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The impact of an urban toll ring on housing prices

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ABSTRACT

Building on standard urban economics theory we set up a stylized model within which we demonstrate that the imposition of a toll ring leads to higher housing prices within the ring, and lower outside the ring. We examine this prediction empirically by using transaction data for 15,306 dwellings in the Norwegian town of Kristiansand, where since 1992 there has been a toll ring. We find that the toll ring implies 6.9 per cent higher housing prices within the toll ring than outside it. The relationship between toll fees and housing prices seems to be stable over time. The impact of the toll ring on the prices of detached houses, apartments, row houses and twin houses is strikingly different. For detached houses, we do not find significant evidence of a price premium within the toll ring. For apartments, the price premium is estimated to be 8.1 percent. For row houses and twin houses taken together, we find a price premium of 19.2 per cent for dwellings within the toll ring.

1. Introduction

The idea of imposing tolls on road users has a long history in the economics literature, dating back to the work of Pigou (1920) and Knight (1924). In Norway, road tolls have been collected for approximately 100 years, first as a pure financial device but in later decades also to reduce the inflow of cars into some of the larger towns. Norwegian economists have contributed actively to the research on toll-financing roads; see for instance Larsen and Østmoe (2001), Odeck and Bråthen (2002), Ramjerdi, Minken, and Østmoe (2004), Bråthen (2005), and Bekken and Norheim (2007). The focus in most of this Norway-based literature, and in the contributions of researchers from other countries, for instance Santos (2005) and de Palma, Lindsey, and Proost (2006), has been on how tolls affect traffic, and how tolls may contribute to finance road construction, i.e., issues typically dealt with in the literature on the economics of transportation. In another part of the literature, researchers have addressed the political economy of financing roads by means of tolls; cf. Hårsman and Quigley (2010) and De Borger and Proost (2012).

In yet another vein of the literature, researchers have examined how transportation infrastructure impacts housing prices, location of residences, and the location of industries, etc. For instance, Boarnet and Chalermpong (2001) study how new toll roads in Orange county, California, impact housing prices in areas near the roads. Similarly, Vadali (2008) examine the impact on housing prices of toll-roads in Dallas County, Texas. Authors of both contributions conclude that toll roads impact housing prices. However, these studies considered toll roads located in areas with a dense network of alternative roads, i.e., cases where drivers could avoid paying tolls through choosing alternative routes. Moreover, albeit considering toll roads, neither Boarnet and Chalermpong (2001) nor Vadali (2008) examined how the *level* of tolls affects housing prices.

The case we study is distinguished from those of Boarnet and Chalermpong (2001) and Vadali (2008) in two important respects: First, we study a complete toll ring around the central parts of a town, i.e., the case where it is impossible to avoid paying a toll by choosing alternative routes. Second, in contrast to the abovementioned studies, we use information on how the level of tolls paid when crossing the toll ring impacts housing prices. To the best of our knowledge, the impact of a complete urban toll ring on housing prices has not previously been studied in the economics literature. The goal of our work is therefore to contribute through the study of this issue. Hence, our first research question is to examine how an urban toll ring affects housing prices for dwellings within such a ring relative to prices outside the ring. Second, we want to study whether a change in the level of the toll is immediately discounted into housing prices. Since a change in the toll alters the long-term spatial equilibrium of the town, it will set into motion processes of sorting and relocation of households and possibly a sorting and relocation of workplaces. Consequently, it may take time before a new equilibrium is reached. Finally, we examine whether a toll ring impacts the prices of different types of housing equally.

Our empirical examination is based on a sample of 15,306 dwellings sold in the Norwegian town of Kristiansand in the period 2010–2017. In this town, there has been a toll ring since 1992, and tolls were increased

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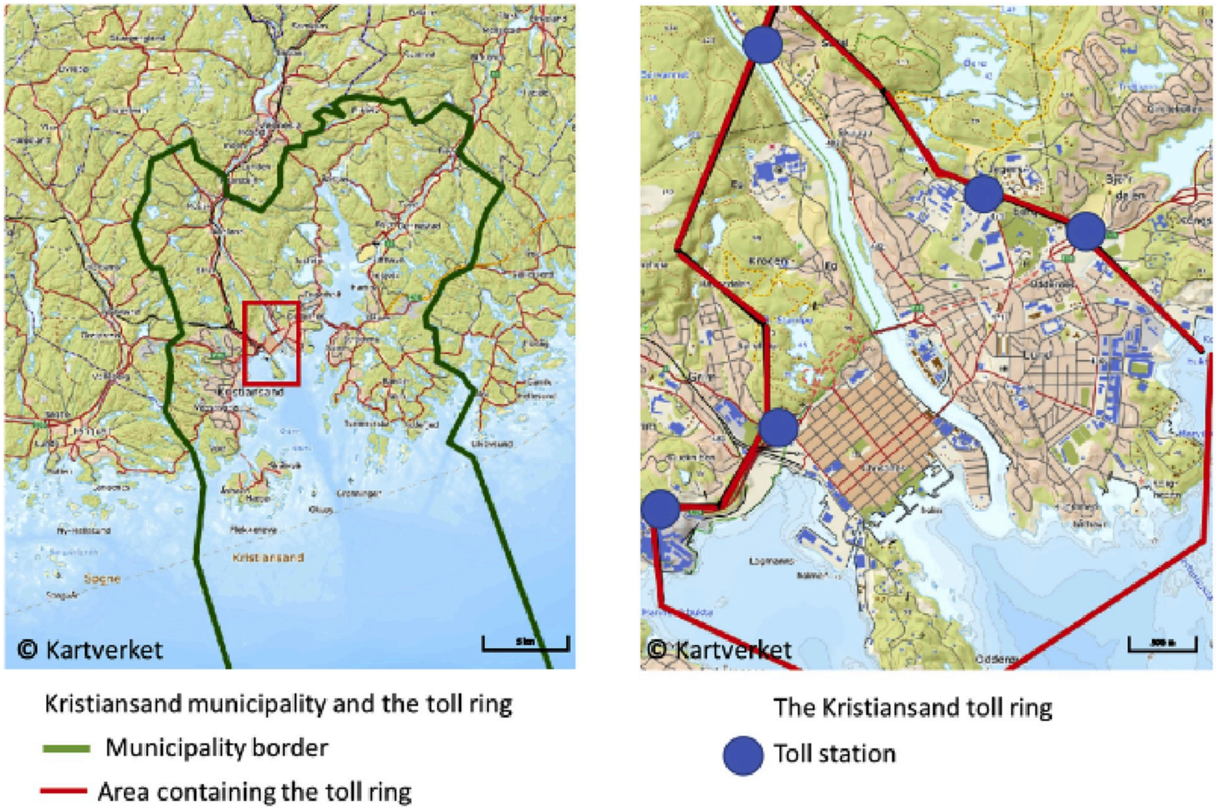

Fig. 1. Map of Kristiansand and the toll ring.
The maps have been downloaded from Kartverket.no and further processed by the author.

twice in the course of the observation period. Hence, Kristiansand provides a suitable case for addressing our three research questions. We find that in 2017, the toll ring on average implies 6.9 per cent higher housing prices within the ring compared to outside the ring. For apartments, the price premium is, however, estimated to be 8.1 per cent, and for row houses and twin houses taken together, 19.2 per cent. For detached dwellings, in contrast, we do not find statistically significant evidence that prices are affected positively by houses being located within the toll ring.

We expect that the results of our examination will be useful far beyond the case studied. In Norway, there are toll rings around Oslo, Bergen, Trondheim, Stavanger, and Kristiansand, and ongoing discussions about establishing toll rings around several other towns. Hence, issues related to toll rings are particularly relevant in the Norwegian context, where tolls recently have become increasingly important and are high on the political agenda. However, also on the international scene, toll rings have been established, for instance, around the inner parts of Stockholm and London. We expect that toll rings in the future may be established in many other towns based on environmental arguments inter alia. While several researchers have studied the impact of tolls on traffic volume, very few have studied the impact on the housing market, despite concerns about high and rising housing prices in the inner parts of many towns and cities. Previous research has not addressed how a dense toll ring around the central parts of a town impacts the housing market. It is precisely the neglect of this issue, both in the economics discipline and among policymakers, that has given us the impetus to carry out the present investigation.

