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An agent-based modelling approach to housing market regulations and Airbnb-induced tourism

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ABSTRACT

Airbnb has shown constant growth and it provides income and taxes to tourist destinations. However, the prevalence of a substantial number of Airbnb providers in tourist destinations may lead to bottlenecks in rental housing markets. Regional planners and policy-makers across the world are therefore imposing restrictions to regulate this hitherto unregulated business model. The present paper sheds light on the link between housing-market regulation and the growth of Airbnb, based upon Norwegian Airbnb listings and agent-based modelling. The simulation results suggest that Airbnb's current growth will not simply flatten out when the supply matches the demand, but will be followed by a series of sudden crises and subsequent quick recoveries. These instabilities will put stress on local rental markets and threaten both the local tourism industry and rental housing markets. Moderate taxation may contribute to a more even distribution of Airbnb listings in Norway, notably across the urban space.

1. Introduction

Online peer-to-peer accommodation services have grown impressively in the past few years, and the emergence of the web-based platform Airbnb is the main reason for this growth. Founded in 2007/2008 as an initiative by former graduate students to offer a low-cost alternative to conference hotels in the U.S. city of San Francisco, Airbnb has by now developed into the strongest rival for the global lodging industry (Guttentag, 2015; Oskam & Boswijk, 2016). The success story of the company's business model, which has inspired other business start-ups in the sharing economy (for example, the French *Nightswapping* or the Spanish *Badi*), can partially be traced back to a void in terms of a lack of regulation which facilitates a seemingly unlimited growth of the Airbnb-induced informal lodging sector (Dogru, Mody, & Suess, 2019; Guttentag, 2015).

In fact, Airbnb's business model has important consequences for the local housing markets and the local economy on several levels: first, the presence of Airbnb letters or leasers alters the provision of informal and short-term accommodation in a given municipality or city, but it also affects the long-term development of local housing markets, as the example of Los Angeles highlights (Lee, 2016). Second, and following from this, the rise of Airbnb with the growth of short-term housing providers using this platform represents a double-edged sword for cities and municipalities: on the one hand, tourists, as the main consumers of these services, bring additional income to the municipalities, through taxes and consumption expenditures, as well as to individual homeowners, through rental payments, which is a positive partial effect. In particular, the extra income generated by letting housing space to Airbnb customers alleviates high housing prices by increasing the income of residents and making them able to stay in their houses longer (Kaplan & Nadler, 2015). On the other hand, as a negative effect, the examples of Berlin and Barcelona show that the number of properties rented out on a peer-to-peer base via Airbnb can grow so considerably that the public authorities are forced to impose restrictions in order to stabilise rental housing markets in the municipalities and safeguard affordable rental opportunities for permanent residents. Notably, large tourist destinations are experiencing the phenomenon that Airbnb renting is also spreading from the city centre, *i.e.*, the core of the tourist destination, to neighbouring residential areas, thereby crowding out the demand of regular long-term rental homes (Gurran & Phibbs, 2017). Given these negative effects, the inherent instability that an unregulated Airbnb-based tourism market generates may threaten not only the traditional tourist providers in a municipality or city, but also the local real estate and rental markets.

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Motivated by a gap on the issues of the regulation of Airbnb and the housing market effects in the existing literature, this paper focuses on the impact of the regulation of Airbnb on local housing markets. Although case-based evidence stresses the need for regulation (Lee, 2016; Wegmann & Jiao, 2017), there is a lack of empirical literature addressing the various types of governmental and municipal restrictions and their respective impact on tourist destinations regarding Airbnb. In practice, the policy measures implemented to date to regulate Airbnb seem to represent more of a trial-and-error approach than a structured political strategy. This is because the business models associated with sharing economic activities do not all fit into the existing public regulation schemes and policies (Interian, 2016). Moreover, while peer-to-peer accommodation platforms continue to grow without interruption all over the world, virtually nothing is known about when or why this growth will flatten out. In particular, there is a lack of cases that give evidence about when Airbnb's growth is expected to flatten out in the long run. Thus, investigating different regulatory measures and their specific impact on Airbnb's growth over time can contribute to a more informed policy approach.

In the light of the above-stated lack of literature and consistency in policies, the present paper uses an agent-based computer-simulated approach to predict the future development of Airbnb as an online peer-to-peer platform. It addresses the following research question: *How can the growth dynamics of Airbnb be predicted with or without policy interventions (e.g., taxes raised by municipalities or temporal restrictions on renting)?* Based upon a historical data series on Airbnb listings in Norwegian municipalities, agent-based modelling (ABM) simulations are conducted, which include both time-based restrictions and taxation. Hence, the results are grounded in a close match between real-world data and model outputs which will be validated against real data. We focus on the supply of Airbnb units in the models in this paper and treat the demand as exogenous.

The simulation results suggest that, while moderate taxation may have a stabilising effect on the market of peer-to-peer accommodation, time-based restrictions have a potential to render crises in the local tourism and housing market even more disruptive. As opposed to an unregulated market scenario and time-based restrictions, taxation may potentially contribute to a more even distribution of Airbnb listings over time, notably across the urban space.

The paper contributes to the existing literature in the following ways: first, it amends the empirical literature on online peer-to-peer accommodation and its effects on local housing markets (Barron, Kung, & Proserpio, 2018; Guttentag, 2015; Oskam & Boswijk, 2016). It does so by offering a theoretically-grounded explanation of the policy interventions which are being discussed and implemented in the unregulated market segment of the tourism sector (Edelman & Geradin, 2015; Gurran & Phibbs, 2017) and a model for the short- and long-term rental market. The paper therefore responds to the fact that research on Airbnb's business model and its sustainability is not adequately developed to date (see, for example, Leung, Xue, & Wen, 2019). Second, it uses ABM as a technically- and conceptually-rich technique to simulate future developments for tourism. Hence, we take up the agenda evoked by Nicholls, Amelung, and Student (2017, p. 4) "*to introduce ABM to a wider tourism audience*". Altogether, the present paper extends the recent debates on cities which are discussing policy measures to regulate Airbnb, such as Los Angeles (CBS Los Angeles, 2018; Lee, 2016), or have recently introduced them, like Berlin (Ksienrzyk, 2018).

The paper is organised as follows. Section 2 introduces Airbnb's business model and its regulation, which will be followed by Section 3, which presents the theoretical model. Afterwards, the ABM simulation and its empirical results will be presented in Section 4. The subsequent section 5 first discusses these results and then gives a conclusion. Finally, Section 6 presents an outlook on future research, the limitations of the paper, as well as some implications for policy-makers and other stakeholders.

