustrate the externalities that may be associated with this temporary land use and what corresponding policy instruments can be implemented to address the corresponding market failure.[2] To achieve these goals, the paper develops a two-period, perfect foresight, spatial general equilibrium open city model to explore the effects of temporary surface parking lots in urban cores in terms of their impact on labor, product, land and transportation urban markets. The model explores these effects while accounting for traffic congestion and agglomeration externalities as well as alternative travel modes. We show that temporary vacant land, ignoring externalities, may be efficient in the presence of growth in the export demand for the tradable output of the city in the presence of commercial producers with perfect foresight. When commuters generate traffic congestion, then we show how a congestion charge can internalize these effects and when temporary surface parking on vacant land creates congestion from non-resident visitors using those spots how a tax on the use of that land can also address the parking externality.

Our model introduces several novel features that allow for rich exploration of the role of vacant land in urban economies. One, landowners can adjust land use between commercial, residential, or vacant land under surface parking use in each period depending upon the return on land over space and time. Because landowners seek to maximize the present value of land use over time, profit maximizing usage in one location in one period may differ from the next. Two, in contrast to the perfect foresight with future export demand causing vacant land, we also explore an alternative mechanism whereby vacant land arises because of regulatory uncertainties and delays. Despite the many potential explanations for vacant urban land, these two channels present a useful set of alternatives, market- and policy-based, that illustrate competing roles of policy and markets.

Three, we allow for two commuting modes for workers, an uncongested public option and cars, whose congestion interacts with that caused by non-resident visitors using temporary downtown surface parking. Four, our model addresses dynamic inefficiencies that are not captured in static urban models with traffic congestion. Since first period development decisions have implications for subsequent period outcomes, the optimal policy in our model is dynamic to

[2] The results are related to work in Franco (2023). That chapter builds on the framework developed in this paper to illustrate the land use effects of first- and second-best congestion tolling. The framework in that chapter is a very simplified version of the model in this paper which does not account for agglomeration economies or the existence of vacant land as a result of regulatory uncertainties and delays or for the substitutability of inputs in the production function.

respond to variation in congestion. This helps illustrate how unaddressed short-run market failures also affect the equilibrium pricing level of congested roads in the short- and long-run. Lastly, the reversibility of surface parking temporary land use allows greater second period commercial land use, which contributes to urban agglomeration economies.

Our work contributes to four principal strands of the literature. First our model extends the two-period, open-form, monocentric, linear city model (Mills, 1981; Ohls and Pines, 1975).[3] Like some of the papers in this literature, we allow for some form of exogenous growth over time (e.g., population or income growth, technological innovation) and with land developers holding perfect foresight or rational expectations. We extend this framework by allowing two alternative travel modes (transit and auto), regulatory delay, endogenous traffic congestion and agglomeration externalities from aggregated production. Vacant land used for temporary surface parking attracts visitors (non-residents) to the downtown area around a trade center, who then create additional traffic congestion to resident car commuters. We also show how land development patterns and urban policies result in multiple channels of adjustment via land and house rents, output prices and wages, labor supply and migration. Lastly, we assume that demolition costs are sufficiently high that it is optimal to hold land vacant in anticipation of subsequent expansion of commercial development.

Second, our paper has important implications for a broader literature of spatial general equilibrium models with multiple externalities and urban policies (Anas and Kim, 1996; Verhoef and Nijkamp, 2004; Wheaton, 2004; Zhang and Kockelman, 2016). Most of these models have sophisticated treatments of the transportation and/or housing sectors, but lack a clear accounting or focus on vacant land and its connection to these markets. The dynamic spatial framework in our paper illustrates how perfect-foresight behavior or regulatory delay may create market failures which interact with these sectors and generate inefficient land use.

Third, our work linking land use to regulatory delay is further related to a larger literature on urban land use controls that considers the balance between reducing inefficient urban sprawl and its associated negative externalities (e.g., traffic congestion, air pollution), the regulatory inefficiencies that these policies may impose (Brueckner, 2007; Brueckner and Lai, 1996; Wrenn

[3] Other contributions to this literature include Fujita (1976), Arnott (1980), Turnbull (1988), Braid (1991, 1988), Moore and Wiggins (1990), Brueckner and Helsley (2011). These models have been used to study various features of urban spatial growth and decline, including urban sprawl, blight, leapfrogging and other forms of discontinuous urban development patterns.

and Irwin, 2015) as well as the investment effects of land use regulations (Miceli et al., 2003; Turnbull, 2005, 2004, 2002).

Lastly, our work builds on an established literature on the determinants, design and effects of urban parking (Cutter and Franco, 2012; Franco, 2017; Zakharenko, 2016; Zheng and Geroliminis, 2016). Our paper is the first to our knowledge to focus on the role of temporary vacant land use as a cause of congestion from surface parking lots.[4]

In the next section, we present descriptive statistics to characterize patterns of vacant land, parking and key economic and policy variables in U.S. cities that motivate key conceptual aspects of our analyses. Section 3 presents the theoretical components of our theoretical model. Section 4 derives the equilibrium conditions of this model under several scenarios. Section 5 derives the set of optimal policies to address inefficiencies in the preceding section. Finally, Sections 6 and 7 extend our theoretical setup via a numerical exercise calibrated to a hypothetical urban environment intended to qualitatively compare policy-relevant features of the urban equilibrium under different conditions. We also allow for greater production substitution. Section 8 concludes.

2 Vacant Land and Surface Parking in US Cities

Surface parking is an attractive short-term transitional land use for vacant sites awaiting development due to regulatory uncertainties and delays in urban cores because it is easily reversible, generally inexpensive to implement yet can generate revenue very quickly, benefitting landowners. Most downtown parking lots in U.S. (United States) cities were created through demolition, with the smallest lots covering the vacated footprints of single buildings and the largest lots stitched together from vacated adjacent properties. This temporary land use of vacant land is nevertheless criticized for taking up valuable land that could be used for more economically productive uses. Moreover, using vacant land for parking is perceived to be worse than leaving it vacant because it encourages more driving, worsening urban congestion and air pollution and, may make urban areas less amenable places to walking, cycling and transit use. As such, critics of surface parking lots in downtown areas often advocate for compulsory building or, for a surface parking lot tax (Schmitt 2017; Osman 2018; CBC News 2022).

[4] Other potential causes of vacant urban land include land speculation, service to adjacent buildings, inactive publicly owned land or land in the planning or approval process for development.

The persistent existence of vacant land in high value urban locations poses an obvious target for urban planners and policy experts looking to point to inefficient uses of land that limit density in the urban core and thereby contribute to urban sprawl, congestion, and even urban blight (Ben-Joseph, 2015; Mallach, 2018; Pagano and Bowman, 2000). The proportion of vacant land in U.S. cities or CBDs varies considerably by city. Pagano and Bowman (2000) find that among the 83 cities in their study, the rate of vacant parcels at the city level was 15%, with 2.6 vacant structures per 1,000 residents. Alexandria, VA had the lowest rate of vacancy (0.6%), while Amarillo, TX had the highest (45%). Newman et al. (2016) analyze U.S. Postal Service records of address vacancies collected by the U.S. Department of Housing and Urban Development and find similar average rates for a sample of 124 U.S. cities, with vacancy rates more than three times higher for business addresses than residential addresses on average.[5]

For context to our subsequent theoretical and simulation analyses, it is helpful to establish the answer to a few questions: where is vacant land in urban core areas substantial? What factors are correlated with large amounts of vacant land? How does the extent of land regulation in cities relate to vacant land?

Table 1 reports the share of vacant business addresses by Census tracts in downtown areas from the Department of Housing and Urban Development's Aggregated U.S. Postal Service Administrative Data on Address Vacancies (HUD, 2020).[6] Vacant business addresses are defined as mailing addresses registered to a business for which the U.S. Postal Service stops delivering mail because it is not being picked up. These are not the same as vacant land, but are likely to be a useful proxy for vacancy. The comparison between 2008 and 2018 is useful given the differential impact of the Great Recession and subsequent recovery across cities in the context of the "urban

[5] The availability of large-scale online databases of commercial land records presents the opportunity to measure the extent of vacant urban land more systematically, but beyond a blog posting by the data provider Yaida Matrix (Ginsac, 2018) documenting the acreage of vacant land across a subset of U.S. cities, there has been little academic work leveraging these datasets thus far.

[6] Following the approach of Baum-Snow and Hartley (2020), we identify CBDs for each Core-Based Statistical Area (CBSA) with a 2008 population larger than 250,000 as the highest population Census Place within the CBSA. We recode the place from Santa Maria to Santa Barbara for Santa Barbara-Santa Maria-Goleta, CA and from Virginia Beach to Norfolk for Virginia Beach-Norfolk-Newport News, VA-NC because these better represent the CBD. We then include in our analysis all census tracts within 4 km of the CBD point for each CBSA and then calculate the share of vacant business addresses relative to all business addresses in the CBSA for a given year. Vacant business address data for Albuquerque, NM, Phoenix-Mesa-Glendale, AZ, San-Diego-Carlsbad-San Marcos, CA and Wichita, KS are missing in all years of the data. It missing for some years for Austin-Round-Rock-San Marcos, TX, Baltimore-Towson, MD, Birmingham-Hoover, AL, Las Vegas-Paradise, NV, Omaha-Council Bluffs, NE-IA, Tucson, AZ and Virginia Beach-Norfolk-Newport News, VA-NC.

revival" of the last 20 years (Couture and Handbury, 2020). We point out the location of the city of Los Angeles given the size of its population, land use patterns and the attention placed in public policy discussions there on land use and traffic congestion. Of note is that vacant land in Los Angeles city has not meaningfully changed over the period in question and that it does not rank towards the top of cities with a high proportion of vacant land. There has been some fluctuation in which U.S. cities have the highest share of vacant land in downtown areas. Oklahoma City (OK), San Juan (TX), Denver (CO) and Detroit (MI) maintain the highest shares of downtown vacant land while New Orleans (LA), Stamford (CT) and Allentown (PA) maintain the lowest.

For illustrative purposes, Figure 1 shows the pattern of surface parking use in locations with planned large-scale developments for a handful of projects in Central Los Angeles (CA). The interaction of downtown parking for non-resident visitors and workers is common in many cities. In Washington, D.C. federal employment is concentrated around the monuments, which attract millions of tourists each year. The Los Angeles downtown is also a hub not only of jobs but also of several superstar art museums and cultural facilities. In 2018 demolition begun on a parking structure east of the Walt Disney Concert Hall to prepare the site for construction of a $1 billion mixed-use development project, dubbed The Grand, designed by Frank Gehry. Another well-known example in downtown Los Angeles is the Circa Complex. The site used to be a vacant parking lot used by Staples Center patrons in the South Park neighborhood of Downtown Los Angeles. Construction began in 2015, adding 48,000 square foot of retail space and a 648-apartment complex with move-ins already in October of 2018.

Panel A of Figure 1 shows development along the Olive Street corridor in the rapidly developing South Park neighborhood, which is just south of Downtown Los Angeles. While there are many other surface parking lots and development projects in this neighborhood, these two projects show clear overlap between the location of two mixed-use towers and surface parking lots visible from satellite photos. Panel B shows a similar pattern for two projects several blocks north. These developments are not limited to downtown, but also extend Westward towards Koreatown, where Panel C shows two nearby developments also with surface parking lots.[7] This provides a sense that while the city of Los Angeles does not rank high in terms of vacant land share, there is

[7] See https://la.curbed.com/maps/south-park-downtown-la-constructionprojects**,** https://la.curbed.com/2018/10/17/17989932/county-vermont-corridor-project-groundbreaking , and https://urbanize.la/post/32-story-tower-planned-6th-shatto for a description of these projects.

at least an anecdotal relationship between vacant land and surface parking in high-value parts of the city under development.

Examining correlates of vacant land and surface parking in U.S. cities provide some insight into the mechanisms we will explore in our theoretical model in Section 3. Figure 2 illustrates data from 930 Core-Based Statistical Areas (CBSAs) in the U.S. (with some variation based on data availability). In Panel A of this figure, we compare data from the U.S. Geological Survey on the share of urban land use allocated to surface parking in 2012 based on aerial photographs (Falcone and Nott, 2019) to the level of urban congestion measured by the Texas Transportation Institute's Travel Time Index (Schrank et al., 2010). The plot illustrates a common concern among urban planners, which is that cities with a large proportion of urban land use for parking also seem to have higher levels of traffic congestion as measured by the Texas Transportation Institute's Travel Time Index.

Panel B of Figure 2 illustrates cities where land use for parking increased also showed increases in the share of tradable employment from U.S. Census Bureau County Business Patterns data for 2010.[8] This correlation will motivate our model for optimal dynamic land use in response to expected increase in export demand for tradable goods in our theoretical analysis. Panel C of Figure 2 shows that there is a positive correlation between land shares for surface parking and the extent of regulatory delay for building permits as reflected by the Wharton Residential Land Use Regulatory Index (WRLURI) (Gyourko et al., 2008).[9] Lastly, Panel D of Figure 2 also shows that this regulatory delay is positively correlated with vacant business address from HUD data. In all, these observed facts provide suggestive evidence of key correlates of vacant land use and surface parking in urban areas that we will examine in our subsequent theoretical and simulation analyses.

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[8] This is defined as employment excluding utilities, construction, real estate and rental, health care/social services, arts/entertainment/recreation, accommodation, other services and public administration and roughly reflects sectors with higher tradable shares (Jensen and Kletzer, 2005).

[9] It is not possible to find comparable data for commercial land use regulatory delay, but it would seem reasonable to assume that it is correlated with residential land use regulatory delay.