In the next section, we provide information about the study town and the toll ring on which the empirical part of this paper is based. Next, in Section 3, a stylized theoretical model of the housing market in a city is set up and used to demonstrate how a toll ring will change equilibrium prices for housing throughout the city. Section 4 contains the econometric model and estimation strategy, and the data are presented in Section 5. Empirical results are provided in Section 6, and robustness checks are added in Section 7. Section 8 concludes the paper.

2. The study town and the toll ring

The study town, Kristiansand, is the fifth largest town in Norway and is representative of urban housing markets in the country. It is located on the south-eastern coast of Norway, approximately 300 km from the capital of the country, Oslo. The Kristiansand municipality had in 2010 a population of 81,295, which increased to 89,268 in 2017. The urban space of the town is very irregular, and as shown in Fig. 1, it is divided by fiords and two large rivers. Near the centre of the town is a large greenfield area where building is not allowed, and several valleys penetrate the landscape.

The history of the Kristiansand toll ring started in 1990, when Kristiansand Toll Road Company Ltd. was established with the goal of financing parts of the costs for replacing an old bridge with a new one. The bridge connects the eastern and western parts of Kristiansand, which are separated by a large fiord as seen in Fig. 1. Since the bridge also is a part of the main road, E−18, running along the coast from Oslo through Kristiansand to other towns further west, a large share of the bridge was financed by the Norwegian central government. The remaining costs were financed through the collection of toll fees at two toll stations. Collection of tolls started in April 1992 and lasted until August 1996. After a pause of nearly one year, collection of tolls started again in July 1997. Moreover, since – for people who were well informed about the road system in Kristiansand – it was possible to find

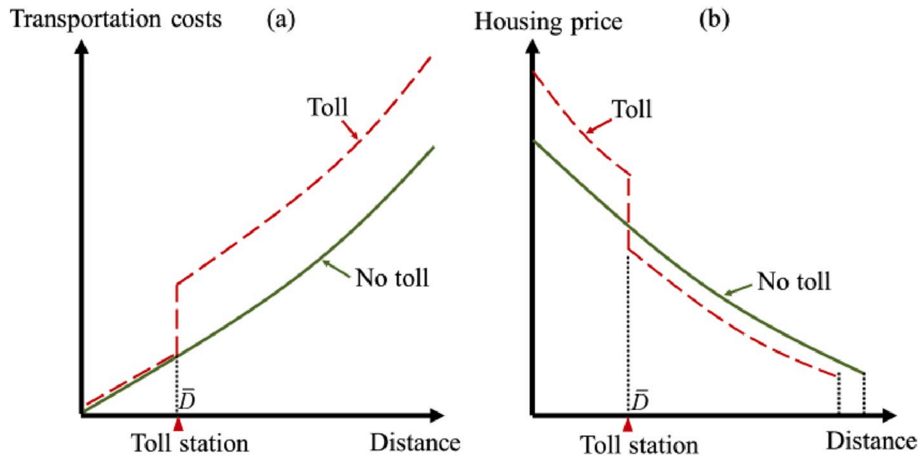

Fig. 2. Housing prices with and without a toll ring.

alternative routes, thereby avoiding paying tolls, three additional toll stations started collecting tolls in February 2000. Since then, the central parts of the town have been completely enclosed by five toll stations on all roads leading into the centre of Kristiansand: see Fig. 1. Hence, since February 2000, it has not been possible to enter the inner parts of the study town by car without passing a toll station.

Table 1 shows that, over time, there has been a substantial increase in the toll fees in the Kristiansand toll ring. In all years since the first toll stations were opened, tolls have, however, only been collected *when cars enter* the central parts of the town. In 2010, the first year for which we have housing price data, the full fee per passing with a small car was 10 Norwegian crowns (NOK), but in July the same year, it increased to 21 NOK.[1] A large share of the car owners in Kristiansand have, however, signed prepayment contracts that reduce substantially the tolls they pay. For instance, from July 2010 to September 2013, a prepayment of 3,775 NOK reduced the fee per a single passing with a small car from 21 NOK to 10.50. In September 2013, the rebate associated with prepayment was, however, reduced, with the result that the rebated toll per single passing in rush-hours on workdays amounted to 16.80 NOK, i.e., an increase of 60 per cent compared with the minimum fee per passing prior to September 2013. Further details about the toll system are provided in Table 1.

The centre of the town is by far the most important amenity in the Kristiansand municipality. It is not only a major shopping area and the location of the most important cultural institutions, offices of public administration, high schools, and restaurants but also the major centre of employment. Almost 50 per cent of the jobs in the Kristiansand municipality are located within the toll ring, but only 30 per cent of the dwellings and only 10 per cent of the population are. The lack of balance between jobs and population within the toll ring implies that many citizens residing outside the toll ring must pass the ring when commuting to work. Most commuters who cross the toll ring use either their own car or bus, but some use a bicycle, while a negligible number of persons walk. Over the period 2010–2017, there have been improvements in biking paths, and busses run somewhat more frequently, but the road infrastructure has not changed.

3. Theoretical model

Assume that households derive utility from housing, h, a Hicksian composite good, x, and leisure, l. The household utility function takes the form $U = U(x,h,l)$, with the marginal utilities $U_x > 0$, $U_h > 0$, and $U_l > 0$. Consider a household residing at a specific location in the urban space, at distance D from the centre of the town (CBD). All workplaces, and all other amenities, are (in the baseline model) assumed to be co-located at the same spot in the centre of the town. The household incurs monetary costs of commuting, $c(D) + b(D;I)$, where the first part captures distance-related costs, and the second part toll costs. For distance-related costs, we assume $\partial c/\partial D = c' > 0$. In the toll-cost function, I is an indicator that takes the value $I = 1$ if there is a toll ring and $I = 0$ if there is no ring. In the case of no toll ring, $b(D;0) = 0$. If there is a toll ring, $b(D;1) \geq 0$, with the equality sign valid for households within the toll ring and the strict inequality valid for those living outside.

Let r be the household's after-tax income, covering expenditures on the composite good, commuting, and housing. With the Hicksian good as the numeraire, the monetary budget constraint takes the form $r = x + \tilde{p}(D)h + c(D) + b(D;I)$, where $\tilde{p}(D)$ is the unit cost of housing. Moreover, the household's time budget is $T = l + a(D)$, where T is the total after-work time available to the household, while $a(D)$, with, $\partial a/\partial D = a' > 0$ is commuting time.[2]

A household at location D maximizes $U = U(r - \tilde{p}(D)h - c(D) - b(D;I), h, T - a(D))$ with respect to h. This yields the first-order condition $U_h/U_x = \tilde{p}(D)$, which together with the monetary budget yields Marshallian demands $x = f_x(1, \tilde{p}(D), r - c(D) - b(D;I), T - a(D))$ and $h = f_h(1, \tilde{p}(D), r - c(D) - b(D;I), T - a(D))$, conditional on residing at distance D from the CBD. Inserting these into the utility function yields the conditional indirect utility function $V(1, \tilde{p}(D), r - c(D) - b(D;I), T - a(D))$.

In a spatial equilibrium, households that are homogeneous in income and other characteristics but live at different distances from the centre of the town, must obtain the same utility. Consequently, taking the derivative of the indirect utility function w.r.t. distance, D, a spatial equilibrium is characterized by $V_p(\partial\tilde{p}/\partial D) - V_x(c' + b') - V_l a' = 0$, where V_p, V_x, and V_l are partial derivatives of the indirect utility function. From this equilibrium condition we obtain the following by using Roy's identity:

$$\frac{\partial\tilde{p}}{\partial D} = -\frac{c' + b'}{h} + \frac{V_l}{V_p}a', \text{where } b' = \begin{cases} 0 & \text{if } I = 0 \\ \text{b} & \text{if } I = 1 \text{ and } D = \overline{D}, \\ 0 & \text{if } I = 1 \text{ and } D \neq \overline{D} \end{cases} \tag{1}$$

[1] At 29.11.2019, according to the Norwegian Central Bank, 1 NOK = 0.0990 Euro = 0.1087 US dollar.

