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# Building the City Under Financial Frictions\*

David Gomtsyan<sup>†</sup>

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## Abstract

Weak financial institutions may affect developing countries due to slowing the much-needed construction process of residential housing. Using novel data collected from Nairobi, I document considerable heterogeneity in the construction duration of new residential buildings, with about 40% of buildings started in 2009 still unfinished in 2018. To understand the role of financial development in constructing residential housing, I develop a heterogeneous agent model with financial frictions in which households construct individual housing units. Counterfactual simulations show that improvements in credit provision can substantially speed up the expansion of the aggregate housing stock and increase the city's density by enabling the construction of taller buildings. The model also predicts that investments in incomplete structures emerge as an alternative savings vehicle in the absence of reliable savings accounts.

**Keywords:** Urban growth, Housing investment, Financial frictions.

**JEL code:** O16, O18, R12.

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# 1 Introduction

Unfinished buildings are common in the cityscape of many low-income African countries. The construction process from commencement to completion of simple structures can take decades. These observations raise questions about underlying frictions and their consequences for city development. Rapidly expanding populations in cities are in a desperate need for housing. The efficiency with which housing is produced and supplied is therefore a vital element of an economy's development path. Yet the economic literature has paid little attention to causes and consequences of slow construction processes and to the preponderance of unfinished construction projects in African cities.

In this paper I hand-collect detailed data from satellite images and track the construction duration of individual buildings, their completion status and the number of stories over the 2009-2018 period. Focusing on Nairobi, I document several novel facts. My data show that 40% of buildings are still under construction 9 years after the commencement of construction works. The average construction duration for completed buildings is above 2.4 years. The corresponding figure for the US is one year.

To understand the role of financial development in the construction of residential housing, I introduce an endogenous house construction process into a model with heterogeneous agents and borrowing constraints. Households can initiate construction projects which can be used to meet their own housing needs and can be rented out to others to generate a stream of income. Housing construction requires determination of the size of the building, investment in the foundation and investments in the stories of the structure. The latter part can be implemented over an arbitrary number of periods. I do not impose exogenous time-to-build assumptions on the construction function. The duration of construction depends only on the households' optimal decisions, which, in turn, are constrained by the availability of funds. Households have strong incentives to complete construction projects as soon as possible because houses are income-generating assets.

However, in the equilibrium the construction of individual projects progresses slowly and may take many years. This outcome emerges because imperfections in financial markets and contracting institutions impose tight borrowing constraints. The large investment required to construct a building exceeds the per period incomes of most households, and households, due to the borrowing constraint, cannot finance their projects by debt. As a result, they have to rely on their own savings. In this context, households with sufficient funds to invest in the foundation start construction, but the process may evolve slowly depending on the dynamic evolution of their income and the planned size of the building. Taking into account the expected slow pace of construction, households optimally choose to build structures with fewer stories. To assess quantitative implications of the model, I parameterize it by borrowing from two independently evolving strands of literature: quantitative spatial models and heterogeneous agent models. I also utilize my collected data to match average building heights.

Next I use the calibrated model to conduct counterfactual simulations. I compare an econ-

omy with a financially developed system, where collateralized loans are available, to an economy without borrowing. In the long run equilibrium the average building has 25% more stories in the economy with borrowing, compared to the one without. There are also substantial differences between the two economies during the transition phase. In the economy with lending 93% of structures are completed after the initial 9 years. The corresponding number in the economy without lending is only 21%.

These findings have important policy implications. A large body of economic literature argues that incomes are higher in urban areas and urbanization can improve living standards in developing countries ([Gollin, Lagakos, and Waugh, 2013](#)). However, urbanization depends on the capacity of cities to provide proper living conditions to potential migrants from rural areas. Furthermore, the urban economics literature has highlighted the role of city sprawl on commuting time ([Harari, 2020](#)). The results of the current paper show that policies oriented towards the improvement of credit for residential construction purposes can substantially increase the speed of housing provision, and hence the transition from rural to urban economy. Moreover, it can lead to an equilibrium with taller buildings, which can reduce the city's sprawl and improve its productivity. My calculations show that more urban sprawl caused by financial frictions increases commuting times by at least 2.6%. I also use the model to study the effectiveness of interest rate and construction cost subsidies. According to my simulations, construction cost subsidies are more effective in increasing the average building height and the output gains resulting from such subsidies exceed their costs.

Motivated by the applied microfinance literature, I explore the role of negative real returns on financial savings. In the presence of negative real returns on financial savings, investments in unfinished buildings emerge as a safe alternative form of preserving the value of money.

This paper contributes to the rapidly expanding literature that uses quantitative models to study different aspects of urbanization and cities in developing countries. [Henderson, Regan, and Venables \(2021\)](#) use a model with slums and formal housing to quantify the role of land titling rights on the development of the city. Their paper features neither heterogeneity among households nor are there financial frictions. In the context of cities in developing countries, borrowing constraints are introduced in some recent papers. [Michaels, Nigmatulina, Rauch, Regan, Baruah, and Dahlstrand \(2021\)](#) assume that a fraction of owners are financially constrained and impose that they cannot develop high quality housing. In that model there is no height dimension but there is a quality dimension. Both concepts are similar from the modeling point of view. In my setting this outcome emerges endogenously. Moreover, that paper assumes that owners should complete the construction process in one period. In [Cavalcanti, Da Mata, and Santos \(2019\)](#) households face borrowing constraints but the entire housing stock is owned by large real estate companies which do not face financial frictions. Such an environment does not allow to capture the effects discussed in the current paper. [Garriga, Hedlund, Tang, and Wang \(2023\)](#) develop a model in which agents can own houses (for personal use only) to study the urbanization dynamics in

the context of China. That paper follows the tradition in the macroeconomic literature, in which ownership appears in the form of shares in the aggregate housing stock. According to this modeling approach, unfinished buildings cannot exist because there are no individual buildings and incremental investments instantaneously expand the aggregate housing stock. I contribute to this literature by proposing a more granular approach for modeling the housing construction process, and show that in this environment financial frictions have quantitatively very large effects on the development of cities.

In the context of advanced countries and China, the existing modeling approach may be appropriate because it allows to avoid additional layers of complication and it may be a reasonable approximation of reality, given that in these countries construction is conducted by large enterprises with access to funds. However, modeling house construction as a household decision problem is more appropriate in the context of many African cities, where households individually engage in construction. The importance of individuals in the process of house construction is also recognized by economists and policymakers. For example, [Romer \(2012\)](#) and [Angel \(2012\)](#) argue that, given the institutional constraints in developing countries, authorities should lay out basic infrastructure on the fringes of cities and allow people to build their own homes. Although I do not have data on the fraction of houses constructed by individuals, from the World Bank report on the housing market in Kenya we learn that even those who are able to secure credit, typically engage in self-construction ([World Bank, 2017](#)).<sup>1</sup> Another strong argument in favor of modeling house construction as a household decision problem comes from recent developments in the macroeconomic literature. Over the last decade there was a rapid expansion of studies which model entrepreneurial activity in the spirit of [Lucas \(1978\)](#). From the point of view of this literature, households' direct involvement in the construction process can be viewed as a form of entrepreneurial activity. In this direction my paper shares similarities with [Buera, Kaboski, and Shin \(2011\)](#) and [Buera and Shin \(2013\)](#), who develop models of entrepreneurial activity with borrowing constraints, to demonstrate how financial frictions affect both the long run equilibrium allocations and the transitional dynamics.

There is a growing empirical literature studying cities in developing countries. Some of those papers have proposed novel methodologies for using satellite images to overcome data limitations (see, for instance, [Donaldson and Storeygard, 2016](#); [Marx, Stoker, and Suri, 2019](#); [Dingel, Miscio, and Davis, 2021](#); [Harari and Wong, 2021](#)). In this paper I use satellite images to document a new stylized fact that is very prevalent in developing countries. My novel methodology of data construction has a potential to be scaled up to gather information on a phenomenon that has important implications for cities.