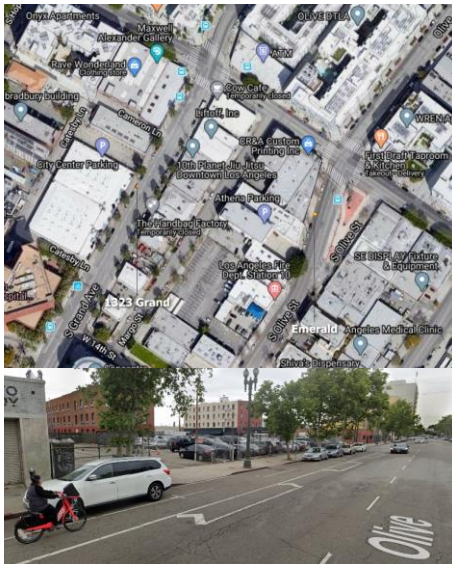
Table 1—Top and Bottom 10: Share of Vacant Business Addresses in Tracts within 4 KM of CBD

2008		2018	
Kansas City, MO-KS	0.162	Cleveland-Elyria-Mentor, OH	0.174
Salt Lake City, UT	0.148	Minneapolis-St. Paul-Bloomington, MN-WI	0.152
Oklahoma City, OK	0.132	San Juan-Caguas-Guaynabo, PR	0.149
Detroit-Warren-Livonia, MI	0.130	Detroit-Warren-Livonia, MI	0.134
Cleveland-Elyria-Mentor, OH	0.129	Oklahoma City, OK	0.133
St. Louis, MO-IL	0.126	Providence-New Bedford-Fall River, RI-MA	0.131
San Juan-Caguas-Guaynabo, PR	0.122	Nashville-Davidson--Murfreesboro--Franklin, TN	0.128
Houston-Sugar Land-Baytown, TX	0.120	Seattle-Tacoma-Bellevue, WA	0.123
Denver-Aurora-Broomfield, CO	0.117	Denver-Aurora-Broomfield, CO	0.121
Milwaukee-Waukesha-West Allis, WI	0.117	Riverside-San Bernardino-Ontario, CA	0.117
…	…	…	…
Los Angeles-Long Beach-Santa Ana, CA	0.051	Los Angeles-Long Beach-Santa Ana, CA	0.046
…	…	…	…
Allentown-Bethlehem-Easton, PA-NJ	0.050	Springfield, MA	0.034
Oxnard-Thousand Oaks-Ventura, CA	0.047	Greensboro-High Point, NC	0.032
Boston-Cambridge-Quincy, MA-NH	0.039	Richmond, VA	0.031
Sacramento--Arden-Arcade--Roseville, CA	0.043	Baltimore-Towson, MD	0.020
Austin-Round Rock-San Marcos, TX	0.030	Bridgeport-Stamford-Norwalk, CT	0.020
Bridgeport-Stamford-Norwalk, CT	0.025	Columbus, OH	0.016
Providence-New Bedford-Fall River, RI-MA	0.028	Omaha-Council Bluffs, NE-IA	0.011
New Orleans-Metairie-Kenner, LA	0.023	New Orleans-Metairie-Kenner, LA	0.004
Columbus, OH	0.024	Allentown-Bethlehem-Easton, PA-NJ	0.003
Greensboro-High Point, NC	0.020	Birmingham-Hoover, AL	0.002

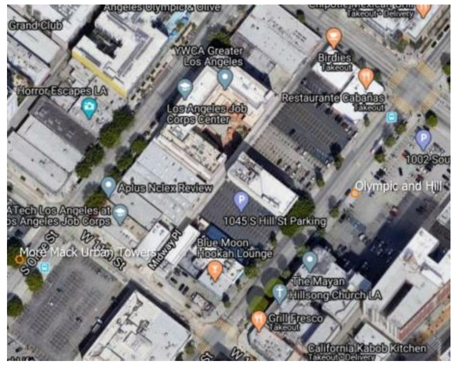
Notes: Table presents 10 CBSAs with the highest and lowest share of business address vacancies in 2008 and 2018. Vacancy data are collected by the US Postal Service and disseminated by the US Department of Housing and Urban Development at the census tract level. Tracts included in the sample are those that lie within 4 km of the CBD. The CBD is identified as the highest population Census place within each CBSA. The share of vacant business addresses for Los Angeles-Long Beach-Santa Ana, which lies between the top and bottom 10 CBSAs, is included for exposition.

Figure 1—Development Projects and Surface Parking in Central Los Angeles

Panel A: South Park

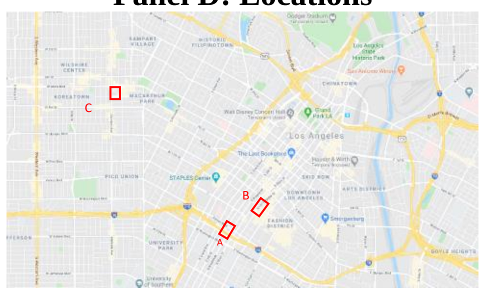


Panel B: Downtown LA



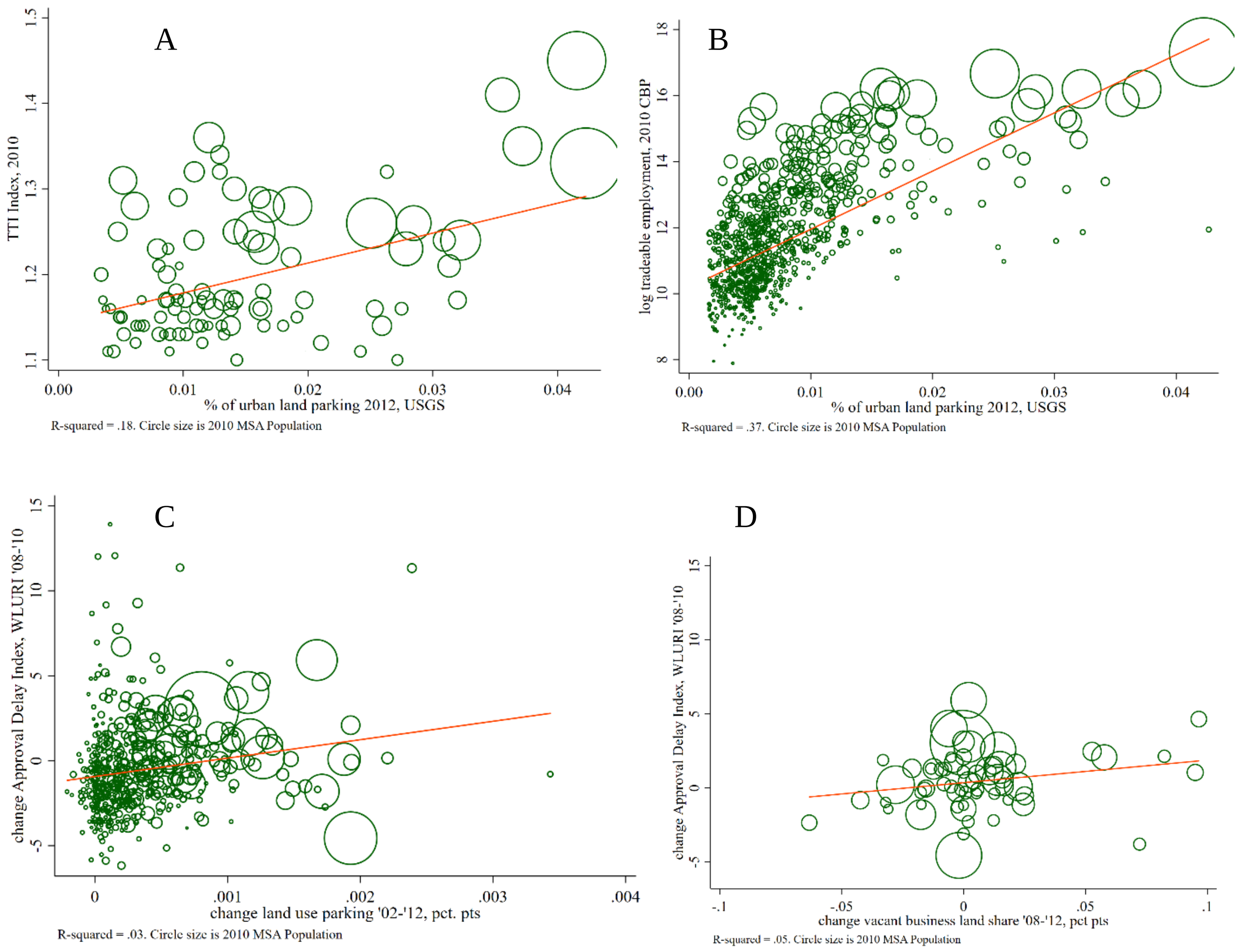
Panel C: Near Koreatown

Panel D: Locations



Notes: This figure illustrates with orange circles various mixed-use and commercial projects planned where surface parking lots exist. Panel A: 1323 Grand, a 28-story high-rise proposed in 2016; Emerald at 1320 Olive Street, shown from street view below. Both properties are in the South Park neighborhood. Panel B: Two nearby projects in southern Downtown Los Angeles, Olympic and Hill at 1034 S Hill Street, a 60-story, mixed-used tower approved in June 2019 and More Mack Urban Towers, a pair of mixed-use skyscrapers at 1115 S Olive Street. Panel C: Vermont Corridor Project at 532 S Vermont Avenue and the Soul Tower at 550 Shatto Place. Panel D shows locations of each map within central Los Angeles. All images from GoogleMaps.

Figure 2—Vacant Land, Surface Parking and Urban Characteristics



Notes: Panel A shows the relationship between Falcone and Nott's (2019) measure of the share of urban land use covered by surface parking in 2012 with the Texas Transportation Institute's Travel Time Index for 2010 and corresponds to 95 cities. Panel B shows the relationship between changes in surface parking land use share and tradeable employment changes from county business patterns and corresponds to 854 CBSAs. Panel C shows the relationship between changes in land use for surface parking and the Wharton Residential Land Use Regulatory Index's (WRLURI) Approval Delay Index (ADI) corresponding to 532 CBSAs, while panel D shows the relationship between changes in the share of vacant business addresses from HUD and changes in the ADI corresponding to 62 CBSAs.

3 Theoretical Model

This section develops a theoretical model of dynamic land use that helps to explain the set of observed facts described in the preceding section. We begin by presenting the main assumptions and theoretical primitives of the urban economy and then proceed in the next section to define how this economy behaves in equilibrium under different economic and regulatory contexts.

3.1 Baseline Model of Rational Vacant Land

Consider an open city represented along a line with a trade center located on the far left-hand side on the origin and the endogenous city boundary, x_c, located on the farther right-hand side of the line.[10] The trade center is bordered to its right by a single endogenous downtown core where all commercial activity results from urban businesses outbidding households and farmers for this location. The market good, Q, produced by the commercial tradable sector, is shipped to the trade center, which is a retailing and transport node located on the origin of the line. Therefore, tradable firms choose production locations that help to minimize the cost of shipping goods to the trade center. The residential zone, on the other hand, is defined as the area over which the housing-supply sector outbids all the other sectors in the economy. Land outside the city boundary is under agricultural use. Three sectors then compete for land in this economy: the tradable commercial, the housing-supply and the agriculture.

Production – The tradable good, Q, is produced using Leontief production technology that combines λ units of land and μ units of labor to produce one unit of Q. Some of this tradable good Q is exported and the rest is for local consumption.

Export demand for the tradable good in each period *t* is an exogenous function, $f(p_t, \Gamma_t)$, of the endogenous unit price for the tradable good in period t, p_t, and an exogenous demand-shifter in period t, Γ_t. Export demand can grow, remain constant or decrease between periods depending on the relative demand-shifter sizes of Γ_t and Γ_{t+1}. There is no storage between periods and Γ_t and Γ_{t+1} are known with certainty in period *t*. All Q must also be transported to the trade center whether it is exported or consumed within the city. Let τ represent the per unit distance shipping cost to the trade center in each period. The tradeable sector employs all resident households in the city.

The housing-supply sector produces single family dwellings of fixed size with on-site parking using 1 unit of land. For simplicity, each unit of residential land bundling housing services and residential parking is time and space invariant. The agricultural sector is assumed to consume only land.

Land Market Outside the Trade Center – All production sectors compete for land over two time periods, $t = 1,2$, of fixed but unspecified length. Absentee landowners anticipate period 2 export

10 The idea of a trade center is related to a central business district but reflects the fact that its importance comes from an employment center for tradable good production.

demand growth with certainty and have perfect foresight of what their land rent will be in both periods for all possible development uses: commercial, residential, agricultural or leaving temporarily land vacant. Temporarily vacant land can still be used for economic return and we assume, following what is observed in many downtown areas, that the highest return temporary use in areas adjacent to commercial land is for surface parking. Assuming that each surface parking space takes s units of land (set to 1 for now) and is sold at an exogenous time invariant price θ per parking space, the return on temporary surface parking per unit of land is $\phi = \frac{\theta}{s} = \theta$.

Land across both periods and in each location is allocated to uses that maximize the intertemporal present value of the return to land over all possible uses. Let R_t^Q represent the bid rent per unit of land for the tradable commercial sector in period t and R_t^H be the bid rent per unit of land for the housing-supply sector in period t. Development projects occur only on undeveloped sites: vacant lots, which could be used as surface parking lots and agricultural land. Conversion from one land use to another in the second period is assumed to be prohibitively expensive and thus irreversible (i.e., residential and commercial structures are durable and nonmalleable).

Land beyond the city boundary is used for agriculture, which earns an exogenous spatially increasing but time invariant return $R_A(x)$ per unit of land, with $R_A(x) < \phi$ inside the CBD, suggesting that land farther away from the CBD has higher-quality soils for agricultural purposes.

City Residents – All city residents are identical and provide a single unit of labor to the tradable commercial sector per period in exchange for a wage w_t. Since multi-destination and multi-purpose trips are not uncommon in urban settings, we assume that city residents combine work and shopping trips when traveling to the trade center either by car or public transit. Once they reach the trade center, they disperse throughout the downtown core by walking. Walking costs are zero within the downtown core. If commuting by car, households park at the trade center. For simplicity, there is unlimited free underground parking provided to all city residents at the trade center.[11]

For analytical tractability, we abstract from substitutability in consumption and assume in each period that city residents consume q units of the tradable good, and one unit of residential land (that is, one single family house with on-site parking) subject to a budget constraint to attain an

[11] For urban spatial models with endogenous parking prices and supply see Brueckner and Franco (2018, 2017). Here we focus on parking land as a temporary urban land use for CBD vacant lots awaiting development.

exogenous utility level which we assume to be constant over time. Given the fixed consumption of housing and allocation to land, housing represents both a consumer good and a spatial location in the city. To ensure that local consumption of the tradable good Q does not exhaust total tradable production, $\frac{1}{\mu} > q$ is assumed to hold.[12] The number of residents in the city in either period, N_t, is endogenous and because the city is open, migration will ensure that every resident obtains the exogenous utility level. Households also consume a fixed amount of an imported good at a fixed time-invariant price (p_Z) normalized to one, that helps to ensure utility balances with changes in q. Because consumption of the imported good does not change and has no impact on the model, we omit it from analytical exposition for parsimony. Therefore, given fixed consumption of housing and the tradable good, household utility is fixed and so changes in rents and commuting costs translate directly into changes in population.