[2] To keep the model simple, we take working time and hence also income as exogenous.

where the first term on the r.h.s. in the expression for $\partial\tilde{p}/\partial D$ captures the impact of the monetary costs of transportation, including the toll fee, on the price of a dwelling, while the second term captures the impact of time costs. Since $V_l > 0$, $V_p < 0$, $c' > 0$, and $a' > 0$, both the monetary costs of travelling and the monetarized time costs of travelling imply that housing prices will be a declining function of distance from the centre of the town.

Consider first a town with an exogenously given population and with no toll ring ($I = 0$). We then have $b' = 0$, and total costs of transportation (monetary and monetarized time costs) will be a continuously increasing function of distance from the centre of the town, as illustrated by the upward sloping no-toll cost curve in panel (a) of Fig. 2. Moreover, we know from Eq. (1) that housing prices will be a downward-sloping function of distance from the town centre, as shown by the fully drawn no-toll curve in panel (b) of Fig. 2.

Suppose now that a toll ring is imposed on the study town and that all toll stations are at distance $\overline{D}$ from the town centre. The transportation cost curve in Fig. 2 (a) then shifts upwards outside the toll ring. Consider a household residing exactly at distance $\overline{D}$ from the centre of the town but outside the toll ring and connected to a road running through the toll station. After the toll ring has been established, this household may avoid the toll by purchasing a dwelling inside the toll ring, for instance a neighbouring house located at the same distance to the centre of the town but inside the toll ring. If the household is the first to realize how the toll ring has changed the economic conditions, it might have luck and purchase a dwelling identical to its present dwelling but inside the toll ring, at a price just marginally above the price its present dwelling may be sold for. When more households realize the change that has occurred in the costs of transportation, however, an increasing number will demand dwellings inside the toll ring. Housing prices within the toll ring are thereby bid up, and – under the assumption of a town with a given population – prices are bid down outside the toll ring. Hence, in the new long-term equilibrium, we obtain the dashed housing price gradient in Fig. 2 (b), with a discontinuity at the toll station. In the new spatial equilibrium, the outer border of the town comes somewhat closer to the centre of the town. This change is due to the assumption of an exogenously given population and to the fact that the toll makes commuting more expensive for those living outside the toll ring. In the effort to avoid tolls, a larger share of the population will therefore in the new equilibrium choose to reside within the toll ring.

We have deliberately kept the model simple, but it may be extended in various ways. Briefly consider for instance the case where there is a shopping mall at the border of the town at distance $\overline{B}$ from the centre of the town. Assume initially that there is no toll and that parts of the population have their workplace at the mall, where they also shop for most of their goods. Housing prices will then in equilibrium be higher near the mall than in parts of the area between the mall and the CBD. In other words, the town will in a sense have two centres in the pre-toll equilibrium. Suppose now that a toll ring is established. Households whose members have their workplaces at the mall will then have a stronger incentive to live close to the shopping mall. Consequently, housing prices near the shopping mall will be bid up, similarly to within the toll ring. In much of the area between the toll ring and the shopping mall, however, housing prices will – with a constant population in the town – be bid down.

The structure of real-world towns, including our study town, is much more complex than in the stylized theoretical model. Schools, kindergartens, grocery stores, and churches, etc. are usually scattered throughout the town. Theisen and Emblem (2018) present a theoretical model of how an equilibrium with higher housing prices near kindergartens then may emerge, and they also find empirical support for this. A similar type of logic lies behind the contributions of Des Rosiers, Lagana, and Theriault (2001), Metz (2015), and others who find that housing prices are higher near schools, except in the immediate neighbourhood of schools. It would be far beyond the scope of our theoretical examination, though, to try to capture all of the above in a coherent model. We will, however, account for the general phenomenon that house prices are likely to depend on the location of a house relative to several amenities. This phenomenon is captured through a vector of distance variables, D^i, where i indexes dwellings, and each element in the vector represents the distance to a specific amenity. Moreover, based on our theoretical model, we include in the housing price function a binary variable, W^i, which equals 1 if dwelling i is located within the toll ring and 0 if located outside, a term, T_y, specifying the toll fee at the point in time, y, when the dwelling is sold. The housing price function then takes the general form $\widehat{p}(D^i, W^i, T_y)$, for which we next chose a specific form.

4. Econometric model

We specify the housing price function as:

$$\widehat{p}\left(D^i, W^i, T_y\right) = e^{\left(\beta_0+\beta_1 D_1^i+\phi W^i T_y\right)} e^{\sum_{j>1}\beta_j D_j^i}, \tag{2}$$

where ϕ and the β_j's (j = 0, …,J) are parameters to be estimated. The first part on the r.h.s. corresponds to the housing price function in Fig. 3 (b), and accounts for the impact on housing prices of distance to the CBD and location within/outside the toll ring. The second part on the r.h.s. of Eq. (2) accounts for the impact of distances to other (local) amenities than the CBD. Assuming, in accordance with the theoretical model, that distance to CBD has a negative impact on housing prices ($\beta_1 < 0$), the price function implies that the *percentage* increase in the housing price due to the toll will be greater just inside the toll ring than at the centre of the town.

The highly stylized model in Section 3, abstracts from many real-world aspects that impact housing prices. Hence, we embed the housing price function (2) in a grand model also incorporating characteristics of dwellings and the year and month in which they are sold:

$$P^{iz} = \chi e^{\left(\beta_0+\beta_1 D_1^i+\phi W^i T^y\right)} e^{\sum_{j>1}\beta_j D_j^i} X \left[\left(\prod_{g=1}^{G}\left(q_g^i\right)^{\alpha_g}\right) e^{\sum_{k=1}^{K}\omega_k r_k^i+\sum_{t=1}^{\overline{T}}\tau_t y_t^i+\sum_{m=1}^{M}\lambda_m \widehat{y}_m^i}\right] e^{\varepsilon^{iz}}. \tag{3}$$

The middle part on the r.h.s. of Eq. (3), enclosed in brackets, is a simple hedonic function, where α_g, ω_k, τ_t, and λ_m are unknown parameters to be estimated, q_g^i are continuously measured dwelling characteristics, r_k^i are dwelling type dummies, y_t^i are time-period dummies denoting the year a dwelling is sold, $\widehat{y}_m^i$ denotes the month the sale has taken place, ε^{iz} is an error term to which we return below, and z is an indicator to which we also return below. By taking the natural logarithm of both sides of Eq. (3), we obtain the following:

$$\ln P^{iz} = \ln\chi + \beta_0 + \beta^1 D_1^i + \phi W^i T_y + \sum_{j=2}^{J}\beta_j D_j^i + \sum_{g=1}^{G}\alpha_g \ln q_g^i + \sum_{k=1}^{K}\omega_k r_k^i + \sum_{t=1}^{\overline{T}}\tau_t y_t^i, + \sum_{m=1}^{M}\lambda_m \widehat{y}_m^i + \varepsilon^{iz} \tag{4}$$

where we assume that the error term contains two random variables: $\varepsilon^{iz} = \mu^z + \eta^{iz}$. For the second term we assume $\eta^{iz} \sim N(0,\sigma_\eta^2)$, $E(\eta^{iz}\eta^{i'z}) = 0$ $\forall\ i \neq i'$, and that η^{iz} is uncorrelated with the regressors and with μ^z. For the first term, we assume $\mu^z \sim N(0,\sigma_z^2)$, $E(\mu^{z'}\eta^{iz}) = 0$ $(\forall\ z, z', i)$ and that μ^z is uncorrelated with the regressors. Observations within the same category, z, may, however, be correlated. Hence, we have a random effects model, or, more precisely, a random intercepts model, where we assume that the z-categories will be postal code based, and where the variance in the distribution from which the μ^{i}'s are drawn is assumed to differ between postal codes. Notice also that since both $\ln\chi$ and β_0 in Eq. (4) are constants, only the sum $\psi = (\ln\chi + \beta_0)$can be identified. This is not a problem for the main issue we address – the impact of the toll ring on housing prices, which can be identified. Without an explicit estimate of β_0, however, the *level* at which the housing price function starts at the centre of the town cannot be determined.