2. Regulation of Airbnb – background and experiences

2.1. Airbnb and its business model

According to Botsman and Rogers (2010, pp. 159–160), the sharing economy is broadly defined as "*traditional sharing, bartering, lending, trading, renting, gifting, and swapping, redefined through technology and peer communities*". The sharing economy involves providers and consumers of goods and services, as well as platforms. Platforms are defined as websites and apps that "*enable, facilitate and mediate exchanges and sharing between peers to create alternate and stable marketplaces*" (De Rivera, Gordo, Cassidy, & Apesteguia, 2017, p. 12).

Airbnb's business model consists of the provision of an online peer-to-peer marketplace which can be accessed by a website. It connects travellers and hosts with physical space(s) (for example, and most commonly, rooms, apartments, and houses) to let out. The hosts can set up the conditions and rules for letting their property (such as the duration of a rental contract) and take the decisions on rental contracts after the travellers have made their bookings. They can also determine the price that they want but can obtain recommendations and help from Airbnb hosts upon request. Experienced and distinguished hosts are showcased by Airbnb as "superhosts". Airbnb earns money based upon two different types of commission: a flat commission paid by the hosts for the usage of Airbnb's platform for their letting of their space, and a commission on every payment made by travellers booking with Airbnb. With this business model, which allows private households to offer accommodation to tourists, the company has grown into a serious competitor for the local lodging industry (Oskam & Boswijk, 2016). Importantly, most housing offered via Airbnb is space that has not been rented out before (see Guttentag, 2015).

2.2. Regulation of Airbnb

Writing about the challenges of regulating businesses in the sharing economy, Interian (2016, p. 131) states that "*the sharing concept erodes disinterested public regulation by either substituting it for private regulation or leaving a void of no regulatory oversight*". Indeed, the emergence of Airbnb was accompanied by an initial period of non-regulation, called a "*honeymoon*" by Codagnone and Martens (2016). However, individual cities such as Amsterdam started to impose regulation quite early on (Rachordas, 2015). The regulatory measures and initiatives imposed on Airbnb differ widely, ranging from taxation (*e.g.*, London), to licences or permission issued by the city or regional parliaments (*e.g.*, Barcelona and Berlin), to fines for non-registered Airbnb listings, to limitations on the rental days for listings (*e.g.*, Amsterdam), and even to classifying listings as illegal (Tun, 2018). To impose such measures, housing lettings are classified according to their primary use, for example, in main or principal *versus* accessory or secondary residences (Gurran, Searle, & Phibbs, 2018). A popular measure is that of establishing a limitation to the letting duration allowed, which, for example, the city administration of Los Angeles, U.S., has just approved (Daniels, 2018) and which European cities, such as Amsterdam, had introduced earlier (Tun, 2018). Generally, the regulatory initiatives taken to date are softer compared, for example, to those taken for the Uber car-sharing service, which faces bans in some cities or countries.

The economic logic behind the regulation of the sharing economy is that different groups of stakeholders in the markets and their interests should be shielded in order to maintain market efficiency, protect consumer and labour rights, and ensure fair competition in the marketplace (Gurran et al., 2018; Koopman, Mitchell, & Thierer, 2015; Lee, 2016). Edelman and Geradin (2015) plead for a general regulation of businesses such as Airbnb because a regulatory framework would safeguard consumer rights while simultaneously opening up the opportunities to reap the efficiencies of such business models. They put forward changes in the neighbourhood and the risk of "gentrification through Airbnb" (Wachsmuth & Weisler, 2018) as the short-term risks of an unregulated

market. In addition, potential long-term market inefficiency is associated with a shortage of local housing facilities and an increase in rents (Edelman & Geradin, 2015; Lee, 2016). Another argument speaking in favour of the regulation of Airbnb is the fact that the income generated by means of renting out housing space via Airbnb is typically not taxed, *i.e.*, municipalities forgo a potentially growing source of tax income (see Wachsmuth & Weisler, 2018).

Altogether, the need to regulate sharing-economy businesses such as Airbnb is now widely recognised, and, as cited above, cities or municipalities have begun to impose selective measures, which range from modest taxation to limitations on usage and authorisation requirements. To conclude, these measures are more a trial-and-error approach by public authorities than an informed policy concept. In the light of this, the question of which measures authorities should take and how they should be implemented becomes increasingly important.

3. A model of the short- and long-term rental market

Short-term letting, such as that facilitated through Airbnb, may be viewed in terms of being a market for the renting of housing units, albeit with an on average shorter duration in terms of the rental period. The market for these units may therefore be considered as a rental market, even though there may be certain differences between this and a conventional rental market with typically longer duration of the rental periods (see, for example, De Leeuw & Ekanem, 1971, for an analysis on the supply side of the rental housing market). Short-term renting also works as a substitute for traditional providers of lodging services, for example, hotels, pensions, *etc.*, in that it usually falls into the tourism market rather than that of renting for local residing households (Lee, 2016). However, since the short-term renting via Airbnb is connected with the development of rental markets, we focus on how Airbnb rentals affect the local short-term rental market rather than their effect on the hotel market.

In the rental market, as well as any other markets, we may model the mechanisms in the market by supply and demand. This holds both for the rental market for short- and long-term rent. Our main focus in this paper is on the supply side of the rental market, including its short- and long-term segments. In particular, we look at how the supply changes in one segment may influence the other segment. This may be the case if a landlord or landlady decides to change from letting out his or her apartment in the long-term rental market to letting it out in the short-term rental market. From the demand side, considering the occurrence of tourism, short-term renting is seen as an alternative to hotel stays, while the supply side of private short-term renting represents an alternative to letting out units for longer terms (see Lee, 2016).

The stock-flow model, in which the stock of rental housing is fixed in the short run, but may evolve over time in response to changes in the expected rate of return on investments in rental properties (Gabriel & Nothaft, 2001) may work as a starting-point for our analysis of the rental market. This suggests that changes in the expected returns may alter the stock of rental housing in the long run, thereby influencing both the total stock of rental housing and the share of rental housing allocated to short- and long-term renting. Excess demand or supply will cause adjustments to the market price for rental units, which, in turn, may influence the decisions of households regarding whether or not to rent out their vacant housing space. However, the stock of housing in the short-term rental market may change quite rapidly as landlords decide between letting out on a short- or long-term.