The rest of the paper is organized as follows: Section 2 presents my hand-collected data from

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<sup>1</sup>Although the self-construction of houses is very common there exist alternative arrangements as well. For example, large property developers promise apartments in the building they are creating to providers of raw materials. This solution comes with limitations because since material suppliers do not demand large numbers of apartments and when it comes to reselling those apartments, they face the same credit-constrained households.

satellite images and shows that the construction process of many buildings in Nairobi evolves very slowly. Section 3 presents the theoretical model. Section 4 calibrates the model and conducts counterfactual analysis to quantify the importance of financial friction on the transition process and on the steady state. The last section provides some concluding remarks.

## 2 Motivating facts

In this section I provide some information on the state of the buildings and the construction process in Nairobi. The construction of most buildings proceeds very slowly in African cities; however, there are no official data sources which can allow researchers to document these patterns.

### 2.1 Evidence on construction duration

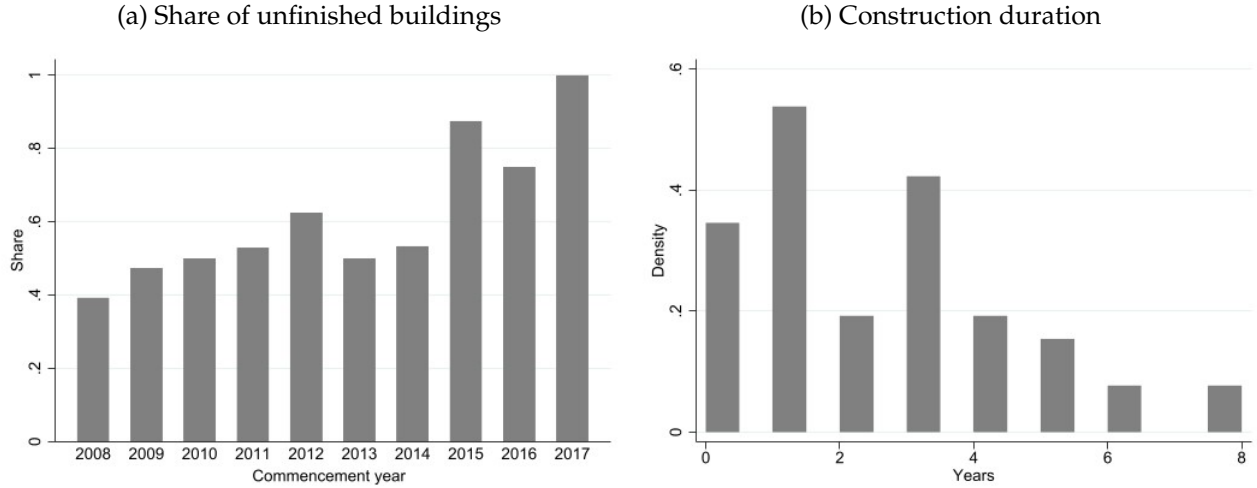
Figure A1 provides an example of a building under construction in Sunton neighborhood in Nairobi. The image is taken from Google's Street View feature and was made in February 2018. Sunton is a neighborhood on the outskirts of Nairobi and according to satellite images it almost did not have built area before 2003 (the earliest year for which satellite images are available). Sunton is not a slum neighborhood and buildings from corrugated iron sheets, which are typically the dominant form of housing in informal neighborhoods, are rare. The vast majority of structures are made from volcanic stone, concrete and iron rods (similar to the one in Figure A1). The construction of a building of the size displayed in that figure in a normal environment takes approximately a year (the corresponding US figures are discussed at the end of this subsection) and it could be that this image was made exactly during that interval. However, the fact that the bottom stories are occupied by residents may suggest that the building has been in this state for a long period of time. This conjecture can be confirmed with the help of satellite images. In Figure A3, I use historical images from Google Earth to determine the approximate date of the commencement of this construction project. For Nairobi, Google Earth provides satellite images taken each year starting from 2009. I identify the locations of buildings and track the history of land plots on which current buildings are located. Panel (a) of Figure A3 shows an image from March 2009 of the land plot on which the building discussed above is located (red arrow). Panel (b) shows another image from October 2009 of the same area. We can observe that some walls had been erected. Thus, we can conclude that the construction started between March and October of 2009. Panel (c) shows that in January 2010 the ground floor is partly covered. Panel (d) presents an image from December 2017 (this date is very close to the Street View date). This image confirms the observation from the Street View that the building is not finished because there are some walls inside the building but the last floor has no cover.

I apply the above described technique to the streets of Sunton neighborhood, for which Google

Street View images are available, and collect information on individual buildings. The final sample includes 412 buildings, the locations of which are displayed in Figure A2. The location of Sunton neighborhood on the map of Nairobi is displayed in Figure B1. For each building, I determine the commencement date, the number of stories, the completion date (for completed buildings), whether they are currently used, the construction material (corrugated iron sheet/stone) and type (residential/commercial). The sample was constructed manually which is a very labor intensive task. Henderson et al. (2021) use height data at two different points in time (2003 and 2015) provided by external organizations. Their data cover the entire city and were constructed with the application of machine learning algorithms. My coverage is much smaller but given my objective, I need to pay attention to important details, so more careful processing of images is required. At the same time, while the remote sensing literature has made significant advances in the direction of determining building heights, I am not aware of any study or off-the-shelf techniques that allow researchers to determine signs of commencement dates. The determination of commencement dates involves additional challenges, compared with building heights. For example, I need images for each year rather than two images for the beginning and end of the study period. Each image needs to be inspected carefully and compared with the preceding and following ones. This time-consuming process may reveal some important details. For example, in the study by Henderson et al. (2021), when the authors observe that the height of a given building on a given land plot changed between two periods, they assume that the building was demolished and a new one was built. My hand-collected data reveals that changes in building heights in most cases are the result of ongoing construction processes. Moreover, with the exception of commencement dates, I need street images to collect information for the remaining building characteristics that were listed above. It also should be mentioned that the main objective of this section is to document that the construction progresses very slowly at the level of individual buildings. Expanding the sample is unlikely to affect this argument.

The choice of Sunton is primarily motivated by the fact that it represents a kind of neighborhood that is studied by Michaels et al. (2021) and advocated by some prominent economists (see the references in Section 1). It is a formal neighborhood with clear signs of urban planning and basic infrastructure. It has equally sliced land plots with significant heterogeneity among buildings. This means that it is neither an unorganized neighborhood nor a centrally planned one. The state has taken the basic steps and let the private sector to develop. Given the institutional constraints, this approach may be the best one for the expansion of cities in Africa. Sunton is not representative of the entire Nairobi but it is also not unique in having these features. In Appendix B I use satellite images of Sunton and calculate their similarity with various other locations in Nairobi. The results show that the similarity index is very high with a number of other parts of Nairobi. There are also neighborhoods that are different. For example, I find that it is less similar to western parts of the city, which are dominated by gated communities. It is also less similar to areas dominated by informal corrugated iron sheet buildings. Neighborhoods similar to Sunton

Figure 1: Completions and durations



Notes : Panel (a) plots the shares of unfinished buildings by commencement years. Panel (b) plots the histogram of construction duration in years for completed buildings.

should be the desired destination for most rural-urban migrants from the policy perspective because newly-arriving migrants cannot afford housing in gated communities and the residency in informal neighborhoods leads to negative welfare implications both from individual and social perspectives.

Panel (a) of Figure 1 displays the share of unfinished buildings by the year of the initiation. The sample excludes buildings from corrugated iron sheets, commercial buildings and buildings that were already completed in 2009. Since satellite images are available from March 2009, I can approximate commencement dates more precisely from 2009. For this reason, for all unfinished buildings that already existed before March 2009 I assign 2008 as the commencement date. As can be seen, for buildings the construction of which started in 2009, about 40% are unfinished after 9 years. Also, we can observe that the share of unfinished buildings is higher for more recent years, which is logical. Panel (b) plots the histogram of construction duration in years for completed buildings. The sample includes buildings that were initiated in 2009 or after. From this figure it is evident that for a substantial fraction of buildings it takes at least 3 years to complete (47%). The average duration for completed buildings is 2.4 years.