Non-Resident Visitors – Visitors reside outside the city and travel to the downtown core solely for tourism purposes by either car or train. Visitor parking at the trade center is exogenously fixed, underground and limited to $\overline{N_v}$ parking spaces, though temporary visitor parking may be endogenously supplied outside the trade center but within the downtown core as a temporary land use of vacant land awaiting development.[13] Visitors are indifferent between parking at the trade center or in surface lots outside the trade center. Once at the CBD, visitors disperse throughout the CBD area by walking at cost zero.

Resource Balance – Total production of the tradable good in a given period, Q_t, satisfies both the external and domestic demands and is represented as

$$Q_t = f(p_t, \Gamma_t) + N_t * q, \quad t = 1,2 \tag{1}$$

with $\Gamma_1 < \Gamma_2$.

Commuting –Residents travel to the trade center either by car or by public transit. Public transit users pay a time-invariant, round-trip fixed cost F^p and a time-invariant, unit distance round-trip

[12] If at least some Q is exported, $f(p, \Gamma) > 0$, so $Q(1 - \mu q) > 0$ and this implies that $\frac{1}{\mu} > q$. $f(p, \Gamma)$ is the domestic production of the exported good, which is decreasing in p increasing in Γ.

[13] Future work may explore the case where visitors participate in the city labor market and/or contribute to the city agglomeration economies in terms of consumption or production.

travel cost of t^p, while the operating cost of the transit system is D per passenger.[14] On the other hand, drivers incur a time-invariant, round-trip fixed cost F^c, with $F^c > F^p$, and a round-trip travel cost t^c per unit distance such that $t^p > t^c$. Resident commuters who drive park their identical cars when commuting downtown in free underground parking structures that take up no additional land in the trade center. Housing includes housing services and on-site parking. The difference in variable unit commuting costs between travel modes means that it is cost-effective for public transit-using households to live closer to the trade center than car commuting households. As a result, there will be a modal boundary in the city in each period t, x_{ts}, separating residents who commute by car from those using public transit Given higher unit distance commuting costs, public transit commuters live on the trade center-side of the modal boundary while car users live on the other side of the modal boundary towards the city fringe as shown in Figure 3.

Driving imposes traffic congestion in the downtown core which we assume to be a linear function of the number of drivers (visitors and residents) entering downtown in a given period, $g(N_t^c) = N_t^c$. The linearity of congestion holds under the assumption of fixed and spatially undifferentiated road capacity.[15] The generalized cost of a resident´s car trip to the trade center from his place of residence located at x is thus $F^c + t^c x + N_t^c$. The costs of a visitor auto commuting include the parking fee θ and a congestion cost. If $\theta + g(N_t^c) < F^v$, visitors commute by car if visitor parking exists in the downtown area. For analytical tractability visitor parking at the trade node ($\overline{N_v}$) is always full (regardless of the period) and this information is known to visitors in both periods. Visitors also know that in period 1 there is visitor surface parking in the downtown area outside the trade center.[16]

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[14] For now, we assume transit is self-financed by the fixed cost of transit, but further financing through alternative policies (e.g., driving tolls) are considered later. In this paper we abstract from scale effects of ridership on fares, though they are clearly important for studies with a greater focus on scale economies in public transit.

[15] A linear congestion function helps to simplify our analytical results, but does not qualitatively change the conclusions. Linear congestion has been used widely in structural analyses of traffic such as the canonical bottleneck model (Arnott et al., 1993). In numerical results in section 6, we explore a non-linear form of congestion which follows Greenshield et al.'s (1935) functional form.

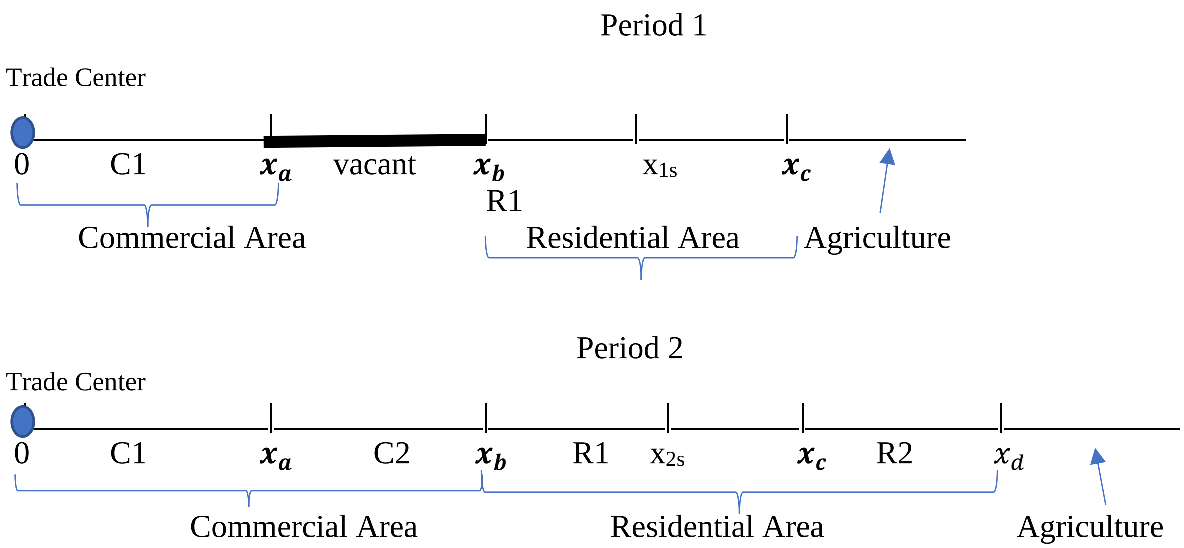
[16] When there is no vacant land in the downtown area, there are no visitors commuting by car to the downtown area, other than the exogenous number $\overline{N_v}$, which represent an exogenous time-invariant fixed source of traffic congestion since visitor parking is always full in each period.

Spatial Structure and Urban Form –All development decisions are made at the start of period 1 with perfect foresight.[17] Provided that $\frac{\tau}{\lambda} > t^p$ is satisfied, residential development lies more distant from the trade center than commercial development in each period. However, it is not certain that all second-period development will lie beyond the first-period city boundary ($\boldsymbol{x_c}$). Given the non-malleability of structures, it may be advantageous for landowners to preserve some parcels in period 1 between the commercial and residential zones for second-period commercial use as seen in Figure 3 and illustrated in Appendix Figure A.1. This vacant land use is more likely to occur the greater $\frac{\tau}{\lambda}$ is relative to t^p. Since this land use pattern is the focus of our study, we assume $\frac{\tau}{\lambda} \ggg t^p$.

Finally, denote x_a as the endogenous outer developed edge of the downtown core, x_b the endogenous inner boundary of the residential zone and x_c and x_d the endogenous outer spatial boundaries of the residential zone (or city boundaries where the urban area ends and the rural area begins) in periods 1 and 2, respectively. Land within the residential zone is fully developed. Since we aim to explore the existence of surface lots on vacant land, we assume that $x_a \leq x_b$ implying that some of the land within the downtown area can be left vacant as shown in Figure 3 and Appendix Figure A.1 using the bid land rent functions.

[17] A full description of the assumptions underlying timing of development decisions is presented at the beginning of the next section.

Figure 3—Equilibrium Land Use Pattern with Vacant Land in Period 1



Notes: This figure illustrates the two-period spatial structure of the urban economy. The blue dot indicates the trade center. C1 and C2 represent allocated commercial land in periods 1 and 2, respectively. R1 and R2 represent residential land in periods 1 and 2, respectively. Note also that urban development is irreversible, each unit of residential land bundles housing with on-site parking and that the trade center houses underground parking for both residents (free and unlimited) and visitors (paid and limited). Visitors can also park in period 1 on vacant land awaiting development under temporary paid surface parking.

4 Causes of Vacant Land and its Use as Temporary Surface Parking Lots

In this section we explore competing explanations for the existence of vacant land in downtown areas. We begin by laying out the baseline use of land with no regulatory delay nor expectation of future urban growth. We then demonstrate the effect of regulatory delay on urban form, urban spatial structure and on other key urban variables and discuss how unexpected regulatory delay can distort the allocation of land over space and time. Next, we illustrate how the expectation of export demand growth can generate rational temporary uses for vacant land (and thus temporary surface parking lots) in the absence of regulatory delay. Finally, we consider cases when both sources of vacant land exist and when there is uncertain regulatory delay, that is, when landowners know there is a probability that just a certain amount of commercial building permits will get approved on time by the beginning of period 1.

We assume a simplified three-stage process for building permit submission and approval that allows us to capture the salient features of this process in a simple model. In the next subsections we will extend our setup to incorporate some greater complexity.

Three-Stage Development Process – In period 0, landowners have access to an area of land that can be developed for urban use and they submit a development plan for the subsequent two periods to the municipal development agency (MDA) who needs to approve the necessary commercial building permits and residential building permits for periods 1 and 2. Since landowners have perfect foresight, decisions concerning first and second period development are incorporated in the development strategy set up in period 0 rather than postponed as in the case of a sequential decision process. Each location along the linear city requires one specific building permit (commercial or residential) to start construction. Even though the land development code mandates a timeframe by which full-cycle site plan applications should be approved/disapproved, sites may suffer a regulatory delay that adds additional time to the mandated timeframe. In our framework and consistent with anecdotal evidence, we assume that there may be delays with the approval of building permits, but there is no delay with the approval of temporary use permits for sites awaiting building permit approval. Temporary use permits are granted in the same period in which they are requested. In addition, we assume landowners know that if regulatory delay occurs, the portions of the city for which building permits approval are delayed will be obtained with certainty by the beginning of the following period. For simplicity, we abstract from the price of building permits.

At the beginning of period 1, whatever development (that is, building permits) is approved by the MDA is built, the corresponding urban equilibrium occurs and then in period 2, the development plan decided in Period 0 occurs. We assume, for the purposes of the context of interest in this study, there is no delay with the required building permits for period 2. Note that if regulatory delay occurs at the beginning of Period 1, landowners may apply for temporary use permits for sites waiting for building permit approval.

4.1 Export Demand is Constant over Time ($\Gamma_1 = \Gamma_2$)

No Regulatory Delay – Table 2 presents the equilibrium conditions when there is no regulatory delay and export demand is constant over time, that is, there is no source of economic growth for the urban area. The equilibrium conditions consist of 18 equations with 18 endogenous variables: $Q_1, Q_2, x_a, x_b, x_c, x_d, x_{1s}, x_{2s}, P_1, P_2, w_1, w_2, R_1^Q, R_2^Q, R_1^{HP}, R_2^{HP}, R_1^{HC}$, and R_2^{HC}. These balance across production, housing, labor and land markets. Note also that the urban equilibrium in this scenario generalizes to the urban equilibrium predicted by a static, traditional monocentric model, with the addition in our framework, of forward-looking developers.[18]

Table 2—No Regulatory Delay, No Export Growth Urban Equilibrium Conditions

	Period 1	***Period 2***
1	$Q_1 = f(P_1, \Gamma_1) + \mu q Q_1$	$Q_2 = f(P_2, \Gamma_2) + \mu q Q_2$
2	$w_1 = R_1^{HC} + P_1 q + F^c + x_c - x_{1s} + \overline{N_v}$	$w_2 = R_2^{HC} + P_2 q + F^c + x_d - x_{2s} + \overline{N_v}$
3	$w_1 = R_1^{HP} + P_1 q + F^p$	$w_2 = R_2^{HP} + P_2 q + F^p$
4	$P_1 = \mu w_1 + \lambda R_1^Q$	$P_2 = \mu w_2 + \lambda R_2^Q$
5	$\lambda Q_1 = x_a$	$\lambda Q_2 = x_b$
6	$\mu Q_1 = x_c - x_b$	$\mu Q_2 = x_d - x_b$
7	$R_1^{HC} - t^c x_c = R_A(x_c)$	$R_2^{HC} - t^c x_d = R_A(x_d)$
8	$x_{1s} = \dfrac{F^c - F^p + x_c + \overline{N_v}}{1 + t^p - t^c}$	$x_{2s} = \dfrac{F^c - F^p + x_d + \overline{N_v}}{1 + t^p - t^c}$
9	$R_1^Q - \dfrac{\tau x_a}{\lambda} = R_1^{HP} - t^p x_a$	$R_2^Q - \dfrac{\tau x_b}{\lambda} = R_2^{HP} - t^p x_b$

The first equilibrium condition in Table 2 equates the total quantity of the tradeable good produced, Q_t, to the quantity exported, $f(P_t, \Gamma_t)$ plus domestic consumption, $\mu q Q_t$. The second and third conditions ensure that city residents' budgets balance for private car and public transit users, respectively. This requires that the households' wage, w_t, equals expenditures on housing, R_t^{HC} and R_t^{HP}, the tradable good, $P_1 q$, and fixed transportation costs including those from traffic congestion for drivers. R_t^{HC} is the bid land rent for a residential site located in the trade center ($x = 0$) for car commuting households in period t, while R_t^{HP} has the same interpretation for public transit commuting households. These bid land rents reflect the maximum willingness-to-pay for a

18 In a city growing gradually over time one would expect developers to take this growth trajectory into account and acknowledge that development is an irreversible investment. Capozza and Helsley (1990) present a different framework from ours, yet tractable monocentric model with irreversible development and perfect foresight.

unit of land for housing at the trade center ($x = 0$) depending upon the commuting technology used by city residents, and therefore variable travel costs are zero.