Since the expected rate of return will depend on the price, which again is determined by excess demand or supply, this will also affect vacancy rates and the duration of vacancies (Gabriel & Nothaft, 2001). Expected returns in the segment for short- and long-term rent may differ, so that possessing a vacant apartment in one segment may affect landlords and make them shift to another segment. In addition, the expected rate of return may, in itself, determine which segment a household with a rental unit will choose from period to period, and thereby affect the rental stock in the two segments even in the short run. Hence, operating with two segments instead of one may causes more volatility in the stock of rental units within each segment, so that the entrance of Airbnb into a market may lead to more volatility. Barron et al. (2018) model the choice of a landlord choosing to supply his housing unit in the short-term rental market as being determined by whether the rental rate of short-term housing (given exogenously) - less all the additional costs of renting in the short-term market - is larger than the rental rate of the long-term housing rental segment.

The modelling of the supply side of short-term housing market is defined as:

$$S = f(Q - R - c) \cdot H_a \tag{1}$$

whereas that of the long-term housing market is defined as:

$$L = H - f(Q - R - c) \cdot H_a \tag{2}$$

Here, S can be thought of as the number of units permanently allocated to short-term rental, Q is the rental rate, R the rental rate of long-term rented housing, c is a common component for both the short- and long-term rental market and H_a is the number of housing units owned by absentee landlords. Furthermore, H is the (fixed) stock of housing. Hence, the equilibrium supply of short-term rental units depends on the rental rate for short-term renting relative to that of long-term renting and common costs, while the equilibrium supply of long-term rental units is the remaining housing stock given that $S + L = H$. A landlord will thus choose to let out a vacant housing unit if $Q - c > R$. Barron et al. (2018) also include an idiosyncratic component across landlords which we exempt from here for the sake of simplicity. The short-term rental rate Q is considered exogenous in Barron et al. (2018) depending on factors such as the elasticity of the tourism demand. We also consider this to be exogenous so that the supply of short-term housing depends on this exogenous price as well as the price of long-term rented housing R, which is determined in equilibrium by the inverse demand function of long-term tenants, *i.e.*, $R = r(L)$ where $\frac{\partial r}{\partial L} < 0$.

Another important factor in the rental market is the choice of the duration of residence for each rented housing unit. Deng, Gabriel, and Nothaft (2003) find that the duration of residence depends on the type of tenant, dwelling and various market characteristics, and that it varies significantly across individual housing units and market segments. They estimate these effects using a hazard model and US data. In particular, they find that duration varies significantly across metropolitan areas after controlling for important housing stock, tenant, and macroeconomic factors. Hence, unobserved factors such as cultural and geographical factors may cause and be caused by the duration of short-term renting. The way duration affects the behaviour of tenants and proprietors may therefore vary across areas. Gabriel and Nothaft (2001) analyse to what extent the duration affects the changes in residential rents and find that landlords are more sensitive to tenant outflow than to duration. They also find a high positive correlation in the data between duration and the incidence of vacancies. Hence, short durations often correspond to low degree of vacancies. Even though duration may not be important for the price set by landlords, it may be affected by or affect the number of vacancies.

In the light of the findings above, we assume that the price of short-term renting is exogenous, and that the duration and number of vacancies may be interrelated. Hence, the amount of short-term housing S, determined in (1), depends on the exogenous rental rate Q as well as vacancies H_a. Since duration and vacancies are related, duration may also be important for whether landlords choose to let an apartment in the short- or long-term rental market. Hence, we include vacancies as a function of duration:

$$H_a = g(d)$$

where $\frac{\partial g}{\partial d} > 0$, into (1) and (2). This gives

$$S = f(Q - R - c) \cdot g(d) \tag{3}$$

and

$$L = H - f(Q - R - c) \cdot g(d) \tag{4}$$

By differentiating (3), w.r.t. the short-term rental rate Q and the duration d, we get

$$\frac{\partial S}{\partial Q} = g(d) \frac{\partial f}{\partial Q} \tag{5}$$

and

$$\frac{\partial S}{\partial d} = f(Q - R - c) \cdot \frac{\partial g}{\partial d} = \frac{\partial g}{\partial d} \cdot \frac{S}{g(d)} \tag{6}$$

Hence, we see that the extent to which the rental price and the duration of the rental periods affect the number of short-term rental units depends on different factors: First, the effect of changes in the short-term rental rate on short-term rental units depends on the relationship between vacancies and duration multiplied with the curvature of the distribution function f. Second, however, the effect of changes in duration on the number short-term rental units depends on the shape of the function describing the relationship between duration and vacancies g as well as the initial number of short-term rental units S relative to vacancies.

This implies that policy effects on the short-term rental market, such as a limitation on the maximum duration or a tax on the rental income affecting the net rental rate for the landlord, will have different effects if it is facilitated through the duration of the rental period rather than through the price. In particular, we should expect a more non-linear effect from changes in duration on the number of short-term rental units than from changes in the rental price, since the effect will depend on the initial number of short-term rental units. In order to investigate further how the market for short-term renting is affected by changes in the rental rates and duration (*e.g.*, due to policy interventions), we should look at a more detailed model for the agents in the market.

4. ABM - agent-based modelling

ABM is a computational methodology which enables the modelling of complex systems in which autonomous agents with certain properties interact according to certain rules of behaviour. ABM is an alternative to traditional equation-based models. While the latter is widely used in virtually all domains of socio-economic research, we find much fewer examples of ABM in the fields relevant to this paper. Whereas AMB has been previously applied in tourism research (Pizzitutti, Mena, & Walsh, 2014), in the context of real estate market (Huang, Parker, Filatova, & Sun, 2014) and for studying the impact of car sharing on the demand for parking (Zhang, Guhathakurta, Fang, & Zhang, 2015), the authors failed to identify any examples of this method when considering the impact of the sharing economy on the rental housing market.

4.1. Agent-based model description

In this article, applying ABM is justified because the deterministic-centralised mindset (Wilensky & Resnick, 1999) fails to predict the emergent patterns in the development of Airbnb. ABM, in contrast to equation-based modelling, is better suited to studying heterogenous populations of property owners. ABM describes the development of Airbnb as a discrete (*versus* continuous) process, *i.e.*, a more realistic description of decision-making in the real estate market, in which the property may either be rented out on short-term or long-term market disabling all continuous measurement of this parameter. Furthermore, ABM considers spatial effects that are difficult to model with equation-based approaches. In addition, ABM provides both individual- and aggregate-level details simultaneously, and it is easy to incorporate the randomness that is present in the real-estate and tourism markets (Wilensky & Rand, 2015).

The clear communication and documentation of the model is important for understanding the method and for facilitating a replication of the simulated results. There is no general agreement on how to communicate and describe an agent-based model in a concise and transparent manner (Groeneveld, Klabunde, O'Brien, & Grow, 2017). However, some protocols have been proposed in the literature in an attempt to make the documentation follow minimum standards.