A substantial share of the housing units in the sample are co-ops carrying a mutual debt. Mutual debt is in effect a deferred payment that is paid down through monthly instalments after the transaction has taken place. Hence, we define the total price of a cooperative dwelling as $P^i = p^i + \zeta * MUT^i$, where p_i is the equity (out-of-pocket) price paid at the time of transaction, MUT^i is the mutual debt resting on the dwelling, and ζ is an unknown parameter. Eretveit and Theisen (2016) demonstrated that in Norway, where interest rates on mutual debt normally fall short of interest rates on private loans, $\zeta < 1$, and they obtained the point estimate $\zeta = 0.87$. We use, however, the estimate $\widehat{\zeta} = 0.77$ obtained by Theisen and Emblem (2018). Using this estimate as prior information, we estimate Eq. (4), but in the robustness checks in Section 7, we examine whether results are robust towards variations in the magnitude of $\widehat{\zeta}$.

Various versions of Eq. (4) will be estimated, accounting for heteroskedasticity by using robust standard errors. The estimation procedure in Section 6 contains five main steps: (I) We first estimate a reference model without random intercepts. This model is the one towards which the random effects models will be tested. (II) We then estimate the simplest possible corresponding random effects model. (III) We estimate an additional variant of the random effects model to examine whether the toll impacts housing prices similarly in different periods. (IV) We estimate the random effects model separately for different categories of dwellings: Detached houses, apartments and small houses (row houses and twin houses). (V) Robustness of the results is checked in Section 7.

5. Data

Data on house prices and dwelling characteristics in the study town were extracted from the register of property transactions in the database of Eiendomsverdi AS and cover the period January 1, 2010, to December 31, 2017. We extracted 18,612 transactions, but after excluding observations with item nonresponse for price, size and age of dwelling, we obtained a final sample of 15,306 transactions. Of these, 4,868, or almost 32 per cent, are located within the toll ring.

Data on transaction prices, dwelling characteristics, location and time of transaction were complemented with data on distance and travel time from each dwelling to the central business district (CBD), two major shopping centres, schools and kindergartens. For this part of the data collection, we used the georoute command in Stata, developed by Weber and Péclat (2017). By means of georoute, we obtained the driving time and distance from each dwelling to each amenity and distances from kindergartens to the nearest grocery store. Distances and travel time are measured from the entrance of the starting address to the entrance of the ending address.[3]

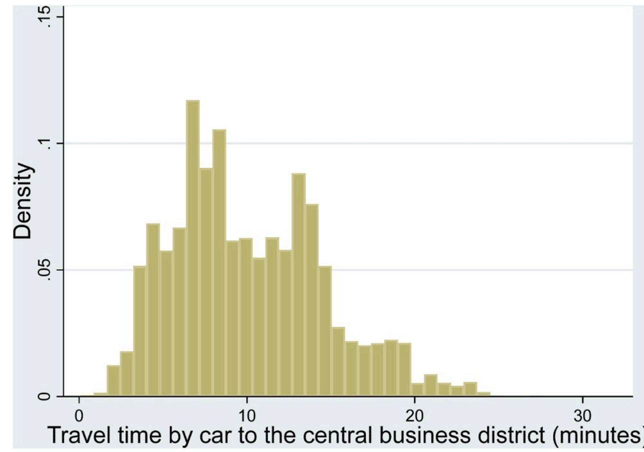

Fig. 3. Travel time from houses to the centre of the study town. N = 15,306.

Exact definitions of the dependent and independent variables are given in Appendix A. In Table 2, we have indicated hypothesized signs of the impact parameters affiliated with independent variables, along with descriptive statistics.[4] As explained in Section 4, the dependent variable (before taking the log) is in our case constructed as Price+0.77*Mutual debt. Hence, the dependent variable is a calculated price that, for a given out-of-pocket price (Price), will be higher the higher the mutual debt. Since the mutual debt parameter is less than 1, however, the person who purchases a cooperative dwelling implicitly pays some for taking over the mutual debt affiliated with the dwelling. Robertsen and Theisen (2011) denote this slightly excessive price the *interest-discount-effect*, and they argue that this effect is related to the fact that interest rates on mutual debt in Norway are lower than interest rates on individual bank loans. Robertsen and Theisen (2011) also argue that there is an *institutional-form-effect* implying that prices of cooperative dwellings differ from prices of self-owned housing units; in their empirical examination, they find that this effect impacts prices of cooperative dwellings negatively. Our hypothesis indicated for the co-op variable in Table 2 is in accordance with this finding. In our sample, 32 per cent of the observations are cooperative dwellings, while co-ops constitute 55 per cent of the apartments. All detached dwellings are self-owned.

Among the independent variables, Toll is the key variable in our context. This variable is defined as $Toll = W^i T_y$, where the r.h.s. is the toll term in Eq. (2). Since the toll paid for passing a toll station one time, T_y, is positive throughout the years covered by our data, and since W^i is

[3] The georoute command returns both distance and travel time by car. Since many may walk or use a bicycle, particularly to local amenities (kindergarten, school and local grocery store), it seems better to use travel distance rather than travel time by car to these local amenities. We use distance also to the shopping centres. For travels to the central business district, however, we use travel time inter alia because time costs constitute a substantial part of the total cost of transportation. Notice that since travel time and travel distance are strongly correlated, including both for travels to the same amenity would imply highly correlated regressors.

[4] A survey of how housing prices in hedonic equations usually are affected by various independent variables is provided by Sirmans et al. (2005).

equal to one for dwellings located inside the toll ring but equal to zero for dwellings outside the ring, the toll variable is positive for dwellings inside the ring and zero for dwellings outside the ring. The magnitude of the toll variable for dwellings inside the toll ring depends, however, on when the dwelling is sold. From Table 1, we find that $T_y = 21^* \, 0.8 = 16.80$ for dwellings sold in Period 3 and $T_y = 21^* 0.5 = 10.50$ for dwellings sold in Period 2. For dwellings sold in Period 1, we calculate the fee as $T_y = 1,500/220 = 6.80$, where 1,500 is the prepayment for one year, and 220 is the number of working days per year. Based on the presumption that commuters are rational, we use this calculated fee rather than the cash fee per passing, since the calculated fee is lower. Notice also that since large vehicles are rarely used for commuting to work, we use the fee for a small car in our empirical analysis. In accordance with the theoretical model in Section 3 we assume that the toll variable has a positive impact on housing prices within the toll ring.

Housing units with large floor-space are hypothesized to be sold at higher prices than smaller units; see for instance Sirmans, Macpherson, and Zietz (2005). Our measure of floorspace does not include storage rooms. Concerning the lot on which dwellings sit, several complications should be mentioned. First, lot size is not easily defined for apartments in block houses. Second, for cooperative dwellings, the lot-size variable in our data set cannot be used, since it measures all land owned by the housing cooperative, not the share of the total lot affiliated with each housing unit. We have "solved" these problems by setting the lot-size variable equal to zero for all apartments, and for all cooperative dwellings. For other types of dwellings, we set lot-size equal to zero if actual lot size is less than 1,000 square metres, while for dwellings with an actual lot size of more than 1,000 square metres, we define lot size as the size exceeding 1,000 square metres. Hence, our lot-size variable measures only the size of large lots, and we hypothesize, in accordance with inter alia Sirmans et al. (2005), that large lots impact housing prices positively. Many detached houses have lots exceeding 1,000 square metres, but very few row houses and twin houses sit on large lots.

Old dwellings are, ceteris paribus, hypothesized to be sold for lower prices than are the newest dwellings. These lower prices may be due inter alia to the need for refurbishing older dwellings to obtain a standard approximately equal to new dwellings. Finally, notice that since old dwellings in urban areas often are centrally located, where land prices usually are high, it is important to control for the location of houses, which we do inter alia by including in the model variables such as distance from each dwelling to the town centre.

We distinguish four types of dwellings (detached houses, row houses, twin houses, and apartments). The distinctions between these categories are in most cases easily drawn, but there are some complications. Twin houses is the most problematic category. Such dwellings consist in some cases of two units located beside each other, separated by a common wall, i.e., as in a two-unit row house. In other twin houses, one unit occupies the lower floor, while the second unit is on the upper floor. The household on the upper floor has, however, almost always the same right to use the garden as the household on the lower floor. Row houses consist of three or more housing units separated by common walls. Some adjacent housing units are separated by a garage but without any open space between units. Such dwellings are often called chain houses and are in our data subsumed under detached dwellings.