How the land price function, represented by the upper envelope of the sectors' bid land rent, evolves with distance from the trade center is illustrated in Appendix Figure A.1. As households move away from the trade center their maximum WTP for a unit of land decreases in the amount of the variable travel cost they must incur. Therefore, the rental price of residential land for car users is given by $R_t^{HC} - t^c x$ and for transit users is given by $R_t^{HP} - t^p x$, where the slopes are determined by unit distance transport cost. Since $F^c + x_c - x_{1s} > F^p$ and $t^p > t^c$, it follows that $R_t^{HP} > R_t^{HC}$ and transit users have steeper bid rents than car users. In addition, the modal boundary occurs where the two residential bid land rents intersect meaning that at that location households are indifferent between the two transport modes for their multi-destination trips. Because there is no vacant land (and therefore no surface lots for visitors) in the first period, visitors commuting by car to the downtown area just park underground at the trade center. Under such a scenario, there is no traffic externality from vacant land as temporary surface parking lot. This outcome will change with regulatory delay or export growth.

The fourth condition enforces zero profits on the production of the tradable good as the market is perfectly competitive. This sets the price of the exported good, P_t, equal to production costs from labor, μw_1, and land, λR_t^Q. R_t^Q is the bid rent for a unit of land for commercial use at the trade center in period *t*. The fifth condition sets equal the amount of land for commercial use, λQ_t, to the boundary of the commercial region, x_a in the first period and x_b in the second, which simply defines the length of these regions relative to the trade center at $x = 0$. The sixth condition equates the amount of land to house all employed city workers, μQ_1, with the area of the residential zone, $x_c - x_b$ in the first period and $x_b - x_d$ in the second period. [19]

The seventh condition states that residential bid land rents at the urban boundary adjusted for the variable commuting costs, $t^c x_c$ in period 1 and $t^c x_d$ in period 2, equal the agricultural rent's value at that boundary.[20] This is the standard urban equilibrium condition that determines the urban

[19] Since there is no unemployment, total population equals total workers and because each resident consumes 1 unit of residential land and the tradable good production function uses a Leontief technology that requires μ units of labor to produce one unit of Q, total residential land demanded by residents in a given period equals μQ_t.

[20] Since $x_d \geq x_c$ and $R_A(x_c) < R_A(x_d)$, $R_2^{HC} > R_1^{HC}$. In our simulation we set $R_A(x_c) = R_A(x_d)$, suggesting there is a distance from the trade center after which the soil quality is equally good for agriculture.

boundary in each period. Here, and even in myopic models, land is developed so long as the urban land rent net conversion costs equals the agricultural land rent.

The eighth condition in Table 2 defines equality of residential bid rents between public transit and private vehicle commuting households at a modal boundary, $x_{ts}, \ t = 1{,}2$. This condition yields an analytical expression for the location of the modal boundary in each period.

Finally, the ninth condition defines the equality of bid rents at the commercial-residential boundary, x_a in period 1 and x_b in period 2. Bid rents for commercial land diminish with the unit transportation cost of goods, $\frac{\tau}{\lambda}$, and those for residential land diminish with the public transportation unit commuting cost, t^p. Once we account for the existence of vacant land in the downtown area, this condition may no longer hold as will become clear next.

In this context described, urban development occurs entirely during the first period and there is no land withheld in the downtown core for future development. In addition, in the second period, equilibrium prices and quantities (i.e., wages, tradable good price, land rents, and the production of the tradable good) remain the same as in Period 1 because there is no growth in the export demand ($\Gamma_1 = \Gamma_2$). This suggests that the equilibrium in both periods is entirely determined in Period 1 and can be expressed as follows:

$$x_b = x_a, x_d = x_c, x_{2s} = x_{1s}, Q_2 = Q_1, P_2 = P_1, w_2 = w_1, \\ R_2^H = R_1^H, R_2^Q = R_1^Q. \tag{2}$$

We now proceed to consider the case where there is regulatory delay with commercial building permits to develop $x_b - x_a$ units of land in the downtown core in Period 1, preventing the landowner from developing the optimal amount of commercial land in Period 1.

Regulatory Delay – Consider now the case where landowners know that at the beginning of Period 1, they just received approved commercial building permits for sites located up to distance $\bar{x}_a < x_b$ from the trade center because of regulatory delay. However, they also know that any remaining approvals to complete the downtown commercial project will arrive at the beginning of Period 2 and that while waiting for the approvals they can get temporary use permits as surface parking lots for those sites awaiting approval to start commercial construction. Given this information on the permit approval process, landowners know with certainty at the outset the nature of regulatory delay and therefore formulate a development plan for Periods 1 and 2 taking into account what is allowable in Period 1. Developers form their plans in a manner consistent with there being a temporary development moratorium over sites located between $\bar{x}_a$ and x_b, where they know that the moratorium will be lifted at the beginning of the second period.

With perfect foresight and regulatory delay, a pattern of leapfrog development emerges with some downtown land $(x_b - \bar{x}_a)$ in Period 1 held vacant awaiting the approval of commercial building permits. This, in turn, implies that the outer boundary of the commercial area (x_a) is determined by the number of approved commercial building permits $(\bar{x}_a)$ available in Period 1 and no longer coincides with the inner boundary of the residential zone (x_b), namely $x_a < x_b$, as it was the case with no-regulatory delay.

Moreover, as a result of this change in land use, the supply of the tradable good, its price, the worker's salary and bid land rents within the urban area will no longer be the same in both periods as in the no-regulatory delay case. Moreover, the fixed proportions production technology means that the extent of these effects may be quite large since firms cannot substitute labor for temporarily unavailable land. We will relax this production technology assumption in our numerical exercises.

The equilibrium conditions under regulatory delay vary from those in Table 2 in a few key ways.[21] With regulatory delay, Period 1 equilibrium conditions (2) and (8) from Table 2 must now account for traffic congestion from visitors parking on vacant land under surface parking. As a result, conditions for the budget constraint of car commuter and the modal boundary in Period 1 become:

$$w_1 = R_1^{HC} + P_1 q + F^c + x_c - x_{1s} + +\overline{N_v} + \frac{x_b - \bar{x}_a}{s} \tag{3}$$

$$x_{1s} = \frac{F^c - F^p + \frac{x_b - \bar{x}_a}{s} + x_c + \overline{N_v}}{1 + t^p - t^c}. \tag{4}$$

In addition, Period 1 land use for commercial sites (condition (5) in Table 2) is constrained by regulatory delay to $\bar{x}_a$:

$$\lambda Q_1 = \bar{x}_a\ . \tag{5}$$

Regulatory delay also adds further conditions on urban boundaries such that $\bar{x}_a < x_b$ and $x_b < x_c < x_d$. We also have that $\Gamma_1 = \Gamma_2$. This means that the equality of prices and quantities over the two periods no longer holds. Furthermore, the existence of vacant land in Period 1 between x_a and x_b means that Table 2 equilibrium condition (9) in period 1 also no longer holds, but rather

[21] Appendix Table A.1 summarizes all the equilibrium conditions when there is regulatory delay and no export growth.

must reflect the trade-off in returns of development at $\bar{x}_a$ between commercial use and the temporary land use as a surface parking lot yielding [22]

$$R_1^Q - \frac{\tau\bar{x}_a}{\lambda} = \theta. \tag{6}$$

There is no analogous condition to equation (6) for Period 2 because $\bar{x}_a$ is no longer a boundary site as commercial land exists on either side of this city location in the second period. Equilibrium condition (10) in Appendix Table A.1, on the other hand, defines the equilibrium condition that landowners follow for determining x_b from the intertemporal relationship between bid rents at this location as

$$R_1^{HP} - t^p x_b + \frac{1}{1+r}[R_2^{HP} - t^p x_b] = \theta + \frac{1}{1+r}\left[R_2^Q - \frac{\tau x_b}{\lambda}\right]. \tag{7}$$

Equation (7) sets equal the present discounted value of development for residential use to that for commercial use at the boundary between vacant land and residential use (x_b). It is worth mentioning that in our setting there is a discontinuity in the equilibrium land bid rent in each period at location x_b, which is absent in the equilibrium properties of static monocentric models. Next, we present the equilibrium land-rent functions in each period as

Period 1		**Period 2**	
$R_1^Q - \frac{\tau x}{\lambda}$,	for $x \in [0, \bar{x}_a]$	$R_2^Q - \frac{\tau x}{\lambda}$,	for $x \in [0, x_b[$
θ	for $x \in [\bar{x}_a, x_b[$	$R_2^{HP} - t^p x$	for $x \in [x_b, x_{2s}]$
$R_1^{HP} - t^p x$	for $x \in [x_b, x_{1s}]$	$R_2^{HC} - t^c x$	for $x \in [x_{2s}, x_d]$ (8)
$R_1^{HC} - t^c x$	for $x \in [x_{1s}, x_c]$	$R_A(x)$	for $x \in [x_d, +\infty]$
$R_A(x)$	for $x \in [x_c, +\infty]$.		

However, according to (7) these discontinuities offset each other once land rent in Period 2 is discounted, indicating that the function of the equilibrium present value of both period´s land is continuous at every city location. From equation (7), if used for residential use, public transit commuters living at x_b have a bid land rent of $R_t^{HP} - t^p x_b$ in each period. Alternatively, land can be left vacant (but temporarily as a parking lot) at x_b in the first period, earn return θ per unit, and

[22] Note that the two land use sequences on the two sides of $\bar{x}_a$ are (commercial in period 1, commercial in period 2) and (parking in period 1, commercial in period 2). These two sequences must provide the same present value at $\bar{x}_a$. Setting $R_1^Q - \frac{\tau\bar{x}_a}{\lambda} + \frac{1}{1+r}\left[R_2^Q - \frac{\tau\bar{x}_a}{\lambda}\right] = \theta + \frac{1}{1+r}\left[R_2^Q - \frac{\tau\bar{x}_a}{\lambda}\right]$ and simplifying yields condition (9)`. Note that second period returns are discounted at a rate r.

then be used for commercial use in the second period, with a land rent of $R_2^Q - \frac{\tau x_b}{\lambda}$.[23] An important implication of the model that will affect our equilibrium conditions is that, as compared with static monocentric urban models, bid rents need not always equate at all boundaries (so the equilibrium configuration in one period may exhibit discontinuities), since one of the boundaries, namely x_b , will be determined by an intertemporal equilibrium condition, so that higher return to land use at that boundary in one period might offset lower return in another.[24]

Proposition 1 summarizes our theoretical findings that relate Period 1 and 2 equilibrium outcomes.

Proposition 1. *In an open city with perfect-foresight, Leontief production of a tradable good and no urban growth, unexpected regulatory delay causes a reduction (relative to the second period) in first period production and city size. It also increases the price of the tradable good in this period. Moreover, regulatory delay generates leapfrog development in the first period by preventing all the downtown core land to be developed at the optimal date which in turn reduces first period commercial and residential land rents inside the urban area.*
Proof: *See Appendix.*

Proposition 1 helps to define a few features of dynamic spatial equilibrium under regulatory delay. The urban equilibrium configuration in Period 1 has leapfrog development ($x_a < x_b$) that affects both urban form and urban spatial structure in this period. As a result, both commercial and residential zones are smaller in the first period, which is amplified by fixed factor production technology. If the commercial zone contracts in Period 1 then less land is needed in Period 1 to accommodate the necessary workers for production, resulting in a city smaller in physical size ($x_c < x_d$) with lower production of the tradable good ($Q_1 < Q_2$) relative to Period 2. Since we assume that $\frac{1}{\mu} > q$ holds, then P_1 must be greater than P_2 to decrease the exported quantity demanded of the tradable good and thus attain the equilibrium between demand and supply in the tradable good market. We will explore these effects further in our simulation exercises.

Unexpected regulatory delay also affects the location of the modal boundary. While the modal boundary in Period 2, x_{2s} , stays in the same location with and without unexpected regulatory

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[23] In our simulations we show that $R_1^{HP} - t^p \bar{x}_a + \frac{1}{1+r}[R_2^{HP} - t^p \bar{x}_a] < \theta + \frac{1}{1+r}\left[R_2^Q - \frac{\tau \bar{x}_a}{\lambda}\right]$ and that condition (10) is just met when evaluated at x_b, where $x_b > \bar{x}_a$.

[24] In section 6, we perform numerical exercises under alternative assumptions including the ability for landowners to re-optimize under regulatory delay.

delay, the modal boundary in Period 1, x_{1s}, faces has two opposing forces: (i) congestion from visitors parking in temporary downtown surface lots decreases the attractiveness of car commuting relative to public transport and pushes the first period modal boundary further away from trade center; (ii) the decrease in city size in the first period pushes the first period modal boundary towards the trade center. This makes the location of modal boundaries in each period relative to each other ambiguous from a theoretical standpoint.

It is also possible to get some insights into what happens to land rents in Period 1 with unexpected regulatory delay. Since there is less land available for commercial development in Period 1, R_1^Q is higher with regulatory delay relative to R_2^Q because of the scarcity created by the regulatory delay. However, because Q_1 uses a Leontief technology, less workers are also needed in Period 1 which decreases demand for residential land outside the downtown area leading to lower residential bid rents, R_1^{HP} and R_1^{HC}, in the first period. Finally, from the zero-profit condition in the first period ($P_1 = \mu w_1 + \lambda R_1^Q$) we note that the effect on wages in period 1 (w_1) is ambiguous. While P_1 increases (and pushes wages up), R_1^Q also increases in Period 1 (which may push wages down if the upward effect of unexpected delay on R_1^Q is very strong). Such ambiguity will also be clarified in our simulation exercises in Section 6.

4.2 Increase in Export Growth in Period 2 ($\Gamma_2 > \Gamma_1$)

No Regulatory Delay – As discussed above, another reason for the existence of vacant land in downtown areas could be rational forward-looking land development when building structures are durable and non-malleable. Under these conditions, it may make sense for landowners to postpone commercial development on downtown parcels when they expect future export growth. Note that the equilibrium conditions under this scenario are the same as those described in the Appendix Table A.1 with the difference that x_a is now endogenously determined by the landowner to maximize profits instead of being imposed by MDA. Similarly, the pattern of land rents corresponds to Appendix Figure A.1.