In this paper, the model description follows (arguably) the most developed and used protocol called ODD (Overview, Design Concepts and Detail) referring also to its extension adopted for modelling human decision-making (ODD+D, where D stands for Decision). ODD was described in the original works of Grimm et al. (2006), updated in Grimm et al. (2010), and later used as a core of ODD-D protocol (Müller et al., 2013). Structured in accordance with the ODD protocol, this section starts with an overview that provides the purpose and description of the state variables and scales, process overview and scheduling, and then continues with design concepts (including individual decision-making) and model details (Grimm et al., 2006; Müller et al., 2013).

4.2. Overview

The purpose of the model is to understand how the Airbnb market develops both with and without policy interventions (for example, taxes raised by municipalities or temporal restrictions to renting). The model simulates a city with most of the dwellings concentrated around the city centre. Fig. 1 illustrates this by showing the spatial distribution of properties of different types after 100 simulation runs. Three types of properties are simulated: 1) properties permanently populated by their owners (green); 2) properties rented out on long-term basis (yellow); and 3) properties rented out short-term via Airbnb (Airbnb listings, red). All Airbnb hosts rent out the whole house or apartment. The computational model has been implemented using NetLogo 5.3.1. software package.

4.3. Design concepts

Changes in the rental market are expressed in dynamic variations of the proportions of properties rented out either in the long run, as ordinary short-time contracts, or through Airbnb. In addition, the geographical distribution of the three types of property used is also developing throughout the run time of the model. Both proportional and spatial changes emerge from the behaviour of individual agents (property owners).

On the individual level, decisions on renting properties on a short-*versus* long-term basis are taken periodically. Only individuals aware of Airbnb are allowed to evaluate this option. The owners compare income from long-term rental contracts with the average income from Airbnb contracts for the last 20 simulation steps. The income from Airbnb is calculated as the number of nights rented out multiplied by Airbnb's price. Each step in the simulation is equal to approximately two to three weeks of real time.

To account for imperfect rationality and exogenous factors preventing some owners from taking instantaneous, and perfectly calculated, decisions as soon as the profit calculations encourage the shift in property use, an element of randomness and probability was added to the model. The owners of the properties that are already rented out are more likely to shift to Airbnb than the owners of the properties in which the owners currently live. The owners of Airbnb listings opt with higher probability for long-term renting than for selling their property.

4.4. Details

It is assumed that the demand for Airbnb-based rentals stems solely

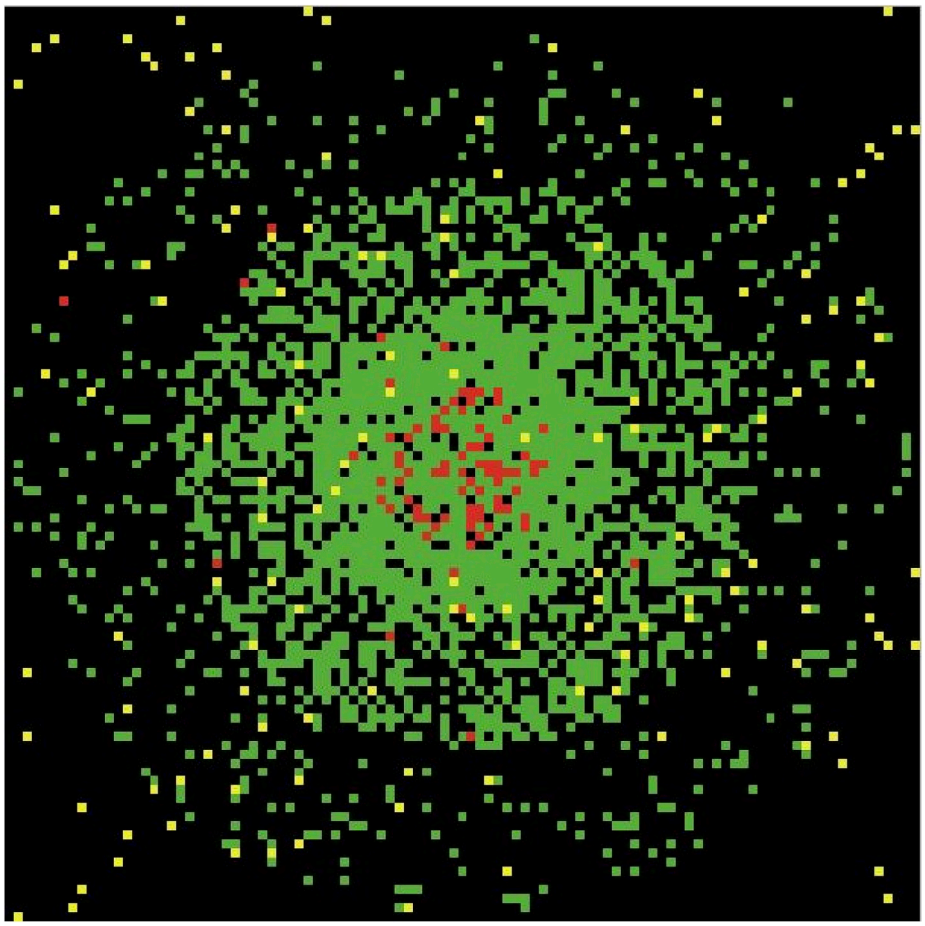

Fig. 1. Spatial distribution of properties of different types after 100 simulation runs: (Green = properties permanently populated by their owners; Yellow = properties rented out on long-term basis; and Red = properties rented out short-term via Airbnb). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

from tourists and is higher close to the city centre, which contains key touristic sites, than in the periphery where less sites for visitors can be found (Gurran & Phibbs, 2017). Rental prices are fixed at the same level for all locations. The user interface of the model allows the following initial parameters to be defined prior to a simulation run:

- city size (0–10,000 citizens);
- share of properties rented out on long-term basis (0–100%);
- total demand for Airbnb services (0–10,000 guest nights per simulation step);
- possibility to turn elements of randomness/probability on and off;
- owners' memory horizon (0–20 simulation steps during which the owners remember their income from various types of renting);
- Airbnb tax (0–100% taxation on individual income from Airbnb activities);
- maximum number of nights per month when a property is rented out via Airbnb (0–30 nights).

The simulation starts with 1.4% of the total 10,000 properties rented out on a long-term basis and no active Airbnb listings. Then, a few randomly distributed owners get to know about Airbnb. As time goes by, more people get information about Airbnb. Some of the owners (randomly) choose to try Airbnb. The demand for Airbnb services is constant and set initially to 1000 guest nights per simulation step.

4.5. Verification

Robustness is an important concern in ABM (Windrum, Fagiolo, & Moneta, 2007). To improve the degree to which the model under consideration functions in a similar fashion to the real-world system, a number of verification steps were followed. First, the code was reviewed to assure that underlying considerations about agents' behaviour were properly programmed. Moreover, an over-simplified test (Pizzitutti et al., 2014) was performed to ensure that single actors behave in an expected way.