By comparing these numbers to the US ones we can develop a better understanding of whether the patterns observed in Figure 1 are also present in a relatively frictionless economy. The U.S. Census Bureau's Survey of Construction provides information on the average duration of construction process for new residential housing. According to these data, for owner-built houses with one unit the average construction duration is 11 months for the 2010-2018 period. The corresponding numbers are 11.2 and 12.5 months for buildings with 2-4 and 5-9 units. The same source also shows that about 70% of projects are completed within a year. This analysis suggests that in Kenya there are bottlenecks which hamper the construction process and cause delays. In this paper, I argue that the main reason behind this observation is volatile income and the lack



of funds to continuously finance the construction process. In Appendix C I discuss a number of alternative explanations, such as taxes, material costs and property rights, and argue that those factors are unlikely to be the key drivers of the empirical patterns documented above.

## 2.2 Evidence on finance and residential housing

In this subsection I present some suggestive empirical evidence in support of one of the main outcomes of the model developed in Section 3. The World Bank conducted a survey on housing conditions in Kenyan cities in 2012-2013 (Gulyani, Ayres, Struyk, and Zinnes, 2017). In this survey households were asked whether they have used loans to finance their structures. I use this information to study whether a positive response to this question is positively related with the number of stories in the structure. To implement this analysis, I regress the log number of stories in the structure on an indicator variable whether loans have been used, while controlling for household characteristics. Household characteristics include total household income, the number of household members, the number of working age members and the number of members aged below 16 (all variables in logs). I also include city fixed effects. Controlling for household income information is important because one major concern could be that higher income households are more likely to build taller buildings and at the same time have access to loans. I restrict the analysis to households who own both the land and the structure to make it consistent with my modeling approach. Those cases that own the structure but not the land may be informal constructions. However, the number of households who own the structure but not the land is very small and does not alter the results.

The estimation results presented in Table 1 show that the indicator variable on the availability of external finance is positively associated with the number of stories in the building. The magnitude of the effect is rather large, given that the mean of the dependent variable is 0.03. The coefficient remains stable across specifications that control for the number of members in different age categories. In columns 3 and 4 the coefficients on the presence of children and their numbers are negative. This is intuitive because those specifications control for the total numbers of members and they suggest that children require less space and decrease the incentives to build high. It should be mentioned that these results provide only a suggestive evidence. More rigorous analysis would require a setting with exogenous variation in access to loans.

## 3 Model

I present a model of a city populated by agents whose incomes evolve according to a stochastic process. Financial markets are imperfect and agents can trade non-contingent bonds. Residency in the city requires one unit of housing each period. Agents can invest in the construction and build multistory houses which they can use for their own residency and rent out to others.

Table 1: Determinants of building height

	(1)	(2)	(3)	(4)
Loan	0.030** (0.015)	0.033** (0.016)	0.034** (0.016)	0.033** (0.016)
HH income	0.030*** (0.006)	0.028*** (0.007)	0.029*** (0.007)	0.029*** (0.007)
# members	-0.007 (0.007)	-0.012 (0.010)	0.009 (0.015)	0.019 (0.017)
# age between 16 and 60		0.011 (0.011)	-0.005 (0.014)	-0.008 (0.014)
Children			-0.024* (0.013)	
# (age < 16) +1				-0.018** (0.008)
R-Adj.	0.053	0.054	0.055	0.056
N	2356	2238	2238	2238

Notes: The dependent variable is the log number of stories. *Loan* is an indicator variable if the household has used a loan during the construction. *Children* is an indicator variable equal to one if there is at least one person aged below 16. All other explanatory variables are in logs. All regressions include city fixed effects. \* (\*\*) (\*\*\*) indicates significance at the 10 (5) (1) percent level.

### 3.1 Environment

**Demographics.** There are two types of agents: patient agents, whom I refer as households, and hand-to-mouth agents, whom I refer as migrants. At time  $t = 0$ , there are  $N$  patient households in the city. Each of these households is endowed with one unit of urban land on which they can reside and build. They also receive stochastic income  $y$ , which evolves according to a Markov transition process  $z(y, y')$ . There is a large number of hand-to-mouth agents residing in the rural area. These agents migrate to the city only if the expected utility from living in the city exceeds their reservation utility in the rural area. Migrants earn some income, pay per period rent and consume the rest.

**Preferences.** The household has utility over non-housing consumption ( $c$ ) which is the numeraire. The household does not derive utility from housing consumption but in order to reside in the city she needs one unit of housing each period. She discounts her future utility using the discount factor  $\beta$ . The preferences over the non-negative consumption sequence in period 0 are represented by the following expected utility:

$$E \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\sigma}}{1-\sigma}.$$

**Housing.** The household starts her life in the city by owning one unit of undeveloped land. I do not model the land purchase process because the main objective of this paper is to study the role of financial friction on the construction process rather than on land acquisition.<sup>2</sup> The household can erect a temporary structure on her land. Temporary structures are modeled in the spirit of [Henderson et al. \(2021\)](#). Such structures are typically made from corrugated iron sheets and require per period maintenance cost  $m$ . The household can also engage in the construction of a permanent multistory housing unit. In order to start construction, the household needs to make a decision on the number of stories in the building  $\bar{h} \geq 1$  which is an integer number. The construction process can take many periods but the maximum number of stories in the building needs to be determined initially because the building should have sufficiently strong foundations to support the remaining structure. The construction process involves two components. The first one is the foundation and the second one is the building itself. The total cost of construction is given by the following function:  $\mu(\bar{h}) = A\bar{h}^\gamma$ , where  $\gamma > 1$ . The same functional form is also used by [Henderson et al. \(2021\)](#) and [Michaels et al. \(2021\)](#) who study Nairobi and Dar es Salaam, respectively.

The total cost of construction is split between two components. A fraction of  $\alpha$  must be invested in the building and  $1 - \alpha$  in the foundation. The assumption that the foundation investment is a fraction of the total cost is consistent with industry estimates and is discussed in more detail in Section 4.1. The results of the model hold even when  $\alpha = 1$ . The only assumption required is that the household needs to make an irreversible decision on the number of floors before starting the construction. The construction of the main part of the building can be done incrementally. If sufficient funds are available, then the household can add layers of stones/bricks to the building and increase its height in a period. If funds are not available, then the household optimally chooses not to engage in construction in that period. There are no technological constraints on the speed of construction or the conversion of the building into a livable place. The speed of construction is determined by the household's optimal decision rules.

If the household has started the construction but has not yet completed her building, then she can reside in the temporary building or inside the unfinished building. She has to continue to incur the maintenance cost  $m$ . When the construction is completed and  $h = \bar{h}$ , the household stops paying the maintenance cost  $m$ . Thus, the household pays the maintenance cost  $m$  starting from  $t = 0$  up until the project is completed. If  $h \geq 2$  the owner occupies one of the stories and rents out the remaining stories to migrants. This modeling approach is also supported by the data. According to the World Bank survey conducted by [Gulyani et al. \(2017\)](#), about one fifth of renters report that the owner lives in the same building.

**Financial markets.** Financial markets are incomplete, households can trade non-contingent bonds (a) and they are subject to a borrowing constraint. Collateralized borrowing is allowed and the

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<sup>2</sup>This approach may be relevant from the practical point of view as well because the allocation of land is not always based on the market value. The Sites and Services project studied in [Michaels et al. \(2021\)](#) is one such example.

size of the maximum debt is restricted by  $\underline{a}$ . The interest on borrowing is given by  $i^l$  which is determined outside the city. The rate of return on savings or deposits is given by  $i^d$  which is also exogenous.

### 3.2 Decision problems.

At any point in time the household can be a land owner, a builder or a structure owner. Let  $s$  denote the status of the household depending whether she is a land owner ( $L$ ), builder ( $B$ ) or structure owner ( $O$ ). Below I present the decision problems of all these types.

**The land owner's problem.** Each period, the land owner chooses whether she wants to start building a house or continue to reside in the temporary building. This decision is given by:

$$V(a, y) = \max_{\{B, L\}} [V^B(a, y), V^L(a, y)], \quad (1)$$

where  $V^B$  denotes the value of the builder and  $V^L$  the value of the land owner. The latter is defined as follows:

$$V^L(a, y) = \max_{c, a'} u(c) + \beta EV(a', y') \quad (2)$$

subject to

$$c + m + a' \leq y + a \times (1 + i), \quad (3)$$

$$a' \geq \underline{a}.$$

$$\begin{cases} i = i^d & \text{for } a' \geq 0 \\ i = i^l & \text{for } \underline{a} \leq a' < 0. \end{cases}$$

The land owner receives a stochastic income, incurs the maintenance cost and decides how much to consume and invest or borrow ( $a'$ ). Next period's expected value function is given by  $EV(a', y')$ , which is the option of choosing between continuing as a land owner or becoming a builder as described above.