We can compare land use under this new scenario to the regulatory delay case. Let $\bar{\bar{x}}_a$ represent the optimal first period boundary between commercial land and vacant land under the current scenario (export growth without regulatory delay). Suppose that $\bar{\bar{x}}_a = \bar{x}_a$, the level set exogenously by the MDA with no growth with regulatory delay. For this to be the case, it must be that Γ_2 under export growth equals export demand in both periods under regulatory delay and, as a result, Γ_1 in the export growth case is lower. It follows that other equilibrium outcomes will also be the same. Yet, the regulatory delay case is economically inefficient due to development restrictions, while under export growth with no regulatory delay and ignoring externalities the outcome would be efficient. In other words, two cities may have the same patterns of vacant land, but one reflects an inefficiency and the other is optimal, suggesting a nuanced approach to policy design may be required to disentangle means from ends.

Regulatory Delay – With export growth and regulatory delay, the equilibrium conditions are also the same as those described in Appendix Table A.1 with the exception that $\Gamma_2 > \Gamma_1$ and x_a is now exogenously determined by MDA. As seen earlier, both features imply vacant land in the first period. While regulatory delay is inefficient, export growth in Period 2 attenuates some of the cost of regulatory delay because it is already optimal without regulatory delay for landowners to leave some commercial land vacant in the downtown core in the first period. We summarize this result in the following proposition.

Proposition 2. *In an open city, with Leontief production of a tradable good, the effect of unexpected regulatory delay will be less costly to output with positive export growth.*

Proof: *See Appendix.*

How much the cost of regulatory delay is attenuated by export growth depends on the level of regulatory delay. We have already shown that regulatory delay results in land being left undeveloped in Period 1, so that the commercial boundary is $\bar{x}_a$ rather than x_b, with $\bar{x}_a < x_b$. With export growth and no malleability, it is also optimal for $x_a = \bar{\bar{x}}_a < x_b$, so that some land near the downtown area is left vacant for second period development. Therefore, the magnitude of the inefficiency created by regulatory delay in terms of land use allocation and remaining urban variables depends on how far away $\bar{x}_a$ is from $\bar{\bar{x}}_a$ with $\bar{x}_a < \bar{\bar{x}}_a$. It is worth noting that if $\bar{x}_a \geq \bar{\bar{x}}_a$, then the effects of regulatory delay are not binding to development plans. In our numerical exercises we illustrate and explore further this equilibrium.

5 Policies to Address Congestion Externalities

The focus of the paper so far has been on understanding the mechanisms that may lead to the existence of surface parking lots on vacant land awaiting development in downtown areas. Two mechanisms have been posited: regulatory delay in the approval of commercial building permits (both unexpected and uncertain) and rational forward-looking behavior with nonmalleable structures. In the first instance, regulatory delay is clearly the source of the inefficiency. In the second instance, the mechanism leading to vacant land is not inefficient, in and of itself. However, its temporary use as surface parking is a source of inefficiency when additional congestion brought by visitor surface parking induces costs on the urban economy. These costs are not considered by landowners when allocating that temporary vacant land and so it is overallocated to this use.[25] In this section we discuss the design of dynamically efficient land use/transportation policy, and then we explore additional issues further in our numerical examples in sections 6 and 7. Since there are two types of individuals in our model generating congestion externalities (driving resident commuters and non-resident visitors) we will consider two distinct policy instruments, one to address each.

Congestion Toll on Resident Commuters – We first consider the case where temporary land use of vacant land waiting for development creates no externalities. In such a scenario, the marginal worker living at $x_{ts}, t = 1,2$, will have equal bid-rent reflecting indifference between each commuting mode:

$$N_t^c + F^c + t^c x_{ts} = F^P + t^P x_{ts}, \quad t = 1, 2. \tag{9}$$

Building on the description of congestion from section 3, the total external cost to all other drivers on the road is N_t^c, which is the optimal dynamic congestion toll for resident commuters.[26] We now turn to the following proposition, which characterizes the effect of a congestion toll on mode shares in the model.

Proposition 3. *In an open city with first period vacant land and traffic congestion, the addition of the Pigouvian congestion toll will shift the modal boundary outwards and reduce the number of resident drivers.*

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[25] For ease of exposition, we will consider next the case where the fixed number of underground visitor parking at the trade center is zero, $\overline{N_v} = 0$. We will also assume there is no regulatory delay, since our focus is on regulating externalities.

[26] The congestion externality imposed by a single driver also depends on fixed road capacity, which can be thought of as a scaling factor $\frac{1}{k}$, where k is the road capacity factor. We assume it is 1, for ease of exposition, so that the total external damages are $\frac{1}{k} \cdot N_t^c = N_t^c$.

Proof: *See Appendix.*

The intuition for this result is straightforward: a congestion charge increases the financial cost of driving but also reduces the congestion time cost. The net effect will be to reduce driving and therefore increase public transit use, shifting the modal boundary to the right.

Tax on Temporary Surface Parking Spaces – We now turn to the endogenous congestion caused from visitor cars. To simplify our discussion, we assume that visitor parking in underground spaces at the trade center is zero, so $\overline{N_v} = 0$. As a result, congestion from visitor cars is tied to the quantity of temporary visitor parking in the downtown core built on vacant lots awaiting development.[27] Since congestion externalities from visitors impose no direct cost on landowners, landowners do not account for its impact in their allocation and use of vacant land, and so to address this additional source of traffic congestion requires an additional policy instrument.

Given that we do not model travel demand for visitors, but their presence comes directly from the existence of temporary surface parking land in our model, the simplest policy to address this type of externality is a tax per unit of waiting vacant land under surface parking charged to CBD landowners in Period 1.[28] Note that the cost of congestion from one additional visitor is N_t^c, so that the corresponding tax per unit of surface parking land is given by $\frac{N_t^c}{s}$. For simplicity, we set the land size of a surface parking space, s , equal to 1.

Since the number of temporary surface parking spaces is given by $\frac{x_b - x_a}{s}$, a policy to regulate the number of visitors effectively determines the amount of vacant land used for temporary surface parking, $x_b - x_a$, and would therefore lower the return of this temporary use on vacant land by N_t^c as follows

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[27] Visitors are expected to demand trips to the commercial area inelastically. While this is not necessarily a realistic assumption, modeling recreational demand for visitors is beyond the scope of this study, which seeks instead to consider the effect of externalities on equilibrium outcomes. More elastic visitor demand would reduce the extent of the congestion externality.

28 Note that an alternative policy would be to set a minimum parking space size, $\underline{\underline{s}}$ which will reduce the amount of visitors for a given amount of vacant land. In the extreme case where $\underline{\underline{s}} > \overline{\overline{x_b - x_a}}$, there are no visitors.

$$R_1^Q - \frac{\tau x_a}{\lambda} = \theta - N_1^c. \tag{10}$$

How will landowners respond to this tax? The answer is complicated by the fact that they can reduce the number of visitors by reducing vacant land as surface parking through either moving x_a rightward which increases the amount of commercial land in period 1, or moving x_b leftward which decreases the amount of commercial land in period 2. To balance equation (10), the addition of N_t^c would mean that either x_a may increase, R_1^Q may decrease, or both. We summarize this result in the following proposition.

Proposition 4. *In an open city with first period vacant land as temporary surface visitor parking in the trade center and traffic congestion from both visitors and residents, the addition of a tax on temporary surface parking charged to landowners of* $\frac{N_t^c}{s}$ *will reduce the quantity of vacant land under surface parking and therefore visitors to the trade center.*

Proof: *See Appendix.*

We have now shown how policies to address the negative congestion externalities can address distortions from vacant land in the absence of regulatory delay. Since it is not possible to obtain analytical (equilibrium) results for all the variables in our model, the results of a numerical illustration fully consistent with the analytical model and discussion are presented next to discuss the effects of traffic congestion, externalities from temporary uses of downtown vacant land and congestion pricing on urban form, urban structure, land rents and travel mode choices.

6 Numerical Examples and Extensions

This section presents a set of numerical examples to evaluate the robustness of the conclusions in section 3 and further explore the results in sections 4 and 5. Part of the insight of these numerical exercises is the ability to compare outcomes between scenarios, whereas our results in Propositions 1-4 focus on differences between the first and second period, comparing an equilibrium with vacant land to a subsequent one where that vacant land has been developed. We first calibrate the model to generate identical levels of first-period vacant land under the two principal mechanisms explored in the paper: i) perfect-foresight with non-malleable structures with export demand growth and ii) regulatory delay. This allows us to understand how the same observed level of vacant land in a downtown area could be either rational and socially optimal or reflective of an inefficiency. This calibration allows us to better compare the relative inefficiencies of similar inefficiencies with different underlying mechanisms (rational vacant land and regulatory delay). We compare urban spatial structure, urban form, prices, output and overall welfare between these two explanations to understand their differences. We then explore how externalities from temporary land uses on vacant land awaiting development, specifically negative ones from visitor congestion occurring even under perfect foresight, can result in less than socially optimal outcomes. This also has further policy implications as temporary land uses or transitional activities on an efficient vacant lot may have external effects on urban areas.

6.1 Setup and Calibration

The model is a two-period dynamic model, where landowners attempt to maximize the net present value of total rents from multiple land uses: residential, commercial, agriculture and temporary surface parking use. We obtain solutions to the endogenous variables of the model by solving the non-linear system of equations defined in Appendix A.3.[29] When there is no regulatory delay or export growth, the model collapses to a single-period static monocentric city model. In our main results, we employ a Leontief production technology as described in the theoretical sections, but in Section 7, we consider the case of a Cobb-Douglas production technology.

Appendix Table A.2 presents the calibration of our parameters. It is worth briefly discussing the choice of parameters. First, several parameters are normalized to unity to simplify analysis since they do not qualitatively change the nature of our results: the quantity and price of the quantity of the exported good consumed by each household, and residential land (bundled with on-site parking) use per household. The intercept of export demand is assumed to increase by 50% in the second period to reflect a substantial increase in export demand. The productivity of labor is assumed to be five times that of land. Unit transport costs for auto users is lower than that for transit users reflecting variable time costs, while fixed costs are higher for auto users reflecting the fixed cost of car ownership.

Rather than model congestion using the simple linear form described in Section 3, we use a more realistic non-linear congestion function. In simulations including congestion from residents, we use the following functional forms to parametrize the congestion function:

29 We repeat solution with different starting values to ensure that the non-linear system of equations has reached the global solution point.

$$\begin{array}{ll} \theta[x_b - x_a + x_c - x_{1s}]^{\Psi} & \text{in first period} \\ \theta[x_d - x_{2s}]^{\Psi} & \text{in second period.} \end{array} \quad (11)$$

Finally, as in our theory sections, we follow the usual assumption implicit in urban models that land rents go to absentee landowners and that tax revenues are equally distributed lump-sum among city residents. Future work interested in considering the efficiency and equity implications of different distributional systems could extend our model by allowing alternative allocation mechanisms for land rents and tax revenues.

6.2 Baseline Models of Vacant Land in a Two-Period Setting

Figure 3 shows various spatial structure configurations for the dynamic monocentric city. Scenarios A1 and A2 illustrate examples of optimal delayed land development and regulatory delay, respectively. Each color corresponds to land area developed for a specific land use across both time periods: blue for commercial land developed in first period, red for land vacant in first period but developed in the second period, green for residential use developed in the first period, and orange for residential use developed in the second period. We remind the reader that structures are durable and nonmalleable in our model and therefore development in a period is an irreversible land use as we abstract from the possibility of redevelopment strategies.

From Figure 4, the region of vacant land in the first period, in red, is identical for both A1 and A2 scenarios (land area 0.169), while the remaining spatial structure differs. In particular, the overall city size in both time periods is smaller under regulatory delay, reflecting its distortionary impacts. Despite nearly identical parametrization, regulatory delay lowers the return on land across both periods in the city and therefore results in smaller land allocations across multiple uses to all city areas. Because of the Leontief production technology and inelastic demand for a single unit of housing with residential parking, relative changes in the urban boundary translate one-for-one into changes in the total urban population: the larger the city, the bigger its population.

We can better understand scenarios A1 and A2 by comparing key economic outcomes in Table 3. Total production of the tradable good is lower with regulatory delay, reflecting the inefficiency that delay creates across both periods. The constraint on land use under regulatory delay also drives way up the present discounted value (PDV) of all urban land across the two periods, which is an order of magnitude larger than in the case of A1. A lot of the increase in the value of land under regulatory delay is concentrated in commercial land rents, which are four orders of magnitude higher than their outcomes for A1. This is not surprising as regulatory delay creates a shortness in downtown commercial land with permission to start construction in the first period.

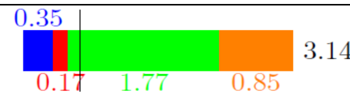
It is noteworthy that the share of resident commuters using transit under regulatory delay is substantially higher, particularly during the first period, which is also reflected in differences in where the modal boundary is drawn. This can be explained by the fact that the city is more compact under regulatory delay than with the mechanism of export growth. In addition, housing prices are also higher in both residential modal mode areas under regulatory delay as the average commuting to the trade center is shorter and wages are higher (since average shipping costs for commercial firms are lower).

Scenarios A3 and A4 consider the effects of externalities on urban spatial structure and urban form. Panel B of Figure 4 examines alternative policy scenarios that address inefficiencies in Panel A. Next, we discuss these numerical exercises.

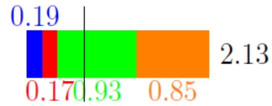
Figure 4—Simulation Results, Urban Structure

Panel A: Baseline Simulations

A1. No Delay, Growth, No Externalities

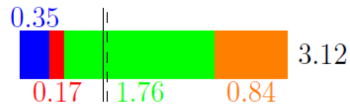


A2. Delay, No Growth, No Externalities



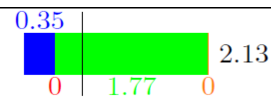
A3. No Delay, Growth, Resident Congestion

A4. No Delay, Growth, Resident & Visitor Congestion



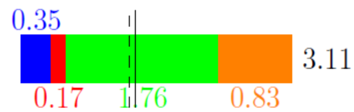
Panel B: Policy Scenarios

B1. No Delay, No Growth, No Externalities (*Remove Regulatory Delay from A2.*)

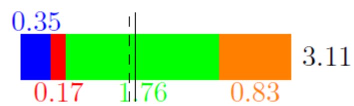


B2. No Delay, Growth, Resident Congestion & Congestion Toll

B3. No Delay, Growth, Resident & Visitor Congestion, Congestion Toll



B4. No Delay, Growth, Resident & Visitor Congestion, Congestion & Visitor Tax



Notes: Each row refers to separate equilibrium with indicated properties. Colored numbers refer to width of regions, vertical lines refer to modal boundaries, the black number refers to urban boundary. The legend below indicates the meaning of each component.