The empirical validation of the model was principally consistent with the so-called History-Friendly Approach described by Malerba, Nelson, Orsenigo, and Winter (1999). The variety of studies on Airbnb described in the theoretical part of this paper, including existing reports, papers, statistical data and anecdotal evidence, are used to specify behaviour, decision rules and the interactions of the agents. During the second step, the initial conditions were identified. The model was also calibrated to behave in accordance with a realistic scenario. Finally, the model output was validated against the empirical data describing the actual development of Airbnb in Norway between 2011 and 2017. This dataset was obtained from Airdna in May 2018 and based upon systematic web scraping of Airbnb web-pages throughout the relevant period.

The empirical validation procedure revealed that the model produces a growth curve for the number of Airbnb listings that is close to the real-world growth, which can be best described as an initial exponential development followed by a period of linear growth (plotted in Fig. 2). The spatial distribution of Airbnb listings with the highest concentration in central areas of the town were also adequately reproduced.

In addition, a sensitivity analysis was conducted, which shows that the model output is not sensitive to the changes in population number or

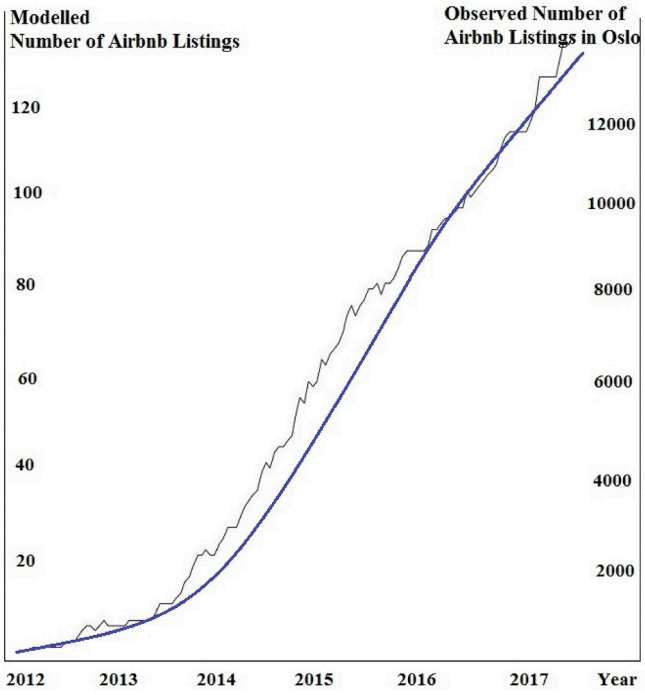

Fig. 2. Modelled number of Airbnb listings (grey line) against actual numbers observed in Oslo (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the initial share of properties available for renting. The total demand for Airbnb impacts upon the results in a significant way. An extremely low demand makes the system unstable, while an unrealistically high demand results in smooth continuous growth.

4.6. Analysis/simulations

The initial simulation run was performed with no taxation or another regulation imposed on the market. In these conditions, the number of Airbnb listings rose linearly until a certain point when most of the demand on the market was satisfied. The majority of the stable and profitable Airbnb listings are then concentrated around the city centre where the demand for Airbnb is highest. Some property owners experiment with Airbnb in the outer suburbs with a varying rate of success. Then, a sequence of sudden drops and rises in supply of Airbnb listings shocks the market. The supply varies cyclically with a drop of approximately 27% from the maximum level. The effect is most noticeable in the suburbs, but central areas are also impaired. The first crisis happens when approximately 70–75% of the citizens are aware of Airbnb, and the level of competition for potential guests reduces the number of guests per Airbnb listing to the level when the expected income from Airbnb is comparable to the income from long-time renting.

Fig. 3 illustrates this growth of Airbnb in an unregulated marked. It shows that the long-time rental market reacts in the opposite direction, but the magnitude of the changes is much smaller than the variations of the supply of Airbnb listings. On average, the number of properties available for long-term renting is slowly increasing throughout the whole simulation period. This increase is faster than would be expected without Airbnb present on the market. The reason for this is that some property owners who were not previously involved in the ordinary rental market chose to experiment with renting out through Airbnb. When the results are disappointing for them, it is, in many cases, easier to try to rent the property out on the long-term market than to move into this property again.

With regard to regulation, the first experiment includes restricting the maximum number of nights per month in a way that a property can

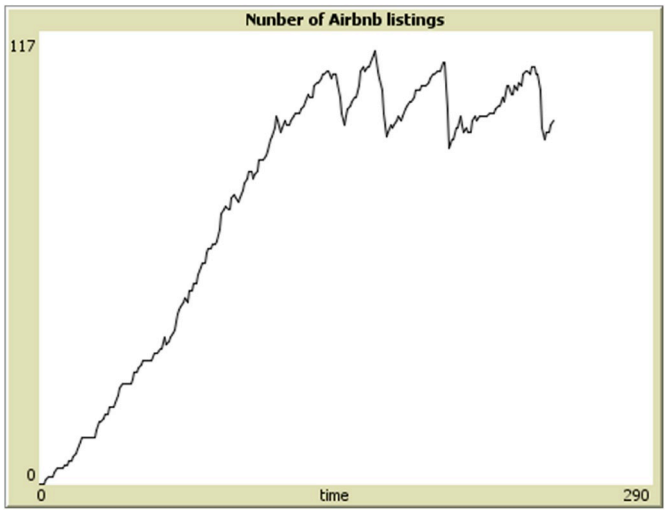

Fig. 3. Number of Airbnb listings with no restrictions imposed.

be rented out for up to 10 days. This type of regulation is imposed or under discussion in London (where a maximum of 90 days per year is allowed for entire houses), Japan (180 nights per year), Amsterdam (60 nights a year) and central Paris (120 nights per year).

Fig. 4 demonstrates that, after a period of normal linear growth, a crisis happens, as was observed in the baseline model. However, the model with a restriction on the maximum number of nights demonstrates much more volatile behaviour compared to an unregulated market. Different runs revealed that the first or second drop in the number of Airbnb listings tends to be as deep as 70–80% from the highest level. If the model is observed for a longer period, the unstable positive growth continues with some minor drop-downs until the next large crisis devastates the market. These effects are not observable in the initial phase when the unsatisfied demand for Airbnb was large, and, until a certain point, the growth pattern remains close to that observed in the unregulated market. Moreover, experiments with different limits in terms of maximum days allowed for renting out showed that the regulation to limit rentals over 20 allowed nights has relatively little effect on the volatility of the market, while restricting to less than 15 nights creates deep shocks.

