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The role of spatial and temporal structure for residential rent predictions

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ABSTRACT

This paper examines the predictive power of five linear hedonic pricing models for the residential market with varying levels of complexity in their spatial and temporal structures. Unlike similar studies, we extend the out-of-sample forecast evaluation to one-day-ahead predictions with a rolling estimation window, which is a reasonable setting for many practical applications. We show that the in-sample fit and cross-validation prediction accuracy improve significantly when we account for spatial heterogeneity. In particular, for one-day-ahead forecasts, the spatiotemporal autoregressive (STAR) model demonstrates its superiority over model specifications with alternating spatial and temporal heterogeneity and dependence structures. In addition, sub-market fixed effects, constructed on the basis of statistical TREE methods, improve the results of predefined local rental markets further.

1. Introduction

The accurate prediction of rental prices is essential for many participants in the real estate market, such as investors, regulators, and policy-makers. For instance, rent forecasts play a crucial role in the property valuation adopted in discounted cash-flow models. In addition, when imputed market rents for owner-occupied dwellings are subject to income tax, as they are in Luxembourg, the Netherlands, or Switzerland, for example, local rent predictions serve as a tax base. Furthermore, the imputed rent constitutes a major component of the gross domestic income measure. A profound knowledge of the structure and development of rents in the local and national housing markets is also of importance for public housing policy.

Hedonic pricing models are the approach that is applied by far the most extensively to the prediction of rental and residential sales prices. In their most basic form, they model real estate prices as a linear function of the properties' attributes. Recent approaches have focused on the temporal structure, but have also paid particular attention to the spatial structure. In this paper, we compare the predictive power of hedonic models with varying levels of complexity of spatial and temporal structures. We focus mainly on comparisons of in-sample model fits, as well as the cross-validation prediction and one-day-ahead forecasting accuracies of the different models. We stress the fact that, while one-day-ahead forecasting, without ex ante information, is the very nature of many practical applications, it has still attracted little attention in the literature.

We restrict the analysis to fully parametric and linear models in order to ensure that the results remain interpretable for practical purposes. Starting with a simple *baseline* model that includes only physical attributes of the dwellings, we incrementally add elements to account

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for spatial and temporal effects. We show that the consideration of a few spatial and temporal components can increase the forecast accuracy substantially. Likewise, significant spatial and temporal effects underpin the inconsistency of hedonic coefficients in the absence of these components, since the assumption of *i.i.d.* errors of the *baseline* model is violated. We demonstrate the empirical bias resulting from spatial heterogeneity, which in general prohibits causal inference. Thus, we aim to improve the prediction accuracy for rental prices by accounting for both the space and time dimensions in our model specifications.

Our paper contributes to the literature in at least three ways. First, we analyze the importance of the temporal and spatial structure of a model for residential markets. Most notably, the models include a spatiotemporal autoregressive (*STAR*) specification, as suggested by Pace, Barry, Clapp, and Rodriquez (1998).[1] Only a few other studies on *rental* price modeling exist, such as those by Sirmans and Benjamin (1991) and Valente, Wu, Gelfand, and Sirmans (2005), with the latter predicting apartment rents based on spatial econometric techniques. However, unlike our approach, they model an explicit spatial process, whereas our *STAR* model merely makes strong structural assumptions about the spatiotemporal dependencies.

Second, our choice of model specifications allows us to determine the *marginal effects* of increasing the complexity of the spatial and temporal structure. Importantly, we pay particular attention to the different prediction approaches, a point that has often been underrated in similar studies. In the forecasting application with a rolling estimation window, we account for temporal heterogeneity to the same degree in all models. We then improve the *baseline* model incrementally by gradually accounting for spatial heterogeneity, as well as temporal and spatial dependence. Finally, we account for spatial heterogeneity by constructing rental sub-markets using a classification and regression tree (*CART*) method. To our knowledge, only Clapp and Wang (2006) have used the CART methodology for sub-market construction in the context of housing price *sales* data.

Third, we use an exclusive rental apartment data set for the canton of Zurich, Switzerland. In countries in which the majority of households are tenants, the higher turnover in the rental market reduces the estimation error due to the rich data availability. Thus, the Swiss housing market, with its low homeownership rate, serves as an ideal testing ground for evaluating the predictive power of different hedonic rental price models.[2] Moreover, the canton of Zurich constitutes a residential market within a homogeneous regional economy, which makes it an ideal laboratory for our analyses.

Our empirical results show that including sub-market dummy variables based on ZIP codes improves the prediction accuracy significantly. However, while this approach systematically ignores the spatial structure, the construction of sub-markets based on a regression tree technique displays a superior estimation strategy. The forecast evaluation shows that augmenting the hedonic model with spatially-lagged variables is particularly successful for one-day-ahead forecasting. These results highlight the STAR model's superiority over other specifications, and emphasize the importance of local dynamics in one-day-ahead forecasting.[3]

The rest of the paper is organized as follows: Section 2 provides an overview of the theoretical and empirical approaches to modeling the temporal and spatial structure in hedonic pricing models. Section 3 introduces the research design and the models that are compared for prediction purposes. The empirical predictive power of these models is evaluated in Section 4. Section 5 summarizes our results and provides concluding remarks.

2. Space–time modeling

Hedonic pricing models have been the workhorse of the housing literature for decades. Since the seminal work of Rosen (1974), the capitalization of dwelling amenities in house prices, based mainly on linear hedonic functions, has been studied extensively in the literature.[4] One of the most important distinguishing features of hedonic housing price models is the underlying assumption about the spatial and temporal structure. Moreover, hedonic pricing models take a wide range of functional forms. In this section, we demonstrate the range of spatial and temporal effects in empirical housing applications, which serve as individual components in our model comparison and evaluation. Concerning the functional form, the potential model complexity has been influenced largely by advances in computer technology. In particular, semi- and non-parametric approaches have attracted a considerable amount of attention. For an overview of these models, see Anglin and Gencay (1996) and McCluskey, McCord, Davis, Haran, and McIlhatton (2013), as well as Martins-Filho and Bin (2005) for the application of artificial intelligence methods to the field of real estate.

Despite the successful application of non-linear and non-parametric methods, we restrict our analysis to linear and parametric methods for two reasons. First,

[1] See also Pace, Barry, Gilley, and Sirmans (2000) for an application of the *STAR* model to housing prices in Baton Rouge, Louisiana.

[2] Switzerland has one of the lowest homeownership rates internationally, at approximately 44%, according to Eurostat (2015).

[3] Note that one-day-ahead forecasting has the conceptual feature of using only information that is available at the time of the prediction. The goal of this study is not to predict prices far into the future, since the temporal market dynamics in the model only account for short-term dynamics, because they are captured by temporally and spatially lagged variables. However, many applications require medium- or long-term forecasts of rental prices, e.g., for investment decisions. For these kinds of applications, the findings in this study can serve as a qualitative basis, since essentially the same out-of-sample prediction could be conducted with a longer time horizon. In contrast, short-term time horizons are more important in regions in which only a few rental price transactions are observable, the local housing market is very dynamic, or a precise valuation at a specific date is required, such as for imputed rents.

[4] Instead of using house prices, the present study is one of the few to apply hedonic pricing techniques to rental price data. For reviews of the earlier literature, see Bourassa, Hoesli, and Peng (2003), Malpezzi (2003) and Sirmans, Macpherson, and Zietz (2005).