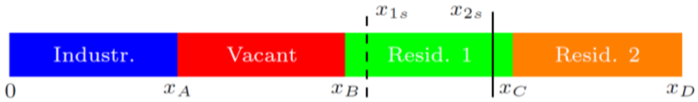


Table 3—Selected Equilibrium Outcomes from Numerical Examples of Spatial Equilibria

Scenario	A1.	A2.	A3.	A4.	B1.	B2.	B3.	B4.
Delay	*No*	*Yes*	*No*	*No*	*No*	*No*	*No*	*No*
Growth	*Yes*	*No*	*Yes*	*Yes*	*No*	*Yes*	*Yes*	*Yes*
Externalities	*No*	*No*	*Resident Congestion*	*Resident & Visitor Congestion*	*No*	*Resident Congestion*	*Resident & Visitor Congestion*	*Resident & Visitor Congestion*
Policy	*None*	*None*	*None*	*None*	*Remove Delay from A2*	*Congestion Tax*	*Congestion Tax*	*Congestion & Visitor Tax*
Production Quantity, Period 1	3.542	1.855	3.534	3.523	3.545	3.533	3.520	3.525
Production Quantity, Period 2	5.234	3.548	5.204	5.201	3.545	5.193	5.190	5.185
Industrial Rent, Period 1	0.781	225.213	0.781	0.780	0.829	0.781	0.779	0.737
Industrial Rent, Period 2	1.079	0.789	1.144	1.176	0.829	1.223	1.260	1.305
Average Residential Rent at x=0, Period 1	0.529	0.428	0.540	0.555	0.513	0.553	0.571	0.571
Average Residential Rent at x=0, Period 2	0.614	0.513	0.635	0.635	0.513	0.660	0.660	0.660
Residental Rent Car Commute at x=0, Period 1	0.479	0.378	0.479	0.478	0.463	0.479	0.478	0.478
Residental Rent Car Commute at x=0, Period 2	0.564	0.463	0.562	0.562	0.463	0.562	0.561	0.561
Residental Rent Transit Commute at x=0, Period 1	0.579	0.478	0.601	0.631	0.563	0.628	0.664	0.664
Residental Rent Transit Commute at x=0, Period 2	0.664	0.563	0.708	0.708	0.563	0.759	0.759	0.758
Congestion Tax on Resident Commuters, Period 1						0.0374	0.0249	0.0250
Congestion Tax on Resident Commuters, Period 2						0.0649	0.0648	0.0647
Share Public Transit Commuters, Period 1	0.081	0.336	0.165	0.285	0.176	0.271	0.411	0.410
Share Public Transit Commuters, Period 2	0.055	0.176	0.174	0.175	0.176	0.307	0.307	0.307
PDV Total Urban Land Rent, Periods 1-2	202.495	2251	205.893	208.051	150.579	212.936	216.200	216.882

Notes: Each column corresponds to a unique equilibrium set of outcomes. Scenarios A1.-A4. Involve no policy intervention. Scenarios B.1-B.4 include policy which eliminates regulatory delay, or taxes congestion and/or visitors. Average Residential Rent is the average across public transit and private car commuters.

6.3 Adding Congestion Externalities

In Figure 4, Panel A, scenarios A3 and A4 account for externalities due to car commuters and car congestion from visitors who park in temporary parking lots downtown. These simulations include export growth, but no regulatory delay and help to illustrate how landowners may choose development plans that become suboptimal when congestion externalities are not internalized.

Comparing A3 to A1, we see the impact of resident traffic congestion on urban form: the city contracts, and a smaller share of commuters drive to work. As shown in Table , production of the tradable good decreases with traffic congestion, but the present discounted value of land rents increases reflecting the higher value of land with a smaller city. Adding road congestion from visitors has a comparably small impact on the urban form, but notably shifts even more commuters away from driving towards transit in the first period when land is left vacant. Examining Table 3, we can further notice that visitor congestion has qualitatively similar effects on equilibrium outcomes as resident congestion: production falls and rents increase.

6.4 Optimal Policy Instruments

Having demonstrated several instances in which distortions in the form of externalities or regulatory delay result in less-than-optimal urban spatial equilibria, we now consider a set of optimal policy instruments to address these distortions. Most simply, if there is regulatory delay, this results in an inefficient allocation of land in the first period, which would be remedied without this delay. This is illustrated in scenario B1 in Figure 4.

Comparing scenarios B2 and A3 in Figure 4, we observe that adding the congestion toll contracts the city slightly and decreases the share of drivers, as expected. From Table 3, we further observe that the dynamic congestion toll is always larger in the second period reflecting the higher congestion level from in-migration due to export demand. The addition of visitor congestion in scenario B3 means that the resident congestion tax from B2 is no longer optimal and must be reduced to account for the reduction in population and production that comes with having visitor congestion. The congestion toll also lowers production and increases overall rents, which is also a reflection of the Leontief production technology for the tradable good and unitary inelastic demand for residential land. The urban spatial structure and urban form remain similar when we add congestion from Figure 4 in scenario B3 and a tax per unit of surface parking land in scenario B4. Table 3 helps illustrate the additional effects on the urban equilibrium under these two scenarios. One limitation to these scenarios is that we have calibrated the model so that the magnitude of the externality from visitors using surface parking on temporary vacant land is small in our baseline cases, which we alter in an extension below.

7. Additional Numerical Extensions

In this section, we extend the numerical exercises from the previous section to explore the effects of changing four assumptions on our results: i) the extent of regulatory delay, ii) the footprint of visitor parking, iii) production agglomeration, iv) input substitutability to production.

Varying the Extent of Regulatory Delay **($\bar{x}_a$) –** In our baseline scenarios, we assumed a level of regulatory delay such that downtown commercial development in the first period could not proceed beyond $\bar{x}_a$ = 0.1855 miles from the trade center. In Appendix Table A.4, we present the effects of varying $\bar{x}_a$ between 0.24 and 0.3544 on the present discounted value of total urban land rent. Land rents decrease monotonically as we reduce $\bar{x}_a$, but are convex, reflecting the scarcity of commercial land in the first period and the Leontief production which does not allow for input substitutability.

Another dimension of regulatory delay is the fact that, as modeled, we assume that it is unexpected but developers are able to re-optimize after regulatory delay occurs to adjust development plans to maximize rents in the presence of this delay. In Appendix Table A.4, we also include the case of unexpected regulatory delay whereby developers are unable to re-optimize after regulatory delay occurs to adjust development plans to maximize rents in the presence of the delay. This allows developers to keep development plans in the second period as planned in Period 0, when they assumed that no delay would occur. As we would expect, the present discounted value of total urban rents is higher when re-optimization is possible, since landowners can adjust development and increase the return on land. However, the size of the reductions of land rents in response to looser regulatory delay are smaller with re-optimization, reflecting the fact that re-optimization reduces the impact of the same level of delay. In addition, adding congestion externalities makes the impact of increased regulatory delay on land rents larger, since higher congestion tends to shrink the city (increasing land rents) as we have shown in our main baseline results.

Varying the Footprint of a Surface Parking Space **(s) –** We vary the size of surface parking spaces on temporary vacant land in our simulations in Appendix Table A.5. Since the number of visitors is inversely proportional to the size of parking spaces, road congestion decreases with an increase in *s*. A decrease in congestion decreases the unit cost of car commuting and so the share of transit users falls with an increase in *s*. In addition, the return on temporary vacant land under surface visitor parking, ϕ, is inversely proportional to *s*, so total urban land value decreases. Since this return is lower, the amount of vacant land used for temporary parking in the first period falls slightly when *s* increases. Lastly, the overall size of the urban area in both periods grows with *s*.

Production Agglomeration Economies **–** In Appendix Figure A.3, we show a subset of the scenarios from Figure 3 with an agglomeration externality. The agglomeration externality, whose functional form is described in Appendix A.3, scales with the amount of output, so is not factor-biased, like an externality that scales with the population size. Across scenarios with agglomeration, the city is more compact relative to the comparable scenarios without agglomeration (e.g., A1 vs. A1.A). This is because the form of agglomeration used affects the efficiency of both inputs and as a result it allows the city to meet export and domestic demand with a smaller amount of land and labor. Appendix Table A.3 shows how these effects translate into several outcome variables. Compared to scenario A.1, A1.A has lower production in both periods, lower rents and a greater share of public transit use. These differences arise because agglomeration scales with output: it requires less labor and land to meet export demand growth and so domestic consumption is lower because the number of residents is also smaller.[31] Comparing scenarios A.2 and A2.A, we can see that during the first period when regulatory delay is binding, different effects occur: production is greater with agglomeration and commercial rents are lower.

In scenario A4.A and B4.A., we can see further how agglomeration interacts with congestion externalities with a congestion toll and a tax per unit of land under surface parking and without: again the city is smaller, rents are lower, production is lower and more commuters use public transit under agglomeration. In all, these results show that unpriced agglomeration externalities also make the city less efficient.

Input Substitutability in the Tradable Good Production **–** In our last extension, we relax the fixed-proportions production technology assumed for the tradable good and utilize a Cobb-Douglas production technology instead. As a result, labor and land can be substituted in production so that changes to the model that decrease the amount of developed land in the city have less of an impact on production because firms can substitute labor for capital. As shown in Appendix Table

[31] In addition, the city's residents have inelastic demand for a unit of the tradable good.

A.6, we calibrate the model under a Cobb-Douglas technology to be close to our main results. For the results to converge, we have to adjust the calibration from our main results slightly: we increase the value of visitor parking spot sizes (*s*) and decrease the unit cost of public transportation. We re-simulate our Leontief results with this new calibration for comparison and present the results in Appendix Figure A.2 and Table A.7.

As the figure makes clear, under Cobb-Douglas technology the urban structure is far more compact—half the original size—reflecting the ability to substitute labor and land in production. The addition of congestion in scenario A3 increases the share of public transit commuters under Cobb-Douglas production as in the Leontief case, although its level is much higher under the former technology. The ability to deploy more labor and less land also makes the effect of land scarcity in period 1 for commercial use in the downtown area less pronounced and therefore rents are lower, particularly in the second period when export growth increases production. These results show that allowing for substitutability for inputs in production in the commercial sector also changes the urban form and of the city: the downtown area is larger, the city is of smaller overall size as shown in Appendix Figure A.3. Nevertheless, the direction of the comparative statics of interest in this study remain the same in the Cobb-Douglas scenarios.

8. Conclusion

In this paper, we develop a dynamic, monocentric urban model of land use to understand the causes and consequences of urban vacant land in downtown areas and consider its implications for optimal transportation, land use and economic development policy. We show that in a simple, two-period model without externalities, growth in the demand for exports of a tradable good produced in a city can result in optimal, temporary vacant lots in the CBD area. However, for this land to generate a positive return while waiting for development, a likely temporary use of it may be commercial surface parking, which can create negative externalities that distort this optimal outcome. The externalities generated by this type of temporary land use are seldom internalized by landowners when creating them on vacant lot waiting for development.

We show that the optimum can be achieved with Pigouvian taxation to address congestion externalities or a tax on temporary surface parking spaces and/or appropriate subsidies for agglomeration economies. We contrast this outcome with a model without export demand growth, but where vacant land is the result of unexpected regulatory delay that is inefficient. We then show

how regulatory delay may interact with other features of the urban economy including externalities and demand growth. We validate theoretical results with numerical examples that allow clear comparison of endogenous variables including urban spatial structure and urban form to each of these scenarios as well as particular modeling assumptions. Finally, we also illustrate the need for a dynamic congestion toll in the presence of a dynamic intertemporal congestion externality setting. In contrast to existing static spatial general equilibrium urban models with road congestion, we consider a case where traffic congestion changes across periods due to population migration and due to visitors' congestion resulting from the allocation of vacant land awaiting development to visitor parking. Our policy results thus show the need to consider dynamic features and the intertemporal interactions of land use and transport when designing optimal congestion tolls.

Future work could explore how alternative revenue recycling schemes with revenue going to public transit or public plazas affect urban form and spatial structure. There may also be a rationale for local governments encouraging temporary land uses that may be more socially desirable than visitor surface parking when the net effect of externalities from this type of temporary use is negative such as gardens which provide visual and recreational amenities to neighborhoods. As we discuss earlier, determinants of demand for visitors to urban areas is not modeled here, but may be a further useful area of inquiry. Temporary vacant land uses may also produce pollution, say oil leaks from parked vehicles, for which remediation may be an additional cost. Lastly, while most parking lots in CBD areas were thought to be only temporary when created, many have survived for decades, so an important question is why this land use appears more permanent than what is modeled in our study.