The second experiment suggests imposing a 10% tax on Airbnb income. The resulting model is characterised by relatively smooth linear

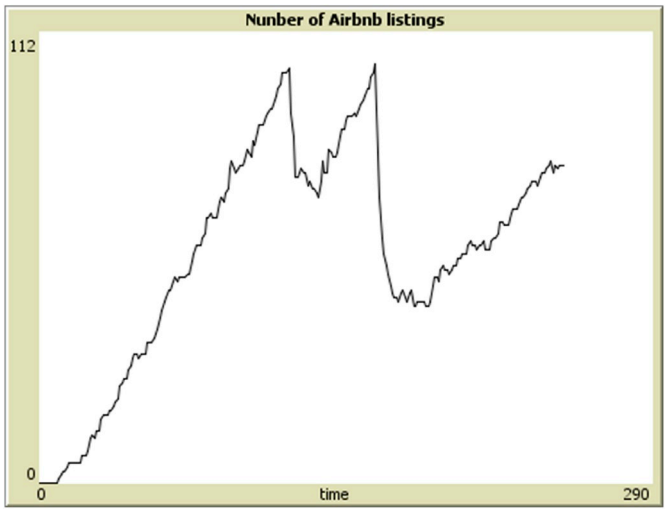

Fig. 4. Number of Airbnb listings when the maximum number of nights per month a property can be rented out via Airbnb is limited to 10.

growth flattening out when the demand for Airbnb is satisfied, as shown in Fig. 5. Exogenous factors cause only small fluctuations, and crises are totally avoided. In our model, large dropdowns start to disappear at approximately 8% tax level, and a further increase of the tax rate leads only to qualitative changes restricting the overall number of listings. In addition, taxation slows down the Airbnb growth compared to the first two models. As opposed to the first two models, taxation allows the concentration of Airbnb listings in the city's central areas to be deduced. At a certain level of taxation (about 15% in our case), the universal distribution of listings between central and peripheral areas is achieved.

5. Discussion and conclusions

5.1. Key findings and discussion

The present paper addresses the research question: *How can the growth dynamics of Airbnb be predicted with or without policy interventions (e.g., taxes raised by municipalities or temporal restrictions on renting)?* Using ABM to simulate an unregulated market *versus* different types of regulation, we find the following answers to the question:

Based upon the general understanding of how the actors behave, the model successfully replicates the growth curve and special patterns observed in real-world situations, as shown in Fig. 2. Since Airbnb is still in a rapid growth phase virtually all over the world, the model is used to test several future scenarios including different kinds of regulations by states, regions or municipalities. The baseline model with no regulations imposed predicts that the linear growth characterising real-world development of Airbnb services will not flatten out as soon as the number of Airbnb listings matches the demand. Instead, a succession of sudden ups and downs will repeatedly shock the short-term renting market. These fluctuations will also influence the long-term renting market, albeit with much lower amplitudes. With regard to previous theoretical approaches, the agent-based model adds an important insight into how the rental market develops over time. Traditional explanations based upon the rate of return (Barron et al., 2018; Gabriel & Nothaft, 2001) seem to be an adequate point of departure for analysing sharing economy solutions on the rental market. The supply side of a conventional rental market can be adequately described by, for example, De Leeuw and Ekanem (1971), and the stock-flow model (Gabriel & Nothaft, 2001), which allows the rapid change in the stock of housing to be captured. The agent-based model can predict periodic fluctuations caused by novel online rental services and will thereby extend conventional models. The introduction of Airbnb, which is characterised by an extremely short minimal period of renting (as compared to the traditional forms of renting), leads to qualitative changes on the rental market, supporting the hypothesis on the importance of a maximally allowed duration of residence (Deng et al., 2003).

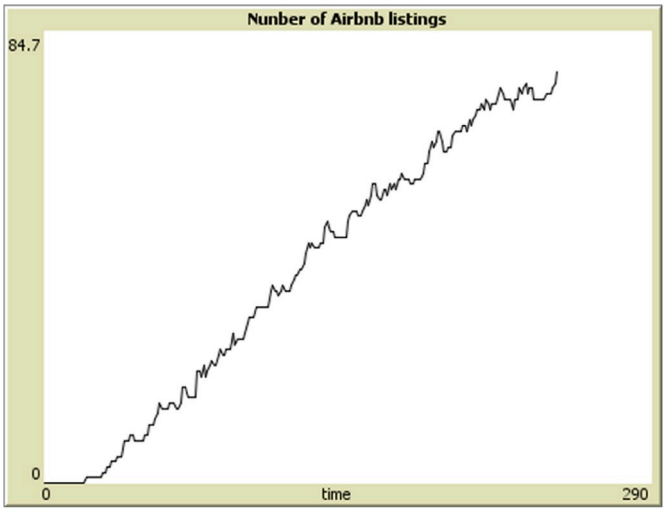

Fig. 5. Number of Airbnb listings with 10% taxation on Airbnb income.

Since several major cities around the globe have newly imposed, or are about to impose, measures to regulate Airbnb, for example, in terms of granting a maximum limit for the number of nights a property can be available through Airbnb, the effect of such regulation was modelled. The experiment reveals that such a limitation may potentially amplify the inherited instability of the Airbnb supply. In this scenario, as in the baseline model, the spatial distribution of Airbnb listings is characterised by high concentration around the city centre. This result is in line with studies suggesting that the accommodation of tourists facilitated by online platforms restricts the supply of regular long-term rental homes (Gurran & Phibbs, 2017) and leads to the "gentrification" (Wachsmuth & Weisler, 2018) of certain urban areas. The model also supports the theoretical arguments about the inefficiency of the free market mechanism concerning the relationships between a growing tourism sector and local public interests (Edelman & Geradin, 2015; Gurran et al., 2018; Koopman et al., 2015; Lee, 2016).

The second experiment shows that imposing taxes on Airbnb-related revenue effectively takes the most unstable listings from the market. In this way, the linear growth flattens out when most of the demand is satisfied. The short-term renting market goes into a stable phase in which the total number of listings available follows the average demand. This scenario is supportive of the expectation stated in Edelman and Geradin (2015) that certain regulatory frameworks safeguard consumer rights while simultaneously opening opportunities to reap the efficiencies of online-based business models for accommodation. It can be assumed that a stable supply of short-term accommodation that is occupied, mainly, by tourists is preferable for the tourism industry, as compared to the market going through serious periodic fluctuations.

