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Optimal housing supply in a bid-rent equilibrium framework

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ABSTRACT

In this study, we examine how the spatial distribution of housing supply impacts people's residential choices and developers' profitability. By optimally providing housing supply in a region, developers attempt to maximize their profits; on the other hand, if residents were given a chance to decide on housing supply, what patterns of housing supply they would prefer in order to maximize their consumer surpluses. This paper studies the interplay between these two perspectives. A nested multinomial-logit choice structure that encapsulates the bid-rent process is used to capture residents' location and travel choices simultaneously, and the resultant rents at different locations. To investigate the optimal housing supply for these two stakeholders, we conduct sensitivity analyzes to explore the impact of different housing supply patterns on total rental profit and total consumer surplus. Specifically, analytical results are derived for a simple linear network with two residential locations and one destination under homogeneous and heterogeneous value(s) of time. The results of the sensitivity analyzes indicate that segregation of housing supplies at different locations for different income classes is, surprisingly, a "preferred" outcome by residents under consumer surplus maximization, whereas creating housing supply shortages at convenient locations is a natural outcome under housing profit maximization. These results provide insights on revealing the differences and tradeoffs in performance between these two different perspectives, and on where land use regulations may be needed to balance these two objectives.

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1. Introduction

In urban development, zones are typically allocated for different uses, such as residential or commercial. Once a zone is designated for residential use, developers bid for parcels of land within for housing development, considering the location's accessibility and neighborhood conditions, etc., subject to planning regulations, such as the types of housing, lot size or development density. The objective of developers is primarily profitability, without much consideration for societal welfare, traffic impact, or other possible externalities. It is, therefore, important for the government to take a system-wide or region-wide perspective to examine the overall impact, and to identify whether certain regulations on housing supply are needed to ensure a proper balance between profitability, consumer surplus, and other externalities. The system-wide or region-wide perspective in this study specifically refers to the spatial location and distribution of housing supply. Studies on spatial location investigate the spatial locations of facilities and their relation to the urban structure, travel pattern and emission, such as the correlation between location advantages of housing and employment as well as peak and off-peak traffic (Murphy, 2012) and the influence of services locations, such as education and health care in different urban centers, on their accessibility to

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the population (Bigotte et al., 2010). The spatial locations of facilities, including housing and utilities, clearly alter travel behavior, location choices and eventually the urban structure and societal welfare. This study addresses the impacts of spatial location and distribution of housing on residents and developers, or the housing supply allocation problem.

Transport facilities around a residential zone influence the location's accessibility and housing prices, which in turn affect their usage and level of service; various theories and models have been developed to describe this interaction between transport and land use. The seminal work of Lowry (1964) modeled the trip interactions between zones based on the activity levels of zones and the transport costs. The random utility theory (McFadden, 1978) was then applied to model residential location choices from an individual's perspective. Eliasson and Mattsson (2000) extended the random utility model by incorporating individuals' budgets and time constraints with choice dimensions such as car ownership and destination choices. Yang and Meng (1998) stratified travelers into various types, with fixed residences and/or fixed job locations, and formulated a combined residents' location and travel choices model based on the stochastic user equilibrium principle. Alonso (1964) developed the classical bid-rent theory to unify agricultural, residential and firms land theories. The bid-rent theory describes the outcome of land use and the resultant price by considering the perspectives of landowners and bidders. Bidders bid for favorable locations while the landowners rent to the highest bidders. Meanwhile, Rosen (1974) proposed the hedonic price theory to differentiate non-homogeneous housing types by relating the hedonic prices to their observable housing characteristics. Later on, the stochastic bid-rent theory was developed (Ellickson, 1981) and extended (Martínez and Henríquez, 2007) to encapsulate the taste variations of bidders and land suppliers. Sharing the same background in microeconomic theory, the random utility theory and bid-rent theory are subsequently proven to be theoretically equivalent for modeling the land use pattern (Martínez, 1992). Around the same time, Chang and Mackett (2006) suggested a bid-rent network equilibrium model using the game theory approach. More recently, Ma and Lo (2012) combined the stochastic bid-rent theory with residents' location choices model and proved that the two approaches are consistent by utilizing an adjustment factor in the equilibrium framework. There are also other approaches to study the problem, such as the adoption of deterministic utility maximization under residents' budget constraint to describe the land use pattern in a linear (Li et al., 2012) and two-dimensional (Li et al., 2013) monocentric city.

While a substantial volume of literature has investigated the interaction between transport and land use in a descriptive manner, fewer studies have considered housing supply as a decision variable in a prescriptive way and investigated its impact on profitability, consumer surplus and social welfare. Early studies considered the demand side rather than the supply side. Herbert and Stevens (1960) formulated the optimal allocation problem of households as a linear programming problem. Given exogenous land supply, area topology, and travel costs among various zones, the model maximizes the aggregated rent-paying ability of households by allocating them in various residential locations. Wheaton (1974) reformulated the Herbert–Stevens model into a nested model, which guaranteed that the equilibrium conditions proposed by Alonso (1964) can be fulfilled. Then an entropy maximizing version of the Herbert–Stevens model was developed by Senior and Wilson (1974) to include the original model as a limiting case. Mirrlees (1972) proposed an economic model and studied the problem of distribution of population as well as the optimal city size. On the supply side, studies started from analyzing the allocation of land between residential and transport use in a narrow linear city (Solow and Vickrey, 1971) and a linear mono-centric city (Solow, 1972), as well as between production and transport use (Kanemoto, 1976). At a later time, housing supply was then considered, starting from Mattsson (1987), who studied the housing supply pattern as a decision to maximize welfare under residential location choices with fixed inter-zonal travel costs. Boyce and Mattsson (1999) later on integrated the formulation in Mattsson (1987) with the traffic network equilibrium approach, which studied the effects of traffic congestion in a road network on the optimal housing supply pattern. Martínez and Henríquez (2007) considered the optimal housing supply from the view of suppliers to maximize rental profit via a fixed point formulation. Ma and Lo (2012) used a quasi-dynamic framework to model the housing supply to be added in the next time period under the principle of profit maximization. Recently, Yin et al. (2012) discussed the optimal housing supply pattern that minimizes the total emissions in a polycentric city. Ho and Wong (2007) studied the housing allocation problem in a continuum transportation network model using the principle of utility maximization. Based on a continuous network with one CBD, that study analyzed the residential choices of heterogeneous income classes given different exogenous housing rent functions according to the residential and development densities. In the numerical example, the study suggested that there existed optimal locations, from the view of residents, to provide housing where the effect of housing rent on residents' total utility compensates the effect of transport cost.

This paper aims to investigate the theoretical basis of optimal housing supplies, not only from the perspective of residents, but also from that of housing developers and that of the society. Specifically, an integrated modeling framework, based on the combined bid-rent and residents' location choices model, is developed to study the impact of housing supply on housing profit and consumer surplus. The approach of discrete network modeling is utilized to allow for multiple transport modes to be incorporated. The housing price is endogenously calculated within the equilibrium model, which explicitly captures the competitive bids from different income classes and for different residential zones. We propose and derive the optimal housing supplies, respectively, for housing developers and residents under mild assumptions, as detailed in Section 2.

Residents seeking housing and developers providing housing are two main stakeholders considered in this study. Residents prefer a residential location near their work and with low rent. Developers provide housing in different locations to maximize their profits. Housing near the CBD or at a location with high accessibility typically has a higher rent; however, providing too much housing at one location, albeit it is highly accessible, would reduce its rental value, thus affecting profitability. In this paper, through the combined equilibrium model developed, we study the interplay between residents and

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