In our hedonic equations, apartment is the left-out category. We hypothesize that detached houses are sold at higher prices than are equally large apartments at the same location, because inter alia they usually have a private garden and because a detached house implies a more independent life than in an apartment. Twin houses and row houses are hypothesized to be sold at lower prices than for comparable apartments. One may argue that such dwellings do not provide opportunities for much more privacy and independent living than does an apartment. In addition, in Norway, the construction costs for twin houses and row houses, which almost always are built with wood as the main material, are lower than for apartments in block houses, which usually are constructed of concrete and/or bricks. Our hypotheses on relative prices of different dwelling types are also in accordance with what is commonly found in the Norwegian housing market; see for instance Theisen and Emblem (2018).

Dwelling type variables should be interpreted in view of the lot-size variable. An important reason for this is that the way we have handled the lot-size variable implies that the dummy variables for types of dwellings and the co-op variable capture not only that types of buildings and ownership differ but also to some extent that lot size for dwellings with small lots may differ between dwelling types, and perhaps also between ownership categories. An additional advantage with our lot-size measure is that the partial correlation between the logarithm of lot-size and the detached dummy is only 0.45, while the correlation between the logarithm of *actual* lot size and the detached dummy is 0.70.

Consider next the impact of distance variables on housing prices. Based on the theoretical model in Section 3 and on a comprehensive theoretical and empirical urban economics literature, originating inter alia from the seminal work of Alonso (1964), we hypothesize that housing prices are a declining function of time used to travel, or, alternatively, distance to the CBD. Fig. 3 shows travel time by car from each dwelling to the town centre. Consitent with the main results of Des Rosiers et al. (2001) and several other contributions, we hypothesize that housing prices will be lower the further away a dwelling is from the nearest primary school.[5] Moreover, in accordance with the results of Theisen and Emblem (2018) we hypothesize that a long distance between a dwelling and the nearest kindergarten affects housing prices negatively. Finally, also in accordance with the reference just cited we hypothesize that a long distance between the kindergarten nearest to a dwelling and the grocery store located the shortest distance from the kindergarten has a negative impact on housing prices in the area "covered" by that kindergarten. The rationale behind this hypothesis is that long distances between such amenities makes it more difficult to combine visits to the grocery store with escorting children to kindergarten. Taken together, the set of distance or travelling time variables included in our analysis provides a many-faceted characterization of the local environments in which dwellings are located. Such variables presumably contribute to a better fit of our estimated models and to more precise estimates of the parameter capturing the impact of the toll ring on housing prices. In principle, it might have been possible to include additional distance variables, but in our study town, many of the potential distance variables not included would be heavily correlated with those included.

Distances or travel times from each house to important amenities measure the location of houses in an important and economically meaningful way. In our random effects model, we assume, however, that the random intercepts are affiliated with variables describing the neighbourhood in which dwellings are located. Specifically, we use postal codes for this purpose. The study town consists of 31 official postal codes containing dwellings, of which 8 are fully contained within the toll ring, 21 are outside the ring, and 2 are partly inside, partly outside the toll ring. Some postal codes within the toll ring contain dwellings located at the seaside or along the lower banks of a large river. We expect such dwellings to be sold at high prices, mainly because of their waterfront location, not so much because they are within the toll ring. We account for this by constructing an "artificial" postal code of dwellings with a waterfront location within the toll ring. Conversely, the dwellings included in this artificial postal code have been excluded from the postal codes to which they officially belong. Finally, we have merged four postal codes on the Western side of the study town (where dwellings are homogeneous in age and price per sqm. floorspace) to a new large postal code. Similarly, we merged two (homogeneous) official postal codes on the Eastern side of the town to a new postal code. After these

[5] Des Rosiers et al. (2005) find that housing prices are highest at some distance from schools, with lower prices near schools and far away from schools.

modifications the number of postal codes is reduced from 31 to 28.

6. Empirical results

Empirical results are shown in Table 3, which contains two versions of the random effects model and the reference model. The reference model is estimated on the assumption that there are no random intercepts and is included in Table 3 since we in the sequel will test the performance of the random effects' models against the reference model. The reference model explains more than 79 per cent of the variation in the dependent variable, and the vif-statistics indicate that collinearity between independent variables is not a problem. The large magnitude of the toll-ring coefficient, which, with the level of tolls in 2017, implies that house prices inside the toll ring can be estimated to be 27.6 per cent higher than outside the toll ring indicates that this model is not well specified. Hence, let us turn to the random effects model.

Random-1 in Table 3 contains the same regressors as the reference model, but it is estimated on the assumption that the error term contains random intercepts at the postal code-level. The interclass correlation coefficient in Table 3 indicates that Random-1 explains 35 per cent of the residual variance in the reference model. Hence, there is strong evidence that residuals within each postal code are correlated. In Random-1, this correlation is accounted for, whereas it is not accounted for in the reference model. A likelihood ratio test also strongly indicates that Random-1 is superior to a corresponding model with no random intercepts; see the Chi sq. test statistic for Random-1. The BIC and AIC statistics also point strongly in the same direction. Hence, based on these general indicators, we conclude that Random-1 clearly outperforms the reference model.

With one exception, all the estimated coefficients in Random-1 carry the expected sign. The magnitudes of the estimated coefficients are also consistent with what other researchers have found when estimating similar hedonic house-price equations. Several of the estimated coefficients in Random-1 are, however, not statistically significantly different from zero. In accordance with our expectations, the toll coefficient in Random-1 is positive and different from zero at standard levels of statistical significance. The coefficient capturing the impact on housing prices of time used to drive to the CBD carries the expected negative sign, and it is on the borderline of being statistically significant. We return shortly to a more extensive discussion of the toll and time coefficients. To conclude the more general discussion of the results for Random-1, we mention that the impact parameter of distance to schools carries a positive sign, although not statistically significant, while we, based on the work of Des Rosier et al. (2001), expected it to be negative. However, since the impact of distance to school is not of primary interest in the present context, we abstain from further discussion of this point.

Fig. 4 shows predicted random intercepts for Random-1, based on

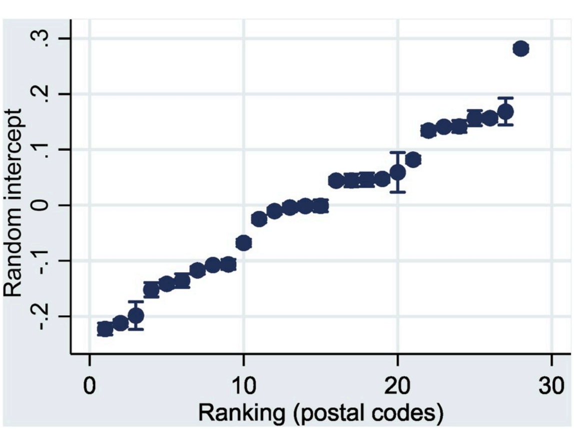

Fig. 4. Estimated random intercepts and ranking by postal codes.

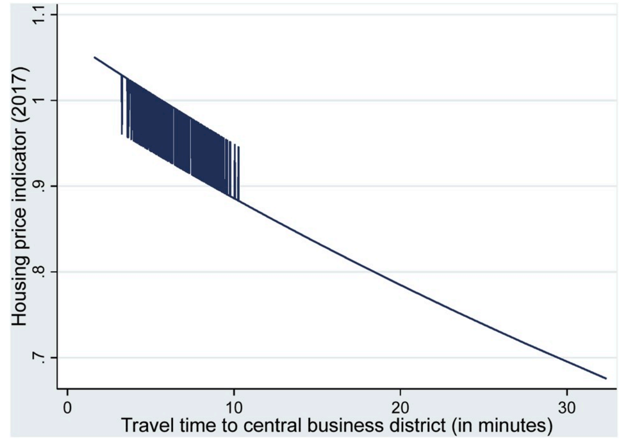

Fig. 5. Housing prices and travel time to the central business district.

postal codes. Almost all random intercepts are statistically significantly different from zero and are contained in narrow 95 per cent prediction intervals, which are barely visible in Fig. 4. Notice also the large variation in the random intercepts, from −0.22 to +0.28. The largest negative random intercept is affiliated with a postal code where there are substantial social problems; it is located on the western side of the town, approximately 4 km outside the toll ring. The largest positive random intercept, in contrast, is affiliated with the artificial postal code constructed of waterfront properties within the toll ring.