**The builder's problem.** When the household chooses to initiate a construction project, she transitions to an intermediate stage, the optimization problem of which is given by:

$$V^B(a, y) = \max_{c, a', \bar{h}} u(c) + \beta EV^O(a', y', \bar{h}, 0) \quad (4)$$

subject to

$$c + a' + (1 - \alpha) \times \mu(\bar{h}) + m \leq y + a \times (1 + i), \quad (5)$$

$$a' \geq \underline{a}.$$

$$\begin{cases} i = i^d & \text{for } a' \geq 0 \\ i = i^l & \text{for } \underline{a} \leq a' < 0. \end{cases}$$

During this stage the household makes a decision on the future height of the structure  $\bar{h}$ . At this stage the household also makes an investment in the foundation of the building given by  $(1 - \alpha) \times \mu(\bar{h})$ . After making these choices the builder becomes an owner, the value of which is given by  $V^O(a', y', \bar{h}, 0)$ . The household does not engage in the construction of the stories at this stage and enters into the next period with 0 stories but with a completed foundation. It is important to note that, while  $\bar{h}$  is an integer,  $h$  is a continuous variable. After the initiation of the construction the household still needs to incur the maintenance cost  $m$  because she still resides in the temporary structure.

**The owner's problem.** Each owner is characterized by  $\bar{h}$  which was determined in the building stage and cannot be changed. The owner takes this value as given and solves the following optimization problem:

$$V^O(a, y, \bar{h}, h) = \max_{c, a', h'} u(c) + \beta EV^O(a', y', \bar{h}, h') \quad (6)$$

subject to

$$c + a' + \alpha \times \mu(h') + 1[h < \bar{h}] \times m \leq y + a \times (1 + i) + \max[0, \lfloor h \rfloor - 1] \times r + \alpha \times \mu(h), \quad (7)$$

$$a' \geq \underline{a}, \quad h \leq h' \leq \bar{h},$$

$$\begin{cases} i = i^d & \text{for } a' \geq 0 \\ i = i^l & \text{for } \underline{a} \leq a' < 0. \end{cases}$$

If  $h < \bar{h}$ , then the owner pays the maintenance cost. Starting from this stage, the interpretation of this cost is twofold. The first interpretation is the same as before. While the first floor is not completed the household needs to reside in the temporary structure. The second interpretation is that after completing the first floor the household moves into the permanent building but since the building does not have a roof, the household needs to undertake some maintenance work. Furthermore, living in a building that is under construction implies potential damages to the interior of the building, for example, due to water leakage. Another interpretation of this cost, which applies to both stages, is that it captures the disutility of living in a corrugated iron sheet building or in a building under construction. To keep the model simple I do not model this through the utility function but  $m$  may partly capture this effect in a reduced form way. It is also worthwhile to mention that it is very common to observe residents in unfinished buildings in

Africa (see Figure A1).

At this stage the household engages in the construction of layers. Per period investment in construction is given by  $\alpha \times \mu(h') - \alpha \times \mu(h)$ . There is no incentive to destroy stories because that does not generate value. If the building is finished ( $h = \bar{h}$ ) the owner stops paying the maintenance cost. The owner generates income by renting out stories of the building to other households. The amount of space available for renting is given by  $\lfloor h \rfloor - 1$ .<sup>3</sup> This indicates that the household occupies one of the stories herself and rents out the remaining completed stories to other households.<sup>4, 5</sup>

**Migrants.** Migrants move to the city if their utility weakly exceeds the reservation utility in the rural area. Their income level in the city is fixed and the only factor that affects their migration decision is the rent ( $r$ ). Each migrant needs one floor in the city. Migrants do not make any intertemporal decisions, their presence is required to generate demand for newly constructed housing. The presence of a large number of potential migrants and their outside option ensure that  $r$  is constant over time. The number of migrants in the city evolves endogenously and I denote it by  $M_t$ .

### 3.3 Equilibrium

The decision rules together with the stochastic income process determine the evolution of the distribution of households over  $y, a, \bar{h}, h$  and  $s$  which I denote by  $G_t(y, a, \bar{h}, h, s)$  and by  $g_t(y, a, \bar{h}, h, s)$  the corresponding probability density function.

An equilibrium consists of an initial distribution of households  $G_0(y, a, \bar{h}, h, s)$ , rents  $r$ , interest rates  $i^l$  and  $i^d$ , a sequence of decision rules, a sequence of distributions  $G_t(y, a, \bar{h}, h, s)$  and migrants  $M_t$  for  $t \geq 1$ , such that:

1. Decision rules solve the household's problem in equations (1), (2), (4) and (6), subject to respective budget constraints (3), (3.2) and (3.2).
2. Demand for living space equals supply for all  $t \geq 0$

$$N + M_t = N \times \sum_h g_t(y, a, \bar{h}, h, s) \times \max[1, \lfloor h_t(y, a, \bar{h}, h) \rfloor]. \quad (8)$$

<sup>3</sup> $\lfloor \cdot \rfloor$  is a mathematical notation for rounding down to the nearest integer number.

<sup>4</sup>The model can easily be modified and calibrated under the assumption that renting is allowed only if the building is fully completed.

<sup>5</sup>I assume that there are no real estate transactions between households. This is an important feature but it introduces substantial computational and quantification complications. It is reasonable to assume that housing transactions are associated with large risks and costs in the context of Nairobi. To keep the model simple, I make a strong assumption that these costs are large enough so that they outweigh potential benefits.

3. The sequence of distributions  $\{G_t(y, a, \bar{h}, h, s)\}, t \geq 1$ , are implied by the sequence of optimal decision rules and the initial distribution  $G_0(y, a, \bar{h}, h, s)$ .

Equation (8) is the market clearing condition for housing. It states that the total number of households and migrants in the city (left-hand side) is determined by housing supply (right-hand side). The elements in the sum cannot be lower than one because land plots that do not have any completed floors ( $\lfloor h \rfloor < 1$ ) can accommodate one household in a temporary structure. The supply and demand for assets do not necessarily equalize because the lending rate ( $i^l$ ) and the return on savings ( $i^d$ ) are determined outside the city.

The key feature of the model is the choice of the planned height of the building  $\bar{h}$ . When choosing  $\bar{h}$ , the household faces a trade off. Higher values of  $\bar{h}$  generate more rental income. But building high implies two types of costs. The first one is the construction cost, which is a convex function. The second one is associated with the longer time required to complete the building. Because of the borrowing constraint the construction process takes longer which negatively affects the household's incentive to plan a tall building.

## 4 Quantitative analysis

The main objective of this paper is to assess the role of financial friction on the process of housing development in the context of a city in a low-income country that experiences a potential inflow of migrants from the rural area. The quantitative analysis focuses on Nairobi which has experienced a rapid expansion over the last decades and is one of the largest cities in Africa. The recent study by [Henderson et al. \(2021\)](#) also focuses on Nairobi which facilitates the calibration process and comparison of the role of new features introduced in the current study. I also use the information obtained from the satellite and street images in the calibration process. Then I use alternative values for  $\underline{a}$ ,  $i^l$  and  $i^d$  which describe the level of the development of the financial system, to conduct counterfactual exercises and assess the extent to which financial development affects the speed of the expansion of housing stock and its level in the long run equilibrium.

### 4.1 Calibration

Some parameters are standard and are taken from the literature with heterogeneous agents and incomplete market models ([Huggett, 1993](#); [Aiyagari, 1994](#)). The model period corresponds to one year. The discount factor is set to  $\beta = 0.96$  and the coefficient of the relative risk aversion is set to  $\sigma = 2$ . The choice of the parameters governing the evolution of household income is more challenging because most studies focus on rich countries. One exception is [Albertini, Fairise, and Terriau \(2021\)](#) who use data from South Africa. The authors have a life-cycle model and estimate

age-specific three-state income process.<sup>6</sup> In order to extend the number of states I generate series from their transition matrix for middle-aged agents and estimate it with the following AR process  $y_{t+1} = (1 - \rho)\eta + \rho y_t + \epsilon_{t+1}$ . The resulting parameters are  $\rho = 0.53$  and  $\sigma_\epsilon = 0.3$ . The standard deviation is similar to the estimates for the US and the autocorrelation coefficient is lower, which is consistent with higher levels of instability in Africa. I discretize this AR process using the algorithm of [Tauchen and Hussey \(1991\)](#).