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Appendix

A.1 Additional Figures and Tables

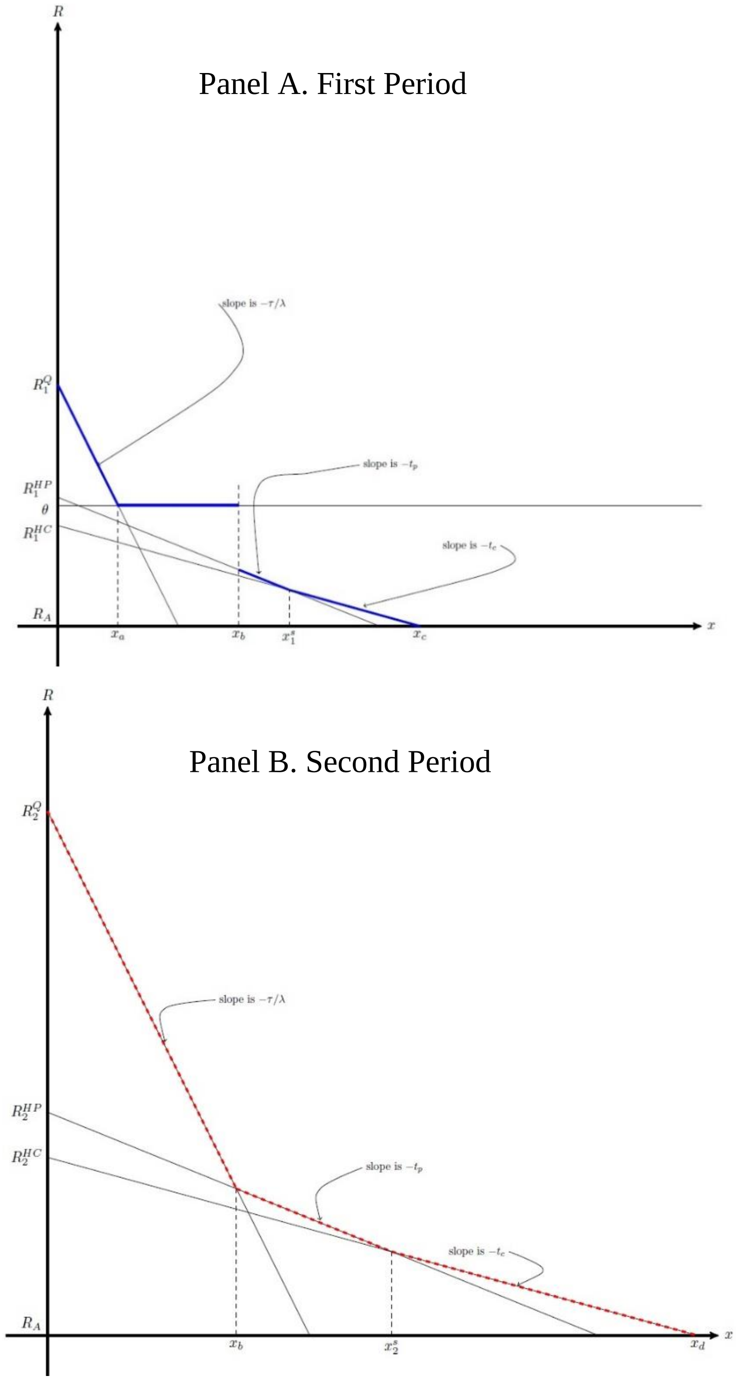


Figure A.1—Bid-rent Curves for the Baseline Model

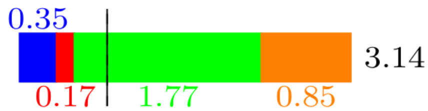
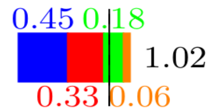
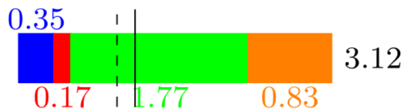
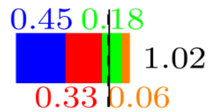
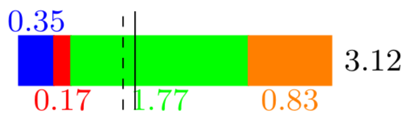
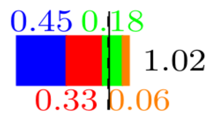
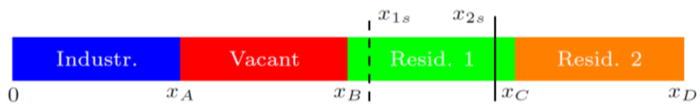
	Leontief	Cobb Douglas
A1. No Delay, Growth, No Externalities		
A3. No Delay, Growth, Resident Congestion		
A4. No Delay, Growth, Resident & Visitor Congestion		

Figure A.2—Comparison of Simulations with Cobb Douglas vs. Leontief Production

Notes: Leontief simulations assume different unit public transit cost (t_p = 0.22) and size of visitor parking spaces (s = 2) than main results (t_p = 0.25, s = 0.16) to match Cobb-Douglas calibration. Boundaries that appear the same across simulations have difference obscured by rounding for figure clarity.



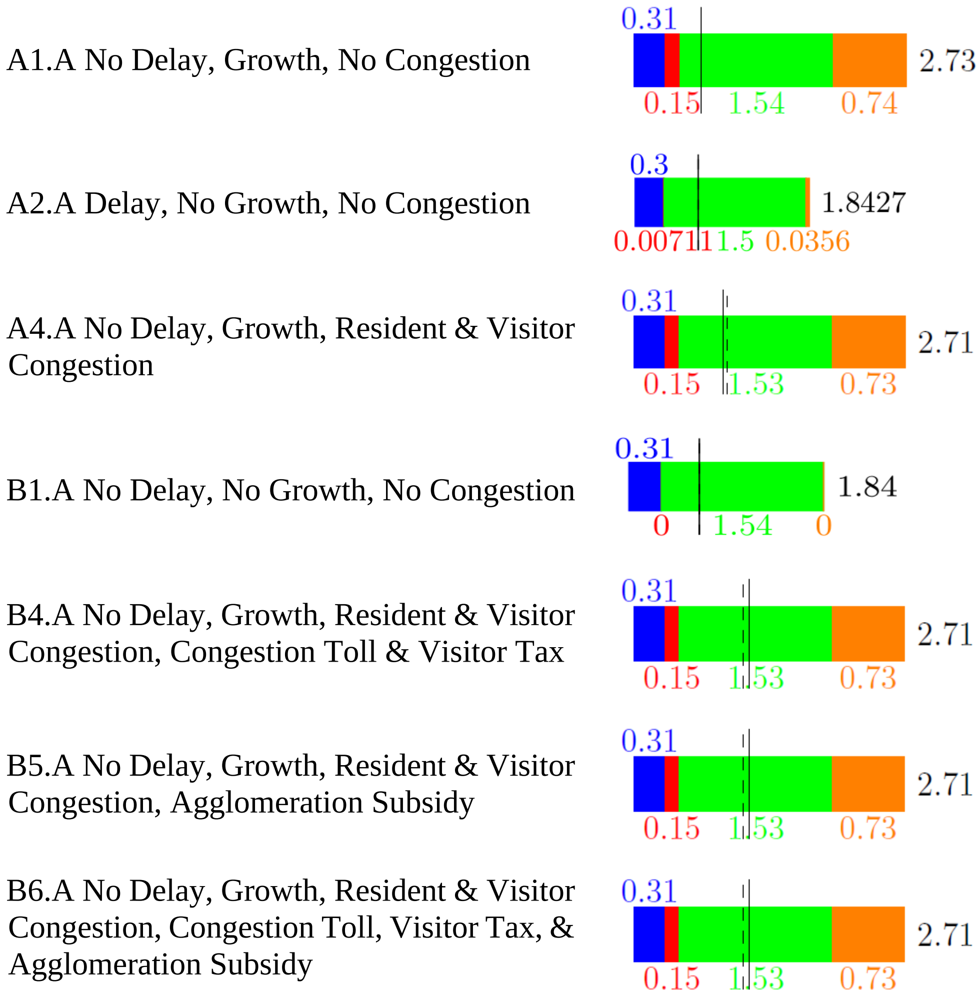


Figure A.3—Numerical Examples with Production Agglomeration Economies

Notes: Each row refers to separate equilibrium with indicated properties. Colored numbers refer to width of regions, vertical lines refer to modal boundaries, the black number refers to urban boundary. The legend below indicates the meaning of each component.

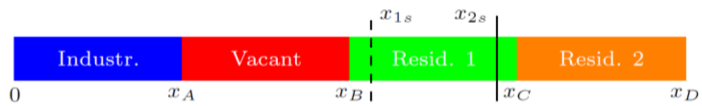


Table A.1—Regulatory Delay, No Export Growth Equilibrium Conditions

	Period 1	*Period 2*
1	$Q_1 = f(P_1, \Gamma_1) + \mu q Q_1$	$Q_2 = f(P_2, \Gamma_2) + \mu q Q_2$
2	$w_1 = R_1^{HC} + P_1 q + F^c + x_c - x_{1s} + \frac{x_b - \bar{x}_a}{s} + \overline{N_v}$	$w_2 = R_2^{HC} + P_2 q + F^c + x_d - x_{2s} + \overline{N_v}$
3	$w_1 = R_1^{HP} + P_1 q + F^p$	$w_2 = R_2^{HP} + P_2 q + F^p$
4	$P_1 = \mu w_1 + \lambda R_1^Q$	$P_2 = \mu w_2 + \lambda R_2^Q$
5	$\lambda Q_1 = \bar{x}_a$	$\lambda Q_2 = x_b$
6	$\mu Q_1 = x_c - x_b$	$\mu Q_2 = x_d - x_b$
7	$R_1^{HC} - t^c x_c = R_A(x_c)$	$R_2^{HC} - t^c x_d = R_A(x_d)$
8	$x_{1s} = \frac{F^c - F^p + \frac{x_b - \bar{x}_a}{s} + x_c + \overline{N_v}}{1 + t^p - t^c}$	$x_{2s} = \frac{F^c - F^p + x_d + \overline{N_v}}{1 + t^p - t^c}$
9	$R_1^Q - \frac{\tau \bar{x}_a}{\lambda} = \theta$	
10	$R_1^{HP} - t^p x_b + \frac{1}{1+r}[R_2^{HP} - t^p x_b] = \theta + \frac{1}{1+r}\left[R_2^Q - \frac{\tau x_b}{\lambda}\right]$	

Table A.2—Calibration of Parameters for Numerical Simulation

Export demand for *Q*		
Period 1 Intercept	T_1	2
Period 2 Intercept	T_2	3
Exponent	δ	-0.2
Leontief production of *Q*		
Unit labor productivity	μ	0.5
Unit land productivity	λ	0.1
Transport costs for firms		
Unit transport cost for firms	τ	0.1
Household commuting costs		
Unit transport cost for transit users	t_p	0.25
Unit transport cost for auto users	t_c	0.1
Car fixed cost	F_c	0.2
Public transit fixed cost	F_p	0.1
Discount rate	r	0.05
Value of agricultural land	a	0.25
Parking		
Value of parking land	v	0.427
Visitor parking spot size	s	0.16
Vehicular congestion		
Congestion cost per mile	θ	0.01
Congestion exponent	ψ	2
Production agglomeration		
Agglomeration coefficient	θ_1	0.1
Agglomeration exponent	θ_2	0.01

Table A.3—Selected Equilibrium Outcomes from Simulation of Spatial Equilibria with Agglomeration

Scenario	A1.A	A2.A	A3.A	A4.A	B1.A	B2.A	B3.A	B4.A	B5.A	B6.A
Delay	*No*	*Yes*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*
Growth	*Yes*	*No*	*Yes*	*Yes*	*No*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Externalities	*No*	*No*	*Resident Congestion*	*Resident & Visitor Congestion*	*No*	*Resident Congestion*	*Resident & Visitor Congestion*	*Resident & Visitor Congestion*	*Resident & Visitor Congestion*	*Resident & Visitor Congestion*
Policy	*None*	*None*	*None*	*None*	*Remove Delay from A2*	*Congestion Toll*	*Congestion Toll*	*Congestion & Visitor Tax*	*Agglomeration Subsidy*	*Congestion Toll, Visitor Tax, Agglomeration Subsidy*
Production Quantity, Period 1	3.381	3.304	3.376	3.367	3.384	3.374	3.364	3.368	3.367	3.368
Production Quantity, Period 2	5.005	3.382	4.983	4.981	3.384	4.975	4.972	4.968	4.981	4.969
Commercial Rent, Period 1	0.734	1.926	0.734	0.733	0.765	0.734	0.733	0.701	0.733	0.701
Commercial Rent, Period 2	0.972	0.793	1.018	1.043	0.765	1.078	1.107	1.140	1.043	1.141
Avg. Resident. Rent x=0, Per. 1	0.499	0.481	0.506	0.517	0.484	0.516	0.530	0.530	0.518	0.530
Avg. Resident. Rent x=0, Per. 2	0.573	0.484	0.588	0.588	0.484	0.607	0.607	0.607	0.588	0.607
% Public Transit Comm., Per. 1	0.138	0.240	0.204	0.310	0.234	0.293	0.421	0.420	0.310	0.420
% Public Transit Comm., Per. 2	0.093	0.234	0.193	0.193	0.234	0.310	0.310	0.310	0.193	0.310
PDV Tot. Urban Land Rent, Periods 1-2	166	148	168	170	125	173	175	176	170	176

Table A.4—Total Urban Land Rent Varying Regulatory Delay

Scenario	1	2	3	4
Re-Optimization			X	X
Congestion		X		X
$\bar{x}_a$	PDV Total Urban Land Rent			
0.24	954.93	956.34	954.94	958.23
0.26	709.33	709.61	709.58	711.42
0.28	528.19	527.79	528.68	529.53
0.3	391.47	390.78	392.21	392.48
0.32	285.86	285.19	286.84	286.87
0.34	202.4	201.97	203.63	203.67
0.35	166.97	166.72	168.32	168.45
0.3538	*NC*	154.17	*NC*	154.17
0.3544	152.35	*NC*	152.35	*NC*

Notes: Re-optimization means that land development in the first period can be modified after the regulatory delay level is announced.. There is no export growth in any of the scenarios simulated in this table. Congestion includes congestion from visitors and residents as calibrated in our main simulation results. "NC" indicates that the spatial equilibrium did not converge with the indicated value of $\bar{x}_a$.

Table A.5—Effect of Increased Parking Space on Spatial Structure and Commute Mode

Size of Parking Space (*s*)	0.16	0.08	0.12	0.2	0.3	0.8
Total Urban Land Rent	208.1	212.0	209.1	207.5	206.9	206.2
x_a	0.352	0.351	0.352	0.353	0.353	0.353
x_b	0.520	0.520	0.520	0.520	0.520	0.520
x_{1s}	1.022	1.301	1.108	0.974	0.914	0.848
x_{2s}	0.974	0.973	0.974	0.974	0.974	0.974
x_c	2.282	2.274	2.279	2.283	2.285	2.287
x_d	3.121	3.118	3.120	3.121	3.122	3.122
Share of Transit Users, period 1	0.285	0.445	0.334	0.257	0.223	0.185
Share of Transit Users, period 2	0.175	0.175	0.175	0.174	0.174	0.174

Notes: The first column (*s* = 0.16) is the benchmark equilibrium used in our main simulations. Results are from a simulation with no regulatory delay, export growth, congestion from residents and visitors, no agglomeration, and no policies.