The toll variable in Random-1 has, in accordance with the prediction of the theoretical model, a statistically significantly positive impact on housing prices within the toll ring. With the fee collected per passing of a toll station in 2017, the estimated toll coefficient in Random-1 implies a price premium of 6.9 per cent (100*0.0040802*16.80) for housing units within the toll ring compared to those outside. Based on this premium, we find that a modest dwelling that is sold for 2 million NOK if located just outside the toll ring could be sold for 138,000 NOK more if located just inside the toll ring. To assess whether this calculation is reasonable, let us compare with discounted future toll-costs. With 220 workdays per year, toll costs for one passing per working day throughout the year amounts to 3,696 NOK. Assuming that the toll ring will exist into infinity and assuming a 5 per cent discount rate yields a discounted toll cost of 3,696/0.05 = 73,920 NOK. Hence, with slightly less than two crossings of the toll ring per working day, discounted toll costs would equal our estimated impact of the toll on housing prices. Since some households cross the toll ring more than once per day, and since many also must travel through the ring on weekends, our estimated price premium of 6.9 per cent seems reasonable. The discount rate we have used in this comparison may, however, be too high; cf. for instance that Simon, Warner, and Pleeter (2015) found personal discount rates of 2–4.3 per cent for officers in the US army, and 7 per cent for enlisted personnel. With a discount rate of slightly less than 2.7 per cent, discounted toll costs for one passing per workday corresponds in our case exactly to the estimate obtained from Random-1. Since we do not have precise information on how individuals discount, however, the calculations presented above should be treated with care.

In Fig. 5, we have used the estimation results for Random-1 to display housing prices as a function of tolls and the time used for travelling to the centre of the town. This figure is the empirical counterpart to Fig. 3 (b). Fig. 5 shows that the upwards shift of the housing price curve extends over an interval of approximately 7 min travel time. The explanation is that some toll stations in our study town are located relatively far from the centre of the town, while the nearest toll station is very close to the town centre; cf. Fig. 1. Notice also that since the parameter β_0 in the housing price function is not identified, there is an arbitrariness concerning where on the vertical axis the housing price function in Fig. 5 starts.

Using the period-specific toll fees calculated in Section 5, and shown in column two of Table 4, the impact of the toll ring on housing prices in Periods 1, 2, and 3 may be calculated. The results from so doing, using the estimated toll coefficient from Random-1, are shown in column four (Impact) of Table 4. These period-specific price premiums for dwellings inside the toll ring are, however, calculated using the same estimated coefficient. Hence, it follows that the calculated percentages are proportional to the fee-levels in the different periods. To obtain a decisive test of whether toll fees impact housing prices similarly in different subperiods, we have estimated Random-2. This estimation differs from Random-1 only because it contains one toll fee variable for Periods 1 and 2 taken together and another one for Period 3.[6] When judged by the AIC, BIC, and the interclass correlation coefficient, Random-2 does not outperform Random-1, and a Chi-sq. test against the reference regression supports this. Unfortunately, the two toll coefficients in Random-2 are also not precisely estimated. However, if despite the lack of statistical significance we use the estimated toll coefficients in Random-2 to calculate price premiums for housing units within the toll ring, the results shown in column six of Table 4 are obtained.

Two important observations can be made from Table 4. First, the estimated coefficients for Random-2 shown in column five of Table 4 are similar, but not identical, across periods. Second, the coefficients for Random-2 in column five are greater than are those in column three but well within a 95 per cent confidence interval of the toll coefficient in Random-1. Consequently, we have no indications that the relationship between toll fees and housing prices differ much between periods. Thus, one may also argue that there are no indications that changes in tolls do not change housing prices. These results are also in accordance with claiming that changes in housing prices appear soon after toll fees have changed. We must make clear, however, that we do not have strong evidence that changes in tolls immediately are followed by changes in housing prices. Stronger evidence would require statistically significant toll coefficients for all periods.

Let us now turn to our third research question, i.e., whether prices of different types of dwellings are affected differently by the toll ring. Table 5 shows the results from estimating equations similar to Random-1 separately for apartments, detached dwellings, and small houses (row houses and twin houses taken together).[7] For apartments, the estimated toll coefficient in Table 5 is highly significant, somewhat larger than in Random-1, but very close to that obtained in Random-2. The toll coefficient implies that prices of apartments just within the toll ring in 2017 are estimated to be 8.1 per cent (100*0.0048*16.80) higher than just outside the ring. For detached houses, the estimated toll coefficient is not statistically significant, but the magnitude in Table 5 is very near the magnitude in Random-1. The estimated toll coefficient in the separate regression for small houses in Table 5 is highly statistically significant, and the point estimate of 0.0114 implies a price premium of 19.2 per cent for small houses within the toll ring in 2017. This large price premium and the result that the price premium for apartments is also slightly higher than in Random-1, while there is no statistically significant sign of a price premium for detached dwellings, requires an explanation.

The large differences in price premiums for different types of dwellings are in our view likely to be related to ongoing transformation and densification processes that can be observed in the inner parts of our study town and in the inner parts of many other growing towns. Inside the toll ring of our study town, the few new detached houses that have been built in recent decades have been set up on small lots made available through the division of existing lots occupied by detached houses. New row houses or twin houses have over the last couple of decades only rarely been set up. Apartments in block houses are, however, continually built both inside the toll ring and in many areas outside the ring. Hence, there may be good reasons to believe that the price premium of 8.1 per cent for apartments inside the toll ring, compared to similar housing units outside, represents an equilibrium price premium, at least approximately.

Consider next detached houses. Next to quite a few detached houses inside the toll ring there has in the course of time been set up new detached houses or multi-apartment buildings of various kinds. The municipality of our study town also has a clearly stated policy to fill in with new buildings in areas where there until recently has been more open space around houses.[8] Consequently, some owners of detached houses have experienced that their neighbours have obtained permission to split a large lot into smaller lots for new houses. Over time, it has therefore become increasingly difficult to find nice detached houses with spacious gardens in the inner parts of the town. Moreover, the prices for which the remaining large lots can be sold may not be very high if they have become surrounded on all sides by houses with minimal gardens. Moreover, many detached houses in the most central parts of the town (the "grid-town"; see Fig. 1) have only a small yard outside the house. Hence, for several reasons, potential purchasers of detached dwellings may be reluctant to offer high prices for such houses within the toll ring compared to outside the ring.

Row houses are much less affected by densification processes than are detached houses. First, at the point in time when they were constructed, row houses already represented a quite dense form of housing. Second, since row houses inside the toll ring usually are older than are those outside, they occasionally have more spacious lots than do those outside the ring. In other words, a row house inside the toll ring may often have qualities that are not easily found in similar housing units outside the toll ring. At the same time, the supply of row houses inside the toll ring is almost completely fixed. While new row houses are continually set up outside the toll ring, such construction projects have in the last decades been very rare within the toll ring. Moreover, existing row houses are not torn down and the land used for other purposes, because this action would require unanimous consent of all section owners of the building. In addition, the municipality would hardly allow such transformation projects. Consequently, there may be several reasons why we have found a large price premium for row houses inside the toll ring. Many of the same arguments also apply to twin houses but, like detached houses, twin houses inside the toll ring may be under more pressure of densification. Finally, notice that our arguments for the rationale of large price premium differences between different housing types are not primarily based on the existence of the toll ring but rather on the transformation of central areas in cities to a denser pattern of buildings. The toll ring is, however, likely to reinforce these processes.

7. Robustness checks

We check the robustness of the results in Section 6 by examining the impact of various modifications of the preferred regression, Random-1. The results of this examination are summarized in Table 6, where the line for Item 1 reports the toll coefficient from Random-1. Item 2 in Table 6 shows the results if the variable measuring time used for travel to the CBD is excluded from the set of independent variables. The lower Log-Likelihood compared to Random-1 clearly implies that it is not a good idea to leave out this variable. Notice, however, that leaving out

[6] Since Period 1 contains only 312 observations within the toll ring we have merged Periods 1 and 2.

[7] We also estimated an equation including all types of dwellings, with interaction terms between the toll variable and dummies for detached and small houses, in addition to the regressors used in Random-1. Since this estimation did not yield statistically significant results for the interaction terms, it does not add to Random-1 or the results in Table 5. Hence, we do not report these results.