The per period rental rate ( $r$ ) is set to 20% of the income of the average household. According to the World Bank survey conducted in Nairobi the average renter spends about 20% of her income on rent ([Gulyani et al., 2017](#)). This figure is also close to the one observed in advanced countries ([Davis and Ortalo-Magne, 2011](#)). [Henderson et al. \(2021\)](#) estimate that the maintenance costs is equal to 25% of the monthly rent. Thus, I set  $m = 0.05$ .

As was mentioned during the description of the model, housing is produced with a convex production function,  $\mu(h) = Ah^\gamma$ . The curvature parameter is set to  $\gamma = 1.53$ . The same value is also used by [Michaels et al. \(2021\)](#). This value comes from a recent study by [Combes, Duranton, and Gobillon \(2021\)](#) who use detailed construction cost data from France to estimate a housing production function. It should be mentioned that [Combes et al. \(2021\)](#) study family houses and not tall buildings, so in terms of sizes buildings are similar. [Henderson et al. \(2021\)](#) use the same functional form for Nairobi but they do not have construction cost data, so they estimate the parameter from the model and obtain a somewhat larger value. One possibility is that because in their model there are no financial frictions they need a larger convexity parameter to match the relatively low building heights.

To the best of my knowledge in the economic literature there are no estimates of foundation cost functions. For this reason, I turn to engineering estimates. The National Association of Home Builders provides cost breakdowns for the US single family houses. According to the most recent report the share of costs on foundation is 11.8% ([Ford, 2020](#)). Thus, I set  $1 - \alpha = 0.12$ .

The key parameter that describes the level of financial development is  $\underline{a}$ . Setting this value to 0 and assuming that borrowing is not possible in Nairobi will be unrealistic. According to [Gulyani et al. \(2017\)](#), 35% of respondents who own houses reported that their buildings were financed by loans. Consequently, I divide the population of households into two groups. The first group consists of households who do not have access to the financial system and for them  $\underline{a} = 0$ .<sup>7</sup> The second group of households do have access to the financial system and they can borrow against the value of their land. The estimated production function of [Combes et al. \(2021\)](#) implies that the share of land in the total value of the building is 35%. Given the parameters of the production

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<sup>6</sup>Since that paper, among other things, studies the effect of health on wealth accumulation, for each income state there are two health states. I focus on individuals in good health.

<sup>7</sup>One may argue that the ownership of land or house mechanically grants access to the financial system. The survey data suggests that that is not the case because the 35% figure mentioned above is among owners of houses from stone and bricks in Nairobi and not for the general population. This means that there are some other factors determining households' ability to borrow, such as formal income.



function, for a building with 4 stories, this implies a land value of 4.7. Thus, I set  $\underline{a} = -4.7$ .<sup>8</sup> I denote the fraction of households who can borrow by  $\mu = 0.35$ . The interest rate on loans ( $i^l$ ) is set to 8%. This value corresponds to the average real interest rate on loans in Kenya during the 2000-2015 period, according to the World Bank's World Development Indicators (WDI). The return on financial savings is set to 0. According to the WDI, on average the return on deposits is not positive. In Section 4.3 I also consider negative returns.

Finally, I choose the construction cost shifter  $A$  to match the average building height. Higher values of this parameter increase construction costs and thus decrease building height. In my context, I need to take into account the fact that the housing expansion process of my selected neighborhood, and many other neighborhoods with similar characteristics, have not yet reached their long run equilibrium as was documented in Section 2. For this reason, I simulate the model for 9 periods and try to match the average completed building height, which is 2.36. By setting  $A = 1.05$ , the model implied average building height completed within the first 9 periods is 2.35.

Table 2: Model parameters

Parameter	Description	Value
$\beta$	Discount factor	0.96
$\sigma$	CRRA	2
$\rho$	Income shock persistence	0.53
$\sigma_\epsilon$	Income shock variance	0.30
$r$	Rent	0.20
$m$	Maintenance cost	0.05
$1 - \alpha$	Cost share of the foundation	0.12
$\gamma$	Convexity of the cost function	1.53
$A$	Shifter of the cost function	1.05
$\mu$	Fraction of households with finance	0.35
$i^l$	Interest on loans	8%
$i^d$	Interest on deposits	0%
$\underline{a}$	Borrowing limit (with finance)	-4.7
$\underline{a}$	Borrowing limit (w/o finance)	0

The key moments of the economy are presented in the fifth row of Table 3. These numbers are the weighted averages of two economies with and without borrowing (with  $\mu = 0.35$ ). The first column presents the average height after the first 9 periods, which is a targeted moment. The second column displays the average height in the long run equilibrium. I do not observe the corresponding number in the data but the average height of the unfinished buildings in the data is 2.39, which is higher than that of the finished ones. It is intuitive that in the long run, as unfinished

<sup>8</sup>It should be mentioned that I need land price to determine the borrowing limit, it does not play any other role in the model. My proposed approach of determining land price depends on the number of stories. In the equilibrium with borrowing, the median building has 3 stories but many households borrow to the limit, which implies that they are still constrained. For this reason I use a building with 4 stories to determine land values. An alternative option would be to impose an ad hoc limit. This approach is also reasonable because according to [World Bank \(2017\)](#), many loans provided for self-construction are unsecured.

buildings get completed, heights go up. According to the third column, on average it takes 3.49 years from the date of investment in the foundation to complete a project. As was mentioned during the discussion of Figure 1, in the collected sample the construction duration for buildings that were started from 2009 and completed before 2018 is 2.4. The actual duration should be longer because many buildings are still under construction, thus when they are completed it will increase the average and reduce the gap between the model and the data. The fourth column shows the fraction of completed buildings after 9 periods. The model generated figure is 0.46, which is somewhat larger than in the data. In the next subsection I separately discuss the dynamics of the model under scenarios where all households either have or do not have access to finance to better understand the mechanics of the model.

Table 3: Summary of moments

	Mean floors after 9 years	Mean floors	Mean duration	Fraction completed after 9 years	Welfare
(1) No borrowing	2.06	2.35	4.78	0.21	1
(2) With borrowing	2.91	2.92	1.08	0.93	1.12
(3) No borrowing, negative rates	2.02	2.32	10.51	0.30	0.96
(4) Borrowing with high rates	2.02	2.03	1.57	0.79	1.06
(5) Weighted (1) and (2)	2.36	2.55	3.49	0.46	1.04
(6) Weighted (3) and (2)	2.33	2.52	7.22	0.52	1.02
(7) (4) with transfers	2.02	2.03	1.53	0.94	1.16
(8) (1) with cost subsidy	3.00	3	9.67	0.05	1.02
(9) Data	2.36		2.4	0.41	