5.2. Conclusion

The present paper addresses the question of how the growth dynamics of Airbnb can be predicted by comparing scenarios with policy intervention with a scenario of no policy intervention. The study supports the suggestion that ABM approaches are applicable for the modelling of both sharing economy phenomena and other phenomena related to modern tourism (Nicholls et al., 2017).

More specifically, they can simulate different scenarios, ranging from a lack of regulation to regulation through a variety of measures, for example, a limitation of the number of days for renting and taxation. These measures are, indeed, currently either being discussed or being implemented by different city and regional parliaments or on the national level across the world. The simulations suggest which measures should be taken because they are able to generate stability in long-term market development, and also show which measures should be avoided in order not to de-stabilise a growing market segment. In addition, the results of the policy interventions simulated were also suggested by the theoretical economic model for the short- and long-term rental market, implying that the simulated ABM model validates the findings of the theoretical model. Hence, the theoretical contribution that the present paper makes is to link sharing economy phenomena such as Airbnb with the development of housing markets in tourist destinations.

6. Implications, limitations and suggestions for further research

The results of this study may probably be generalised to the broader spectre of sharing economy sectors and services. One may expect that sharing economy platforms operating in other weakly regulated markets may suffer from cyclical crises following the period of initial expansion. Moreover, the study may have valuable implications for policy-makers, urban and regional planners, and other practitioners concerned with tourist accommodation. First, while the unregulated short-term renting market maximises the number of Airbnb listings, some regulations may

be necessary in the long run to avoid cyclical fluctuations. Regulations may have various consequences for the actors. Second, the free market allows more people to experiment with their property and to implement more flexible income plans. However, the predicted fluctuation in Airbnb supply may add to uncertainty and send shock waves of varying magnitudes through other markets (long-term renting, hospitality and even related tourism markets). Both the type and level of restrictions/regulation should be carefully evaluated. The maximum number of nights that a property may by rented out for should not exceed a certain level, because, otherwise, the market becomes too unstable. Moreover, this measure has no effect on the spatial distribution of Airbnb listings. Taxes seem to be the most appropriate instrument for the regulation of a short-term renting market, notably a modest level of taxation on Airbnb services, because it eliminates the fluctuations and helps to distribute Airbnb listings more evenly across the urban space. The latter effect is especially important for making tourism more sustainable by reducing the competition and tensions between the local population as long-term residents and short-term visitors and tourists. However, too high tax rates effectively kill the market. There is probably no optimum level of taxation that works equally well in all situations, but agent-based models using real-world data for individual cities may be a valuable tool for choosing optimal practical solutions in each individual case. Altogether, the present paper can support policy-making in taking a more informed approach on the regulatory decisions of modern tourism-oriented services such as Airbnb.

As with any model, this study suffers from a number of limitations and simplifications. Some of these issues may be addressed in future studies. The model is based upon a simplistic notion of how the owners of real estate make rational decisions on the renting market, which are based upon the expected revenues. Referring to the broad psychology literature could probably improve the quality of the model. Moreover, the real-estate market represented in this study as a composition of properties rented out in two different ways as opposed to not-renting is, again, an over-simplification. While the model in question operates with cases when only the whole property is rented out, modelling the whole spectre of opportunities (for example, renting a part of the apartment or renting out just in high seasons) that Airbnb and other platforms provide to tourists may give a more realistic picture of this specific sharing economy market. Lastly, while the current study operates with fixed prices, future studies may also consider flexible prices on the renting market.

Contribution note

Evgueni Vinogradov has contributed to all sections focusing most on the conceptual idea, theory behind ABM method and empirical testing and implications.

Birgit Leick has contributed to all sections focusing most on the introduction, theory, conclusions, limitations and implications.

Has contributed to all sections focusing most on the introduction, theory, conclusions, limitations and implications.

Bjørnar Karlsen Kivedal has contributed to all sections focusing most on the theory, method, and discussion.

Declaration of competing interest

We hereby confirm that there are no competing interests involved in the paper submitted.

References

Barron, K., Kung, E., & Proserpio, D. (2018). *The sharing economy and housing affordability: Evidence from Airbnb*. Available at: SSRN: https://ssrn.com/abstract=3006832 https://doi.org/10.2139/ssrn.3006832.

Botsman, R., & Rogers, R. (2010). *What's mine is yours*. London: Collins.

CBS Los Angeles. (2018). *Possible crackdown on Airbnb rentals have some worried about making ends meet*. Los Angeles: CBS Los Angeles. https://losangeles.cbslocal.com/2018/09/13/possible-crackdown-on-airbnb-rentals-have-some-worried-about-making-ends-meet/. (Accessed 29 May 2019).

Codagnone, C., & Martens, B. (2016). Institute for prospective technological studies, digital economy working paper 2016/01. JRC100369. Brussels, European Union. In *Scoping the sharing economy: Origins, definitions, impact and regulatory issues*.

Daniels, J. (2018). *Los Angeles passes regulation targeting Airbnb and other short-term rental services*. CNBC, 12 December 2018 https://www.cnbc.com/2018/12/12/los-angeles-passes-regulation-targeting-airbnb-rental-hosts.html. (Accessed 29 May 2019).

De Leeuw, F., & Ekanem, N. F. (1971). The supply of rental housing. *The American Economic Review, 61*(5), 806–817. Available at: https://www.jstor.org/stable/1813143.

De Rivera, J., Gordo, A., Cassidy, P., & Apesteguia, A. (2017). A netnographic study of P2P collaborative consumption platforms' user interface and design. *Environmental Innovation and Societal Transitions, 23*(1), 11–27. https://doi.org/10.1016/j.eist.2016.09.003.

Deng, Y., Gabriel, S. A., & Nothaft, F. E. (2003). Duration of residence in the rental housing market. *The Journal of Real Estate Finance and Economics, 26*(2–3), 267–285. https://doi.org/10.1023/A:1022987010545.

Dogru, T., Mody, M., & Suess, C. (2019). Adding evidence to the debate: Quantifying Airbnb's disruptive impact on ten key hotel markets. *Tourism Management, 72*, 27–38. https://doi.org/10.1016/j.tourman.2018.11.008.

Edelman, B. G., & Geradin, D. (2015). Efficiencies and regulatory shortcuts: How should we regulate companies like Airbnb and Uber. *Stanford Technology Law Review, 19*, 293–328. https://law.stanford.edu/publications/efficiencies-and-regulatory-shortcuts-how-should-we-regulate-companies-like-airbnb-and-uber/. (Accessed 29 May 2019).

Gabriel, S. A., & Nothaft, F. E. (2001). Rental housing markets, the incidence and duration of vacancy, and the natural vacancy rate. *Journal of Urban Economics, 49*(1), 121–149. https://doi.org/10.1006/juec.2000.2187.