[8] Norwegian municipalities have much more discretion in deviating from zoning regulations than is true in, for instance, the USA and the UK.

travel time to CBD increases the toll coefficient only marginally. This coefficient increases because the toll variable in the regression behind Item 2 in Table 6 picks up some of the effect of distance to CBD. Hence, we conclude that it is important to keep distance to CBD in the model. If this distance variable is not included, the toll coefficient will be overestimated.

Items 3 and 4 in Table 6 show results if distances to two major shopping centres, the East-Mall and the Centre-West, are included in the set of independent variables. The East-Mall is a large centre located on the eastern border of the study town, but most households in the municipality now and then go there for some of their shopping. The Centre-West is much smaller than the East-Mall, and it is almost only frequented by households in the western parts of the study town. From Item 3, we notice that including distance to the East-Mall changes the estimated toll-coefficient only marginally but improves somewhat the precision with which it is estimated. Moreover, a Chi-sq. test of the model including distance to the East-Mall shows that this model performs better than Random-1; cf. the LR chi2(1) in Table 6. Item 4 in Table 6 shows results if distance to the Centre-West is included in the set of independent variables. The estimated toll-coefficient then changes only marginally, but the precision with which it is estimated is somewhat higher than for Random-1. Moreover, a Chi-sq. test of the model including distance to the Centre-West shows that this model performs better than does Random-1. We conclude that our results for the impact of the toll fees on housing prices are robust towards including/excluding variables measuring the distances to the two major shopping centres in the study town.

In Section 6 we found large differences in the price premium of a location within the toll ring for different types of dwellings. Based on this result it might be interesting to examine the possibility that impact coefficients of different dwelling types may differ between postal codes. To test this possibility, we have estimated regressions allowing for random slope coefficients, in addition to the random intercepts in Random-1. We carried out the examination by re-estimating Random-1 allowing for a random slope of the coefficient affiliated with one variable at a time, while keeping the random intercepts in the model. The results are summarized as Items 5, 6 and 7 in Table 6. Using the LR chi2 (1) for testing, we conclude that allowing for random slope coefficients for detached dwellings and row houses improves the model relative to Random-1. However, this conclusion is not true for twin houses. In our context, it is much more important, however, to observe that allowing for random slope coefficients for row houses and twin houses impacts the estimated toll coefficient very little compared to Random-1. For detached houses, allowing for random slope coefficients impacts the toll coefficient somewhat more, but the impact is not very strong. Moreover, notice that allowing for random slope-coefficients for dwelling types reduces the precision with which the toll coefficient is estimated. Item 8 in Table 6 shows the results of allowing for a random slope-coefficient for the ownership variable, co-op. Again, we see that this change improves the model compared to Random-1, while the toll coefficient is only moderately affected. We conclude that the estimated impact parameter of the toll-fee variable is quite robust towards allowing for random slope-parameters for housing types and ownership category.

As a final robustness check, we provide estimation results in Table 7 for the two key parameters in the housing price function if the mutual debt parameter is set to a magnitude different from that in Random-1. If this parameter is set to $\widehat{\zeta} = 1.0$ instead of $\widehat{\zeta} = 0.77$, which has been used when estimating all previous equations, Table 7 shows that the magnitude of the estimated toll-parameter is almost unchanged. Similarly, from the right column in Table 7 we also notice that basing the estimation on the magnitude $\widehat{\zeta} = 0.5$ does not lead to a significant change in the estimated toll-parameter. Hence, the estimated magnitude of the toll parameter is very robust towards even extremely large variations in the mutual debt parameter. Similarly, the impact parameter for travel time to the CBD is also little affected by the magnitude of $\widehat{\zeta}$.

8. Concluding remarks

Although toll rings around Norwegian towns and cities have existed for approximately 30 years, to date little has been known about how tolls influence housing prices. The main goal of our research has been to examine this influence. We found clear evidence that the Kristiansand toll ring impacts housing prices. On average, the results indicate that the toll ring causes an increase in housing prices within the ring by 6.9 per cent compared to outside the ring. For an average dwelling inside the toll ring this increase amounts, with the level of toll fees in 2017, to 192,100 NOK. With 12,600 dwellings within the Kristiansand toll ring at the end of this year, the aggregate housing-wealth effect of this toll ring can be estimated at 2,420 million NOK. Hence, we conclude that the establishment of a toll ring around the central parts of a town leads to a substantial redistribution of housing wealth. This issue has to date largely been neglected not only in economic research but also in the political sphere.

In our third research question, we wanted to examine whether the toll ring impacts prices of different types of dwellings differently. We found a price premium for apartments within the toll ring of 8.1 per cent in 2017. For small houses, the price premium in the same year was estimated to be as high as 19.2 per cent. In contrast, we found no statistically significant price premium for detached dwellings within the toll ring. We therefore conclude that the inner parts of the town over time seem to lose much of the qualities appreciated by those who prefer to live in detached houses. We ascribed these differences mainly to how the different types of dwellings are affected by densification and transformation processes in the inner parts of the town, but the toll ring tends to reinforce these processes.

The Kristiansand toll ring was, like most other Norwegian toll roads, long purely a device for collecting money to finance the construction of better roads. In recent years, the focus has shifted more towards an emphasis on limiting the inflow of cars into the town. In the future, we expect that the emphasis on reducing traffic may become even stronger for environmental reasons inter alia. Our results may be useful in evaluating the consequences of such policies. Specifically, whatever the reasons for establishing a toll ring may be, the consequence will be higher housing prices within the ring. This increase in housing prices will not only give an impetus to densification but also squeeze detached houses out of city cores. Higher housing prices will also cause poor households living in the cores of towns to become even poorer and over time to migrate to cheaper dwellings outside the toll ring. The area inside the toll rings will then increasingly be populated by wealthy people and less and less be a place for families with children. Hence, the result is a sorting of the population according to wealth and demography.

In our view, an important strength of the case we have studied is that the road infrastructure and system of transportation in the study town has been largely unchanged over the observation period considered. The moderate improvements in public transportation and biking paths that have occurred imply, however, that the impact of the toll ring on housing prices may be slightly underestimated. An important weakness is that we were not able to be conclusive on our second research question, i.e., how quickly tolls are discounted into housing prices, and on whether the relationship between toll fees and housing prices is stable over time. With a larger data set, including also the time before a toll ring is established, or the time after it is removed, one would be better equipped to address these issues.

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Appendix A

Table A.1
Variable definitions.

Price	Transaction price of dwelling, in Norwegian currency (NOK).
Mutual debt	Mutual debt at the time of the transaction, measured in NOK
Floor-space	Size of the dwelling measured in m^2, storage rooms not included.
Age	Age of dwelling, measured in years.
Lot	Lot size measured in m^2.
Detached	Dummy variable equal to 1 if a detached house and 0 otherwise.
Twin house	Dummy variable equal to 1 if a twin house and 0 otherwise.
Row house	Dummy variable equal to 1 if a row house and 0 otherwise.
Apartment	Dummy variable equal to 1 if an apartment and 0 otherwise.
Co-op	Dummy variable equal to 1 if a cooperative dwelling and 0 otherwise.
Within	Dummy variable equal to 1 if a dwelling is within the toll ring, 0 otherwise.
Toll	Toll fee for entering the town one time multiplied by Within.
Toll 1 + 2	Toll fee for entering the town one time in period 1 or 2 multiplied by Within.
Toll 3	Toll fee for entering the town once in period 3 multiplied by Within.
Time-CBD	Time used for travel from dwelling to CBD, measured in minutes.
DKind	Distance from dwelling to nearest kindergarten, in kilometres.
DSchool	Distance from dwelling to nearest primary school, in kilometres.
DShop	Distance from nearest kindergarten to nearest grocery store, in kilometres.
Year-20yy	Dummy variables equal to 1 for if the transaction took place in year 20yy (yy = 10, …, 17), 0 otherwise.
Month-mm	Dummy variables equal to 1 if the transaction took place in month mm (mm = 1, …, 12), 0 otherwise.

Table 1
Toll fees in NOK.