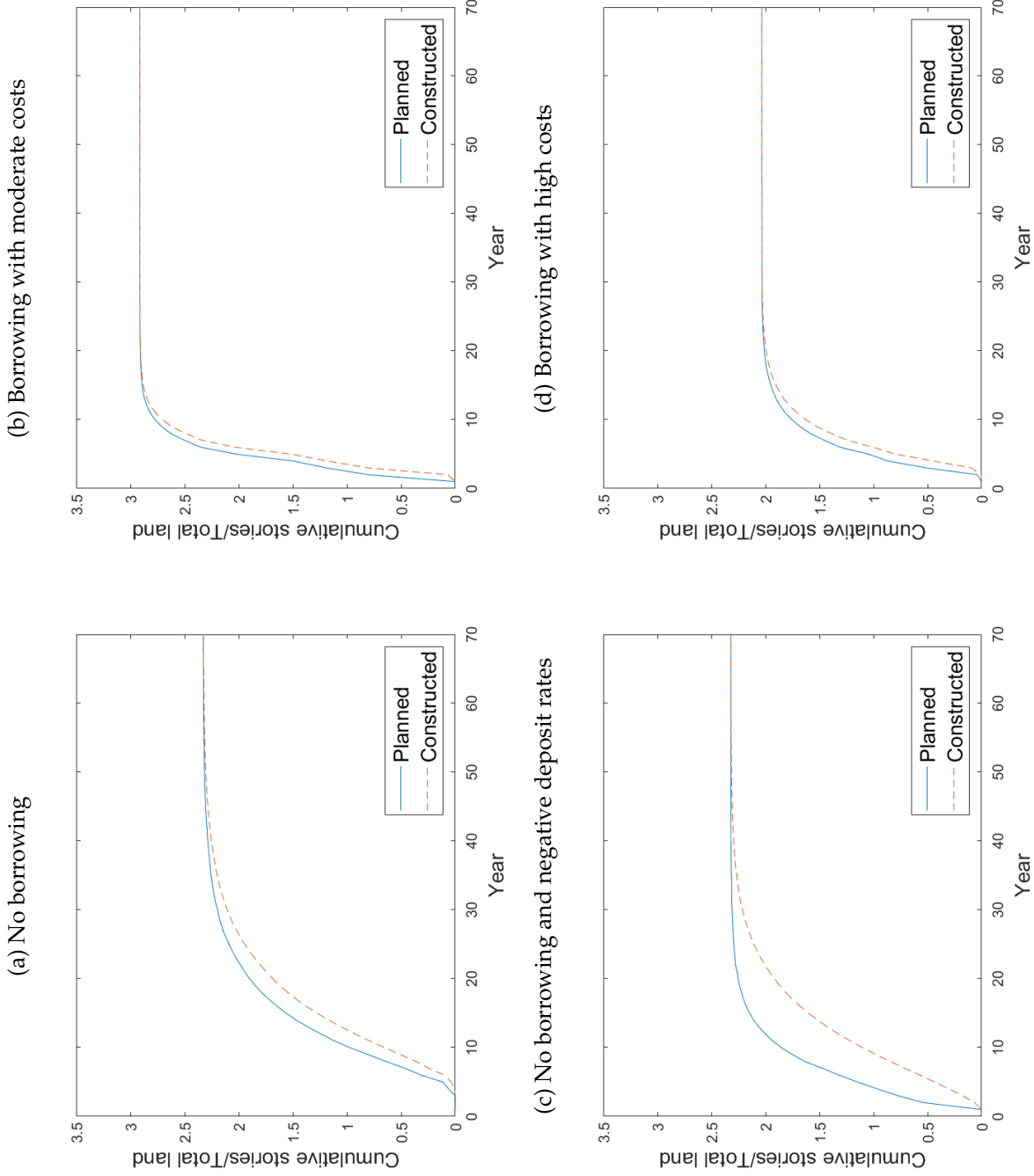
Notes: The table shows the average number of floors after 9 periods of simulations (column 1), the average number of floors in the long run equilibrium (column 2), the average construction duration (column 3), the fraction of completed houses after 9 periods (column 4) and welfare (column 5). Welfare is expressed relative to the specification without borrowing (row 1). More specifically, each reported welfare figure is calculated as  $\left[ \frac{\sum_y V_i^L(0,y)\Pi(y)}{\sum_y V_1^L(0,y)\Pi(y)} \right]^{\frac{1}{1-\sigma}}$ , where  $\Pi(y)$  is the invariant distribution of the Markov chain for  $y$ , and subscript  $i$  corresponds to the rows of this table. Row (1) is the economy without borrowing ( $\underline{a} = 0, i^d = 0\%$ ). Row (2) is the economy with borrowing ( $\underline{a} = -4.7, i^d = 0\%, i^l = 8\%$ ). Row (3) is the economy with negative deposit rates ( $\underline{a} = 0, i^d = -7\%$ ). Row (4) is the economy with high borrowing costs ( $\underline{a} = -4.7, i^d = 0\%, i^l = 12\%$ ). Row (5) is the weighted combination of row (1) (0.65) and row (2) (0.35). Row (6) is the weighted combination of row (3) and row (2) with the same weights. Row (7) is the economy in row (4) in which households receive a lump-sum transfer at the initial period equivalent to 1.05 of the average household's annual income. Row (8) is the economy in row (1) in which construction costs are subsidized by 10%. Row (9) presents the moments in the data.

## 4.2 Main quantitative experiment

Figure 2 displays the dynamics of the construction in the city under different scenarios. Panel (a) considers the case with no financial system. The first time series (solid line) is the ratio of cumulative planned stories to total land area available for development in the city, or equivalently the number of households ( $N$ ). Since I assume that all households start their lives in the city with zero assets, it takes several periods until households, who are experiencing positive income shocks, accumulate some assets to cover the costs of the investment in the foundation. After that there is a

raise in the stock of planned projects. As more households start their projects, the number of potential builders and newly planned buildings decrease, which is reflected in the declining slope of the solid line. The average household plans to build a house with about 2.35 stories (see the first row of Table 3). The dashed line shows the dynamics of the cumulative constructed stories over total land. This ratio is always lower than the one for planned houses because households first make decisions on the maximum number of stories and then start construction which can take several years. In the long run both measures converge. On average it takes 4.78 years from the date of investment in the foundation to complete a project (Table 3). After 9 periods of simulation only 21% of houses are completed.

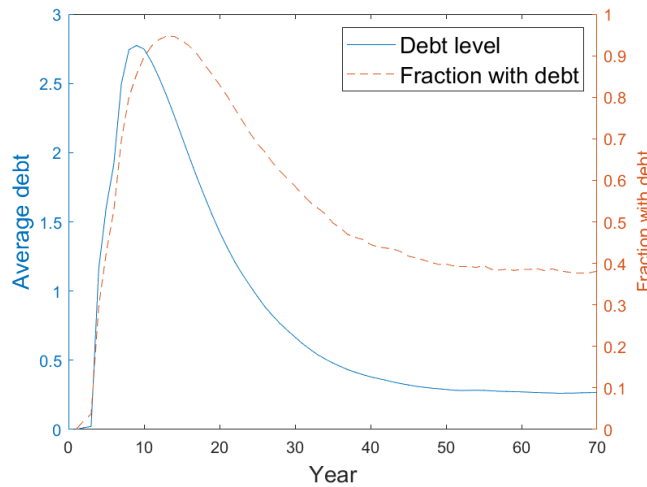
Figure 2: Counterfactuals



Notes : These figures plot the dynamics of (i) cumulative planned stories divided by total land area and (ii) cumulative constructed stories divided by land area. Panel (a) plots the dynamics of time series for the counterfactual with no borrowing ( $\bar{a} = 0, i^d = 0\%$ ). Panel (b) for the counterfactual with borrowing ( $\bar{a} = -4.7, i^d = 0\%, i^l = 8\%$ ). Panel (c) for the counterfactual with no borrowing and negative returns on savings ( $\bar{a} = 0, i^d = -7\%$ ). Panel (d) for the counterfactual with borrowing at high costs ( $\bar{a} = -4.7, i^d = 0\%, i^l = 12\%$ ).

Panel (b) presents the same time series for the case when all households have access to the financial system. We can notice that under this scenario all processes take place at a much faster pace. On average it takes just one year to complete a project and after 9 periods of simulations 93% of projects are completed. Another important difference is that the average building has 2.92 stories (see the second row of Table 3). Welfare comparison figures presented in the last column of Table 3 indicate a 12% improvement compared with the economy without borrowing. In my framework the concept of welfare takes into account only the welfare of households. Given the rental rate, migrants are marginally indifferent between staying in the rural area or migrating to the city, thus the migration does not affect their welfare. Figure 3 presents the evolution of the average debt and the fraction of households with debt. Around period 10 almost all households are debtors and the debt level reaches its maximum. At this stage all households borrow heavily to finance construction after which they rapidly pay down their debts. In later periods debt is only used to smooth temporary income shocks and both series decrease substantially.

Figure 3: Debt dynamics



Notes: This figure shows the evolution of average debt and the fraction of households with debt in the specification with low borrowing costs ( $\underline{a} = -4.7$ ,  $i^d = 0\%$ ,  $i^l = 8\%$ ).