Table A.6—Calibration of Parameters for Cobb Douglas Numerical Simulation

Export demand for *Q*		
Period 1 Intercept	T_1	2
Period 2 Intercept	T_2	3
Exponent	δ	-0.2
Cobb Douglas production of *Q*		
Output Elast. wrt Labor	α	0.5
Output Elast. wrt Land	β	0.5
Total Factor Productivity	A	10
Transport costs for firms		
Unit transport cost for firms	τ	0.1
Household commuting costs		
Unit transport cost for transit users	t_p	0.22
Unit transport cost for auto users	t_c	0.1
Car fixed cost	F_c	0.2
Public transit fixed cost	F_p	0.1
Discount rate	r	0.05
Value of agricultural land	a	0.25
Parking		
Value of parking land	v	0.427
Visitor parking spot size	s	2
Vehicular congestion		
Congestion cost per mile	θ	0.01
Congestion exponent	ψ	2
Production agglomeration		
Agglomeration coefficient	θ_1	0.1
Agglomeration exponent	θ_2	0.01

Table A.7—Comparison of Simulations with Cobb Douglas vs. Leontief Production

Scenario	A1.		A3.		A4.	
Delay	*No*		*No*		*No*	
Growth	*Yes*		*Yes*		*Yes*	
Externalities	*No*		*Resident Congestion*		*Resident & Visitor Congestion*	
Policy	*None*		*None*		*None*	
Production Technology	*Leontief*	*Cobb Douglas*	*Leontief*	*Cobb Douglas*	*Leontief*	*Cobb Douglas*
Production Quantity, Period 1	3.542	2.878	3.536	2.878	3.533	2.878
Production Quantity, Period 2	5.231	4.395	5.206	4.395	5.205	4.394
Commercial Rent, Period 1	0.781	0.715	0.781	0.715	0.781	0.715
Commercial Rent, Period 2	1.111	0.562	1.164	0.562	1.172	0.563
Average Residential Rent at x=0, Period 1	0.529	0.396	0.537	0.396	0.541	0.396
Average Residential Rent at x=0, Period 2	0.614	0.402	0.632	0.403	0.632	0.403
Share Public Transit Commuters, Period 1	0.175	0.313	0.258	0.322	0.295	0.354
Share Public Transit Commuters, Period 2	0.119	0.230	0.244	0.243	0.244	0.246
PDV Total Urban Land Rent, Periods 1-2	204.55	51.83	208.27	51.86	208.87	51.90

A.2 Additional Theoretical Results

Proposition 1. *In an open city with perfect-foresight, Leontief production of a tradable good and no urban growth, regulatory delay causes a reduction (relative to the second period) in first period production, city size and an increase in the first period price of the tradable good and the wage. Moreover, regulatory delay generates leapfrog development in the first period by preventing all the downtown core land to be developed at the optimal date which, in turn, reduces first period commercial and residential land rents inside the urban area.*

Proof: Since $\bar{x}_a < x_b$ in period 1 because of regulatory delay, then from condition 5 in Table A.1 we have that the production of the tradable good increases in period 2, $Q_1 < Q_2$. This increase in production also requires an increase in total workers residing in the city in period 2, as the residential-to-commercial land ratio $\frac{\lambda}{\mu}$ is constant, and therefore an expansion in the residential zone from x_c to x_d occurs, $x_c < x_d$. From condition 7 we also have that $R_1^H < R_2^H$. In addition, from condition 1 and since export demand is constant over time ($\Gamma_1 = \Gamma_2$), the tradable good becomes less expensive in period 2, $P_1 > P_2$ and from condition 3 it follows that a worker´s wage is also higher in period 1, $w_1 > w_2$. Finally, from conditions 6-10 we have that $R_1^Q < R_2^Q$. ■

Proposition 2. *In an open city, with Leontief production of a tradable good, the effect of unexpected regulatory delay will be less costly to output with positive export growth.*

Proof: Define the decrease in first period output under unexpected regulatory delay as $\Delta = Q_2 - Q_1$. With export demand growth, the distortion under unexpected regulatory delay is $\Delta' = Q_1^* - Q_1$, *where* Q_1^* is output under export demand growth and unexpected delay. ■

Proposition 3. *In an open city, with Leontief production of a tradable good, the effect of regulatory delay will be less costly in terms of reduced output with positive export growth than with no change.*

Proof: With no export growth, optimal output is the same in both periods, so regulatory delay causes underproduction of $Q_2 - Q_1$. With export growth, optimal output is less in the first period, so that underproduction is $Q_1^* - Q_1 < Q_2 - Q_1$, where Q_1^* is optimal output in the first period with no regulatory delay. ■

Proposition 4. *In an open city with first period vacant land and congestion, the addition of the Pigouvian toll will shift the modal boundary inward and reduce the number of drivers*.

Proof: With a toll on drivers imposed, the new modal boundary will be

$$x_{1s}^{toll} = \frac{F^c - F^p + 2N_1^c}{t^p - t^c} = \frac{F^c - F^p + 2\frac{x_b - x_a}{s} + 2x_c}{2 + t^p - t^c} \quad (A.5)$$

in period 1 and

$$x_{2s}^{toll} = \frac{F^c - F^p + 2N_2^c}{t^p - t^c} = \frac{F^c - F^p + 2x_d}{2 + t^p - t^c} \quad (A.6)$$

in the second period.

Comparing this expression to that without the tax, so long as $\frac{x_b - x_a}{s} + x_c$ and x_d remain at greater than 50% their pre-tax levels, this will move the modal boundary rightward in both cases and correspond to a reduction in the number of car commuters. ■

Proposition 5. *In an open city with first period vacant land and congestion, the addition of the tax on visitors paid by developers will reduce the quantity of vacant land and therefore visitors.*

Proof: A tax on visitors charges developers N_t^c per visitor or $\frac{N_t^c}{s}$ per unit of vacant land. This lowers the return to vacant land so that equilibrium condition 6. becomes

$$R_1^Q - \frac{\tau x_a}{\lambda} = \theta - \frac{N_t^c}{s}. \quad (A.7)$$

To keep the equation balanced relative to no tax means an increase of x_a and/or a decrease of R_1^Q.

Focusing on the latter, from the Q-producing firm's zero-profit condition in equilibrium condition 3,

$$P_1 = \mu w_1 + \nu\rho + \lambda R_1^Q \quad (A.8)$$

note that if wages are held constant, then $dP_1 = \lambda dR_1^Q$, so a fall in R_1^Q would also decrease P_1.

To see how vacant land is affected we combine the equations from equilibrium condition 4.:

$$\begin{aligned} x_b - x_a &= \lambda(Q_2 - Q_1) \\ &= \frac{\lambda}{1-\mu q}\big(f(P_2, \Gamma_2) - f(P_1, \Gamma_1)\big), \quad (\text{A}.9) \end{aligned}$$

where the second line comes from substitution of equilibrium condition 1. Changes in the quantity of vacant land on the left-hand side have to be balanced by an adjustment in effective export demand for Q, which happens via adjustments in P as shown from (A.8) and the fact that the tax on visitors to developers would tend to lower R_1^Q. ■

Proposition 7. *In an open city with vacant land in the first period and two modes of transportation, the addition of congestion will shift the modal boundary outward, making the average commute for public transit users longer.*

Proof:

In the absence of congestion, the modal boundary is fixed in both periods at

$$\mathrm{x_s} = \frac{\mathrm{F^c} - \mathrm{F^p}}{\mathrm{t^p} - \mathrm{t^c}}. \quad (\text{A}.10)$$

Comparing this outcome to that with congestion, we can see that the modal boundary is shifted rightward in the first period if

$$\frac{\mathrm{x_b} - \mathrm{x_a}}{\mathrm{s}} + \mathrm{x_c} < \frac{\mathrm{F^c} - \mathrm{F^p}}{\mathrm{t^p} - \mathrm{t^c}}, \qquad (A.11)$$

and in the second period if

$$\mathrm{x_d} < \frac{\mathrm{F^c} - \mathrm{F^p}}{\mathrm{t^p} - \mathrm{t^c}}. \quad (A.12)$$

Compared to equilibrium condition 8, without congestion, the present setup means that the modal boundary moves outward in the second period if $\mathrm{x}_{2s} > \mathrm{x}_{1s}$, which holds if and only if $\frac{\mathrm{x_b}}{\mathrm{x_a}} < \mathrm{s}$. ■

Proposition 8. *In an open city with first period vacant land and agglomeration, the addition of an output subsidy of $(1 - A)P_t$ to producers will increase city output of Q and the size of the commercial area.*

Proof: Adding the subsidy firm's zero-profit condition amounts to:

$$\begin{aligned} (A-1)P_t + P_t &= \frac{\mu w_t + \lambda R_t^Q}{A} \\ P_t &= \mu w_t + \lambda R_t^Q,\ t = 1,\ 2 \end{aligned}$$

so that production is larger and the agglomeration externality is internalized. From equilibrium condition 5, the subsidy also have the effect of increasing the size of the commercial area in both periods. ■

Alternatively, this subsidy can be administered to developers since their allocation of land to production will achieve this optimal production with internalized agglomeration externalities. If developers are given a subsidy $\lambda(A - 1)P_t$ per unit of commercial land, then this would have the same effect.

A.3 Functional Forms for Numerical Simulation

A.3.1 Congestion Toll on Commuters

Congestion toll on car commuting residents

$$\theta\Psi(x_c - x_{1s})[x_b - x_a + x_c - x_{1s}]^{\Psi-1} \qquad \text{in first period}$$
$$\theta\Psi(x_d - x_{2s})[x_d - x_{2s}]^{\Psi-1} \qquad \text{in second period}$$

Total revenue from congestion tax on auto residents

$$TR_1 = \theta\Psi(x_c - x_{1s})^2[x_b - x_a + x_c - x_{1s}]^{\Psi-1} \quad \text{in first period}$$
$$TR_2 = \theta\Psi(x_d - x_{2s})^2[x_d - x_{2s}]^{\Psi-1} \quad \text{in second period}$$

Lump sum transfer of tax revenues to households:

$$\frac{TR_1}{x_c - x_b} \quad \text{in first period}$$
$$\frac{TR_2}{x_d - x_b} \quad \text{in second period}$$

A.3.2 Tax on Visitors

Tax on visitors (first period only)

$$\theta\Psi(x_c - x_{1s})[x_b - x_a + x_c - x_{1s}]^{\Psi-1}$$

Revenue from tax on visitors (first period only)

$$TR_{1,v} = \theta\Psi(x_b - x_a)(x_c - x_{1s})[x_b - x_a + x_c - x_{1s}]^{\Psi-1}$$

Lump sum transfer to all households from visitor tax (first period only)

$$\frac{TR_{1,v}}{x_c - x_b}$$

A.3.3 Agglomeration Externalities

Agglomeration subsidy per unit of production

$$\theta_1\theta_2{\sigma_1}^{\theta_2-1}$$

Uniform agglomeration tax per household (first period):

$$\frac{\theta_1\theta_2{\sigma_1}^{\theta_2-1}}{x_c - x_b}$$

Change to equilibrium conditions

Zero profit

$$P_1 + \underbrace{\theta_1\theta_2{\sigma_1}^{\theta_2-1}}_{\text{subsidy}} = \frac{\mu w_1 + \lambda RF_1}{1 + \theta_1{\sigma_1}^{\theta_2}}$$

Modal boundary

$$F_c + \underbrace{\theta[x_b - x_a + x_c - x_{1s}]^{\Psi}}_{\text{congestion cost}} + \underbrace{\theta\Psi(x_c - x_{1s})[x_b - x_a + x_c - x_{1s}]^{\Psi-1}}_{\text{congestion tax}} = F_P + (t_p - t_c)x_{1s}$$

$$F_c + \underbrace{\theta[x_d - x_{2s}]^{\Psi}}_{\text{congestion cost}} + \underbrace{\theta\Psi(x_d - x_{2s})[x_d - x_{2s}]^{\Psi-1}}_{\text{congestion tax}} = F_P + (t_p - t_c)x_{2s}$$

Commercial boundary in period 1

$$RF_1 - \frac{tx_a}{\lambda} = \upsilon - \underbrace{\theta\Psi(x_c - x_{1s})[x_b - x_a + x_c - x_{1s}]^{\Psi-1}}_{\text{congestion tax on visitors}}$$

Inner residential boundary in period 1

$$R_1^{HP} - t^p x_b + \frac{1}{1+r}[R_2^{HP} - t^p x_b]$$
$$= \theta - \underbrace{\theta\Psi(x_c - x_{1s})[x_b - x_a + x_c - x_{1s}]^{\Psi-1}}_{\text{congestion tax on visitors}} + \frac{1}{1+r}\left[R_2^Q - \frac{\tau x_b}{\lambda}\right]$$

Budget Constraints

	First Period	**Second Period**
Car Commuters	$w_1 + \frac{\theta\Psi(x_c - x_{1s})^2[x_b - x_a + x_c - x_{1s}]^{\Psi-1}}{x_c - x_b} + \frac{\theta_1\theta_2{\sigma_1}^{\theta_2-1}}{x_c - x_b} = R_1^{HC} - P_1 q + F^c + x_c - x_{1s} + \Psi(x_c - x_{1s})[x_b - x_a + x_c - x_{1s}]^{\Psi-1}$	$w_2 + \frac{\theta\Psi(x_d - x_{2s})^2[x_d - x_{2s}]^{\Psi-1}}{x_d - x_b} = R_2^{HC} - P_2 q + F^c + x_d - x_{2s} + \theta\Psi(x_d - x_{2s})[x_d - x_{2s}]^{\Psi-1}$
Public Transit Commuters	$w_1 + \frac{\theta_1\theta_2{\sigma_1}^{\theta_2-1}}{x_c - x_b} + \frac{\theta\Psi(x_c - x_{1s})^2[x_b - x_a + x_c - x_{1s}]^{\Psi-1}}{x_c - x_b} = R_1^{HP} - P_1 q + F^p$	$w_2 + \frac{\theta\Psi(x_d - x_{2s})^2[x_d - x_{2s}]^{\Psi-1}}{x_d - x_b} = R_2^{HP} - P_2 q + F^p + \theta\Psi(x_d - x_{2s})[x_d - x_{2s}]^{\Psi-1}$