	Per passing		Prepayment[1]	
Type of vehicle:	Small	Large	Small	Large
Period 1: December 1997–June 2010	10	20	1,500	3,000
Period 2: July 2010–September 2013	21	42	3,775 (50) 2,202 (40) 367.50(30)	7,350 (50) 4,410 (40) 735 (30)
Period 3: September 2013–April 2018	21	42	2,100 (20)	4,200 (20)
Monday-Friday 06.30–09.00 and 14.30–17.00	14	28		
Saturday, Sunday, non-rush hours on workdays				

1. Percentage reduction by prepayment in parentheses. Prepayment of 1,500 NOK in the first period implies that the car can pass toll stations an unlimited number of times in one year. In the period July 2010–September 2013, prepayment of 3,775 NOK implied that the toll per passing with a small car was reduced by the percentage indicated, i.e. to 10.50 NOK instead of 21 NOK. The rebate works similarly after September 2013.

Table 2
Descriptive statistics and hypothesized impact of variables. N = 15,306.

Variable	Impact	Mean	Standarddeviation	Minimum	Maximum
Price		2,606,057	1,357,051	50,000	20,000,000
Mutual debt[1]		298,803	383,897	1	2,835,000
Floorspace[2]	+	103.170	52.491	14	435
Age	–	39.595	28.236	0	319
Lot-size[3]	+	756.261	2,521.551	4	90,124
Detached	+	.2264	.4185	0	1
Twin house	–	.0964	.2951	0	1
Row house	–	.1215	.3267	0	1
Apartment	0	.5557	.4969	0	1
Co-op	–	.3227	.4675	0	1
Within	+	.3180	.4658	0	1
Toll	+	13.5061	3.4989	6.80	16.80
DKind	–	.7775	.7199	0	14.388
DSchool	–	1.3095	.8695	0	12.87
DShop	–	.7118	.5244	.0490	4.054
Time-CBS	–	10.0911	4.5508	.0833	32.3667
Years[4]	+			.1209	.1365
Months[4]	+/–			.0433	.1126

1. The mean, standard deviation and maximum of mutual debt refer to cooperative dwellings only.
2. For a small share of the dwellings with item non-response for floorspace, we estimated floorspace from the variable "gross" floorspace; see Theisen and Emblem (2018) for further details.
3. The mean, standard deviation and maximum and minimum lot-size refer to non-cooperative detached houses, row houses and twin houses.
4. Minimum and maximum numbers refer to year/month with the fewest and largest number of observations.

Table 3
Main results. N = 15,306.[1]

	Reference	Random-1	Random-2
Ln(Floorspace)	.7256***	.6984***	.6984***
	(.0000)	(.0000)	.0000)
Ln(Age)	-.0997***	-.0872***	-.0872***
	(.0000)	(.0000)	(.0000)
Ln(Lot)	.0049***	.0039**	.0039*
	(.0002)	(.0100)	(.0104)
Detached	.0214**	.0539	.0538
	(.0073)	(.0900)	(.0904)
Twin house	-.0671***	-.0392	-.0393
	(.0064)	(.0559)	(.0557)
Row house	-.0909***	-.0632***	-.0632***
	(.0054)	(.0083)	(.0008)
Co-op	-.0805***	-.0581***	-.0581***
	(.0000)	(.0000)	(.0000)
Toll	.0182***	.0041*	
	(.0003)	(.0318)	
Toll 1 + 2			.0061
			(.3371)
Toll 3			.0051
			(.1971)
Time-CBD	-.0116***	-.0121	-.0120
	(.0000)	(.0607)	(.0637)
DKind	-.0509***	-.0433**	-.0434***
	(.0000)	(.0012)	(.0012)
DSchool	.0226***	.0077	.0076
	(.0000)	(.5366)	(.5391)
DKind-shop	-.0297***	-.0156	-.0156
	(.0000)	(.3780)	(.3779)
Constant	11.82***	11.93***	11.92***
	(.0000)	(.0000)	(.0000)
Random intercepts	No	Yes	Yes
Year dummies	Yes	Yes	Yes
Month dummies	Yes	Yes	Yes
R-Sq.	.7806		
R-Sq. adjust	.7802		
AIC	−6,248.782	−9,219.47	−9,218.69
BIC	−6,012.66	−8,987.48	−8,959.06
LR chi2(1)		2,974.68***	2,975.90***
		(.0000)	(.0000)
Vif average	1.85		
Vif max	3.06		
Interclass correlation		.3496	.3297

1. Dependent variable: Ln(Price+0.77*MUT). Estimation method: OLS for the reference model, maximum likelihood for the random effects models. Robust p-values in parentheses. Stars indicate statistical significance, with p-values: *p < 0.05, **p < 0.01, ***p < 0.001.

Table 4
Impact of the toll ring on housing prices in different subperiods.

	Fee	Random-1		Random-2	
		Coefficient est.	Impact (%)	Coefficient est.	Impact (%)
Period 1	6.80	0.0040802	2.8	.0060755	4.1
Period 2	10.50	0.0040802	4.3	.0060755	6.4
Period 3	16.80	0.0040802	6.9	.005079	8.5

Table 5
Results for different types of dwellings.[1]

	Apartments	Detached	Small houses
Ln(Floorspace)	.7222***	.6579***	.6039***
	(.0000)	(.0000)	(.0000)
Ln(Age)	-.0823***	-.0924***	-.0938***
	(.0000)	(.0000)	(.0000)
Ln(Lot)		.0063***	.0060***
		(.0010)	(.0100)
Co-op	-.0550***		-.1037***
	(.0005)		(.0017)
Toll	.0048**	.0048	.0114***
	(.0051)	(.2891)	(.0047)
Time-CBS	-.0180*	-.0015	-.0045

(*continued on next page*)

Table 5 (*continued*)

	Apartments	Detached	Small houses
	(.0025)	(.8391)	(.4964)
DKind	-.0364*	-.0334	-.0671***
	(.0336)	(.0343)	(.0010)
DSchool	.0125	-.0105	.0069
	(.3428)	(.5779)	(.6740)
DKind-Shop	-.0450	.0082	-.0061
	(.0961)	(.6917)	(.7699)
Constant	11.89***	12.06***	12.24***
	(.0000)	(.0000)	(.0000)
Interclass correlation	.3367	.4141	.3732
Number of observations	8,506	3,466	3,334

1. Dependent variable: Ln(Price+0.77*MUT). Estimation method: maximum likelihood. Robust p-values in parentheses. Stars indicate statistical significance, with p-values: *p < 0.05, **p < 0.01, ***p < 0.001.

Table 6
Robustness checks – exclusion/inclusion of variables, random slopes. N = 15,307.[1]

Item		Toll coefficient	Log-likl.	LR chi2(1)
1	Random-1	.0041(.0318)*	4,643.7919	
Include/exclude independent variables:				
2	Exclude Time to CBD	.0045(.0083)**	4,572.1716	
3	Include DEast-Mall	.0042(.0207)*	4,656.633	27.80(.0000)***
4	Include DCentre-West	.0042(.0215)*	4,661.0917	36.72(.0000)***
Allow for random slope coefficients:				
5	Detached	.0037(.0419)*	4,829.6575	373.85(.0000)***
6	Twin-house	.0041(.0336)*	4,645.4490	5.43(.0622)
7	Row-house	.0040(.0385)*	4,666.0432	46.62(.0000)***
8	Co-op	.0044(.0097)**	4,790.3127	295.16(.0000)***

1. Dependent variable: Ln(Price+0.77*MUT). Estimation method: maximum likelihood. Robust p-values in parentheses. Stars indicate statistical significance, with p-values: *p < 0.05, **p < 0.01, ***p < 0.001.

Table 7
Robustness checks – Impact of mutual debt parameter. N = 15,306.[1]

	Magnitude of the mutual debt parameter		
	$\hat{\zeta} = 1.0$	$\hat{\zeta} = 0.77$	$\hat{\zeta} = 0.5$
Toll	.0040(.0307)*	.0041(.0318)*	.0042(.0392)*
Time to CBD	-.0113(.0793)	-.0121(.0607)	-.0132(.0428)

1. Dependent variable: Ln(Price+$\hat{\zeta}$*MUT). Estimation method: maximum likelihood. Robust p-values in parentheses. Stars indicate statistical significance, with p-values: *p < 0.05, **p < 0.01, ***p < 0.001.

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