These results indicate that access to the financial system can play an important role in the development of cities in Africa. It can substantially speed up the process of the expansion of the housing stock. At the same time it enables households to choose to build structures that have more stories. Thus, in the long run equilibrium there is more living space per area of land which implies higher density and less urban sprawl. This means that a more developed financial system can allow cities to expand and mitigate the negative consequences of congestion. In Section 4.5 I quantify this effect.

The slow construction process can also be a source of negative externalities. For example, Michaels et al. (2021) argue that there is a complementary between the quality of private buildings and public infrastructure. An unfinished building or a building under construction is one

form of low-quality building. Such buildings do not look nice and they are sources of dust and noise. These factors have negative externalities on neighbors. Even if all buildings are expected to be completed eventually, both in the data and in the simulations there are large numbers of unfinished buildings even after 9 years. In the model such buildings do not have negative effects on the neighborhood but if one assumes that buildings under construction create negative externalities, then households anticipating the slow evolution of the construction in the neighborhood can update their initial plans and build lower quality houses themselves.

### 4.3 Interest rates

Figure 2 presents the results for two additional counterfactual simulations. The counterfactual in Panel (c) and in the third row of Table 2 is a modification of the one in Panel (a) with the difference that savings deliver negative returns ( $\underline{a} = 0$  and  $i^d = -7$ ). In the context of low-income countries, in addition to low returns on safe accounts, there are a number of additional factors that prevent households from generating positive real returns on their savings, such as the lack of access to bank accounts, social pressure to help friends and relatives and theft (see, for instance, [Dupas and Robinson, 2013](#)).

One interesting result that emerges from this exercise is that the completion of the total housing stock proceeds faster, compared with the specification with no borrowing but with 0 interest rates (Panel a). In particular, after 9 periods 30% of the projects are completed. The corresponding figure was 21% in the model with 0 rates. The intuition behind this result is that in the case of negative rates households start the construction projects earlier because investments in the building serve as an alternative means for asset accumulation. Conditional on starting a project, on average it takes slightly more than 10 years to complete it, which is longer than in Panel (a). Compared with conventional non-contingent bonds, small investments in construction do not allow households to smooth consumption in response to temporary income shocks because it is not possible to destroy a fraction of a building and sell it. But when it comes to households' long term objective of completing the housing project, households find it optimal to make small investments in the project rather than accumulate liquid assets and make a large investment at a later period because such accumulated assets depreciate over time. Thus, with negative interest rates investments in unfinished buildings emerge as an alternative to conventional deposits. Meanwhile, in the scenario with zero rates, households prefer to accumulate liquid assets and make large investments because there is no risk of depreciation. In this case, households also enjoy the advantage of being able to smooth consumption in response to temporary income shocks. It should be highlighted that faster construction speeds in the third row of Table 3 do not imply that households are better off, in terms of welfare, because they are not able to smooth their consumption.

In calibrating the model I assumed that it is a convex combination of rows (1) and (2). Perhaps one can assume that it is a combination of rows (3) and (2). In the survey by [Gulyani et al. \(2017\)](#), in addition to the question about loans, there is also a question about bank accounts and only 57%

hold such accounts. For this reason, the sixth row of Table 3 presents the aggregate moments of an economy that is a convex combination of rows (3) and (2) which may more correctly capture the situation on the ground.

Panel (d) presents the results for an economy which is a modification of the financially developed one with the difference that the cost of borrowing is higher ( $\underline{a} = -4.7$ ,  $i^d = 0$ ,  $i^l = 12$ ). The dynamics of main time series evolve somewhat slower in the scenario with higher borrowing costs. More importantly, the number of average stories is affected and decreases to about 2, which is even lower than in the model without borrowing (Panel a). This is happening because the ability to borrow allows households to smooth their consumption in response to temporary negative income shocks. Meanwhile, in the economy without borrowing households have stronger incentives to build taller structures to generate income from alternative sources.

## 4.4 Government policies

I consider two government policies that aim to overcome the negative consequences of credit market frictions.

**Interest rate subsidies.** The first policy subsidizes the interest rates. As was discussed above the average building heights were much lower in the economy with 12% lending rate compared with the one with 8%. So, the government can subsidize the 4 percentage point difference. I assume that the subsidy is in place for 30 years. As is shown in Figure 3, by that time almost all construction debts are paid down. The flow cost schedule of this program is presented in Panel (a) of Figure D1. The present discounted cost of the policy is 105% of the average household's income. I use the model calibrated discount factor to calculate present discounted values ( $\beta = 0.96$ ).<sup>9</sup> Next, I consider an alternative scheme under which the government provides lump sum transfers of equivalent amount to households in period 0. The results of the simulations are presented in the seventh row of Table 3. Comparing these results with the ones in the fourth row, we see that there are almost no differences in terms of building height and mean duration. The fraction of buildings completed in 9 years increases because households hold more wealth and start their projects earlier. Logically, the welfare is higher because households receive a huge transfer. Overall, transfers are a very ineffective policy because they have very little effect on construction decisions of households.

**Construction cost subsidies.** Interest rate subsidies can work only if lending is a possible option but in the model and in reality some households do not have access to finance and banks may not be willing to lend even if they are subsidized. For this reason, I consider an alternative policy which is subsidizing the cost of construction by 10%. The flow cost schedule of this program is

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<sup>9</sup>The calculations are made under the assumption that households do not anticipate that the policy will be withdrawn.



presented in Panel (b) of Figure D1. The results of the simulations are displayed in the eighth row of Table 3. As can be seen, the average building height increases to 3, which is slightly higher than in the economy with borrowing at low costs. But this comes at the cost of much slower construction speed. The present discounted value of this policy is 30% of the average household's annual income. Overall, this policy seems to be very effective and less costly compared with interest rate subsidies. Moreover, interest rate subsidies assume that banks are willing and capable to lend, while construction subsidies can be implemented in an environment without a financial system.

There are a number of practical issues that should be taken into account. First, in the model construction cost captures both the costs of materials and labor. In the context of Kenya subsidizing labor does not seem to be practical because many construction projects involve family or informal labor which is hard to monitor. So, the governments should subsidize the costs of materials. Even in the case of construction material subsidies there is a risk that material may be resold or used for other purposes, which may substantially increase the cost for the government. Second, the policy is effective in increasing the heights of buildings but not the speed of construction. Third, the policy should stay in place for a sufficiently long period of time and it depends on the government's ability to make a credible commitment.

It is also worthwhile mentioning that markets for some construction inputs are distorted in Africa (Beirne and Kirchberger, 2021). In the model the construction cost parameter  $A$  captures these distortions. The elimination of distortions will decrease  $A$ , which will have the same effect as construction cost subsidies. Thus, eliminating distortions and increasing competition in input markets is another important dimension on which policymakers can focus.

## 4.5 Quantifying the cost of urban sprawl

Introducing location and commuting time into a heterogeneous agent model is computationally cumbersome because policy functions need to be computed for a large discretized grid of locations. Instead, I conduct a simple exercise to assess the deadweight loss from urban sprawl. In the model, I assumed that residents are located on a unit interval. As is standard in urban models, I assume that one of the endpoints is the city center where households work. Under the scenario with low interest rates, the average building has 2.93 stories. In order to accommodate the same number of residents under the scenario with higher interest rates (row (4) of Table 3) the city needs 1.44 times more land. Thus, I can calculate the cumulative time spent on commuting by residents under both scenarios. To do this, I need an estimate of elasticity of commuting time with respect to distance. Henderson et al. (2021) obtain an elasticity of 0.07 for Nairobi. For this value the amount of extra time spent on commuting is 2.6% higher in the city with more sprawl.<sup>10</sup> The infinite present discounted value of output lost on commuting is equivalent to 62% of the

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<sup>10</sup>I calculate commuting times with the following expression:  $\int_0^{\bar{l}} \bar{h} x^{\delta} dx$ , where  $\bar{l}$  is the length of the interval,  $\bar{h}$  is the number of stories in the average building and  $\delta$  is the distance elasticity.



average household's per period income. This is a large figure but lower than the cost of the interest rate subsidy (105%). For the second policy experiment, I need to compare the first and last rows of Table 3. In this case the present discounted value of saved time amounts to 42% of the average household's per period income which exceeds the 30% cost of the subsidy. In another study [Kreindler and Miyauchi \(2023\)](#) estimates the distance elasticity for Dhaka using cell phone data and obtain a value of 0.31. With this value the amount of extra time spent on commuting for the experiment with interest rates reaches 12% and the benefits from the implementation of such subsidies exceed their costs.