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., et al. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling, 198*(1–2), 115–126. https://doi.org/10.1016/j.ecolmodel.2006.04.023.

Grimm, V., Berger, U., DeAngelis, D. L., Polhill, J. G., Giskee, J., & Railsback, S. F. (2010). The ODD protocol: A review and first update. *Ecological Modelling, 221*(23), 2760–2768. https://doi.org/10.1016/j.ecolmodel.2010.08.019.

Groeneveld, J., Klabunde, A., O'Brien, M. L., & Grow, A. (2017). How to describe agent-based models in population studies?. In A. Grow, & J. Van Bavel (Eds.), *Agent-based modelling in population studies. The springer series on demographic methods and population analysis* (Vol. 41, pp. 237–254) Cham: Springer.

Gurran, N., & Phibbs, P. (2017). When tourists move in: How should urban planners respond to Airbnb? *Journal of the American Planning Association, 83*(1), 80–92. https://doi.org/10.1080/01944363.2016.1249011.

Gurran, N., Searle, G., & Phibbs, P. (2018). Urban planning in the age of Airbnb: Coase, property rights, and spatial regulation. *Urban Policy and Research, 36*(4), 399–416. https://doi.org/10.1080/08111146.2018.1460268.

Guttentag, D. (2015). Airbnb: Disruptive innovation and the rise of an informal tourism accommodation sector. *Current Issues in Tourism, 18*(12), 1192–1217. https://doi.org/10.1080/13683500.2013.827159.

Huang, Q., Parker, D. C., Filatova, T., & Sun, S. (2014). A review of urban residential choice models using agent.based modeling. *Environment and Planning B: Planning and Design, 41*(4), 661–689. https://doi.org/10.1068/b120043p.

Interian, J. (2016). Up in the air: Harmonizing the sharing economy through Airbnb regulations. *Boston College International and Comparative Law Review, 39*(1), 129–161. http://lawdigitalcommons.bc.edu/iclr/vol39/iss1/6. (Accessed 29 May 2019).

Kaplan, R. A., & Nadler, M. L. (2015). Airbnb: A case study in occupancy regulation and taxation. *University of Chicago Law Review Dialogue, 82*(1), 103–115. https://chicagounbound.uchicago.edu/uclrev_online/vol82/iss1/7. (Accessed 29 May 2019).

Koopman, C., Mitchell, M., & Thierer, A. (2015). The sharing economy and consumer protection regulation: The case for policy change. *The Journal of Business, Entrepreneurship & the Law, 8*(2), 529–545. http://digitalcommons.pepperdine.edu/jbel/vol8/iss2/4. (Accessed 29 May 2019).

Ksienrzyk, L. (2018). *Neues Gesetz stellt Airbnb und Gastgeber vor große Probleme. Gründerszene. Berlin: Vertical Media GmbH*. https://www.gruenderszene.de/perspektive/zweckentfremdung-airbnb-berlin. (Accessed 29 May 2019).

Lee, D. (2016). How Airbnb short-term rentals exacerbate Los Angeles's affordable housing crisis: Analysis and policy recommendations. *Harvard Law & Policy Review, 10*(1), 229–253. https://harvardlpr.com/print-archive/volume-10-1/. (Accessed 29 May 2019).

Leung, X. Y., Xue, L., & Wen, H. (2019). Framing the sharing economy: Toward a sustainable ecosystem. *Tourism Management, 71*, 44–53. https://doi.org/10.1016/j.tourman.2018.09.021.

Malerba, F., Nelson, R. R., Orsenigo, L., & Winter, S. G. (1999). History friendly models of industry evolution: The computer industry. *Industrial and Corporate Change, 8*(1), 3–41. https://doi.org/10.1093/icc/8.1.3.

Müller, B., Bohn, F., Dreßler, G., Groeneveld, J., Klassert, C., Martin, R., et al. (2013). Describing human decisions in agent-based models - ODD + D, an extension of the ODD protocol. *Environmental Modelling & Software, 48*(1), 37–48. https://doi.org/10.1016/j.envsoft.2013.06.003.

Nicholls, S., Amelung, B., & Student, J. (2017). Agent-based modeling: A powerful tool for tourism researchers. *Journal of Travel Research, 56*(1), 3–15. https://doi.org/10.1177/0047287515620490.

Oskam, J., & Boswijk, A. (2016). Airbnb: The future of networked hospitality businesses. *Journal of Tourism Futures, 2*(1), 22–42. https://doi.org/10.1108/JTF-11-2015-0048.

Pizzitutti, F., Mena, C. F., & Walsh, S. J. (2014). Modelling tourism in the galapagos islands: An agent-based model approach. *The Journal of Artificial Societies and Social Simulation, 17*(1), 23–33. https://doi.org/10.18564/jasss.2389.

Rachordas, S. (2015). Does sharing mean caring? Regulating innovation in the sharing economy. *Minnesota Journal of Law, Science and Technology, 16*(1), 413–475. https://scholarship.law.umn.edu/mjlst/vol16/iss1/9. (Accessed 29 May 2019).

Tun, Z. T. (2018). *Top cities where Airbnb is legal or illegal. Investopedia, 23 October 2018.* https://www.investopedia.com/articles/investing/083115/top-cities-where-airbnb-legal-or-illegal.asp. (Accessed 29 May 2019).

Wachsmuth, D., & Weisler, A. (2018). Airbnb and the rent gap: Gentrification through the sharing economy. *Environment & Planning A: Economy and Space, 50*(6), 1147–1170. https://doi.org/10.1177/0308518X18778038.

Wegmann, J., & Jiao, J. (2017). Taming Airbnb: Toward guiding principles for local regulation of urban vacation rentals based on empirical results from five US cities. *Land Use Policy, 69*, 494–501. https://doi.org/10.1016/j.landusepol.2017.09.025.

Wilensky, U., & Rand, W. (2015). *An introduction to agent-based modelling.* Cambridge: The MIT Press.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic system approach to making sense of the world. *Journal of Science Education and Technology, 8*(1), 3–19. https://doi.org/10.1023/A:1009421303064.

Windrum, P., Fagiolo, G., & Moneta, A. (2007). Empirical validation of agent-based models: Alternatives and prospects. *The Journal of Artificial Societies and Social Simulation, 10*(2), 8. http://jasss.soc.surrey.ac.uk/10/2/8.html. (Accessed 29 May 2019).

Zhang, W., Guhathakurta, S., Fang, J., & Zhang, G. (2015). Exploring the impact of shared autonomous vehicles on urban parking demand: An agent-based simulation approach. *Sustainable Cities and Society, 19*, 34–45. https://doi.org/10.1016/j.scs.2015.07.006.

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