## 5 Conclusions

The main objective of this paper is to highlight the slow construction process of buildings in African cities and explore the role of financial development in explaining this phenomenon. To this end, I assemble a dataset from satellite images and document the slow construction process and the preponderance of unfinished buildings in Nairobi. Next, I introduce housing construction decisions into a model with heterogeneous agents, income risk and borrowing constraints to explain the stylized facts observed in the data. I use the calibrated model to conduct counterfactual simulations and quantify the role of different types of financial imperfections. The results show that the possibility of borrowing can substantially increase the speed of the construction process and allow the city to expand vertically. The model also shows that in the presence of negative returns on conventional deposits, households invest in unfinished buildings because such buildings allow them to preserve the value of their savings.

These results have important income and efficiency effects for developing countries. Many economists and development organizations see rural-urban migration as an important channel for closing income gaps between rich and poor countries. However, a vital element in the rural-urban migration process is the availability of housing and the structure of cities. This paper highlights the role of the financial system in shaping the structure of the city and the speed of provision of housing.

To the best of my knowledge this is the first attempt in the literature to document the slow construction process of houses in developing countries and to study the role of the financial development in explaining this phenomenon. Both the collected data and the model imply that the quantities involved are large and have important implications for the urbanization process and urban structure in developing countries. Given these results, there is substantial room for future work. By deploying machine learning algorithms it may be possible to expand the dataset and study the relationship between neighborhood characteristics and construction duration. Such data can be valuable both for academic purposes and for local authorities. I also studied a number of government policies that can lead to net efficiency gains. However, as discussed in Section 4.4 there could be a number of practical challenges in implementing these policies. Those issues

should be considered seriously in the context of local environments to increase the chances of successful implementation.

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# Online Appendix for Building the City Under Financial Frictions

## A Data construction

Figure A1: An unfinished building



Notes: An image of a building in Sunton neighborhood in Nairobi in February 2018. The image is from Google Maps' Street View option.

Figure A2: Geolocations of buildings



Notes: This map shows the geolocations of buildings in Sunton neighbourhood of Nairobi for which information was collected.



Figure A3: Determining the commencement dates

(a) March 2009



(b) October 2009



(c) January 2010



(d) December 2017



Notes :Images show the satellite view of the building in Figure A1 on different dates. Images are from Google Earth.

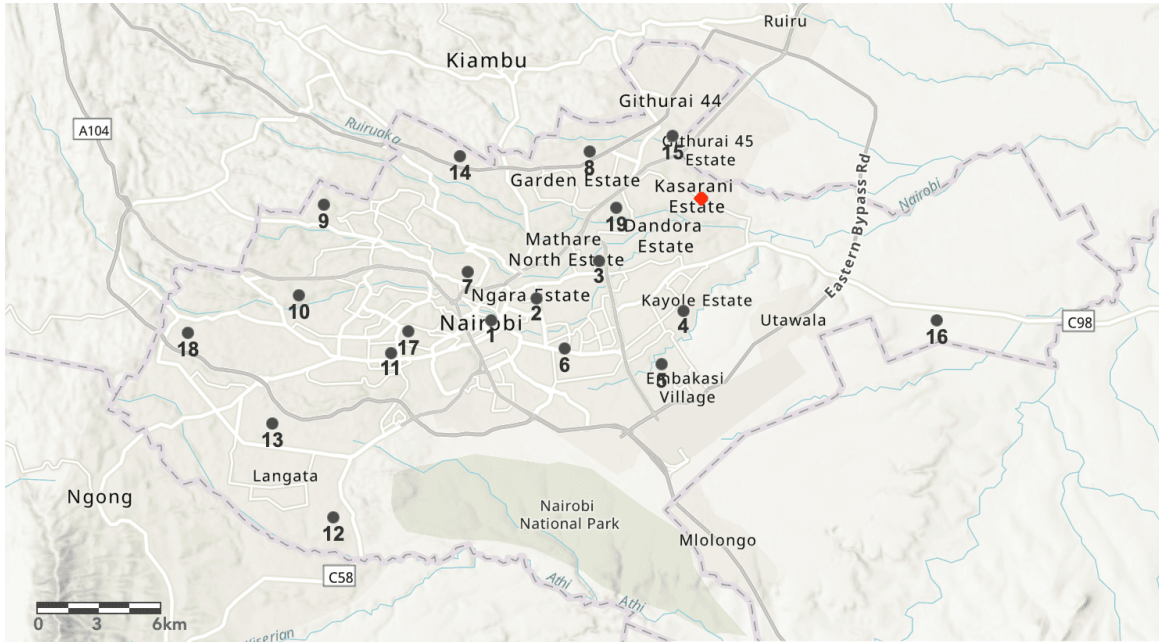
## B External validity

In this section I compare satellite images of the Sunton neighborhood with various parts of Nairobi to assess the relative representatives of this specific neighborhood. First, I created  $100 \times 150$  meter satellite image blocks of Sunton. I excluded the parts of the neighborhood without buildings. As can be seen from Figure A2 the East-central part of Sunton is relatively empty, which is due to rugged geography. Next I collected images of the same sizes in various parts of Nairobi. Figure B1 shows the geolocations of those points. I selected these locations to evenly cover various parts of Nairobi. Within each area I selected a point which has residential buildings. The objective of the exercise is to compare the similarity of residential buildings in various parts and avoid comparisons of residential buildings with parks, stadiums, airports and other objects.

Then, I used a Python library called *image-similarity-measures* to calculate indices of bilateral similarities between the collected images. Similarities were calculated using the Structural Similarity Index. The similarity index is a value between 0 and 1. When images are identical the index is equal to 1. The results of the exercise are presented in Table B1. The first row presents the bilateral similarities between all pairs of images within the Sunton neighborhood. There are 13 images which leads to 78 pairs. This information provides some reference point to assess the similarities of other neighborhoods with Sunton. In the remaining rows I compare each point from Figure B1 with each of the 13 images in Sunton and present descriptive statistics. Sunton is a rather homogeneous neighborhood with low standard deviation and the minimum value within this neighborhood is 0.777. As can be seen from the table, most points are rather similar to Sunton because their mean and even minimum values are above this level. Locations with mean values above 0.8, which is the mean for the within Sunton comparison, can be considered as highly similar. Substantial dissimilarities are observed in locations 9, 11, 12, 13, 16 and 18. This is not strange because in the western parts of Nairobi most neighborhoods are wealthy with large single-family houses with wide and fenced green areas around them. Although such neighborhoods occupy substantial space, they are unlikely to become a destination for rural-urban migrants who need affordable housing. In contrast to that, eastern areas are more densely populated and both within neighborhoods and around them there is space for further expansion. These areas are arguably more affordable. Given the high similarity index between Sunton and these areas, we can conclude that Sunton is more representative of the locations where future city expansion is likely to take place.



Figure B1: Geolocations of comparison points



Notes: This map shows the centroids of images used to calculate distance indices with Sunton. The location of Sunton is indicated by a red rhombus.

Table B1: Descriptive statistics for bilateral distances

	Obs	Mean	Std	Min	Max
Within Sunton	78	0.803	0.013	0.777	0.834
Location 1	13	0.788	0.006	0.778	0.800
Location 2	13	0.808	0.014	0.788	0.833
Location 3	13	0.796	0.008	0.779	0.808
Location 4	13	0.818	0.011	0.801	0.840
Location 5	13	0.801	0.012	0.779	0.820
Location 6	13	0.802	0.009	0.785	0.815
Location 7	13	0.787	0.008	0.771	0.805
Location 8	13	0.819	0.011	0.804	0.838
Location 9	13	0.711	0.010	0.696	0.723
Location 10	13	0.802	0.009	0.789	0.818
Location 11	13	0.736	0.009	0.718	0.750
Location 12	13	0.688	0.007	0.678	0.701
Location 13	13	0.625	0.008	0.618	0.641
Location 14	13	0.690	0.010	0.670	0.709
Location 15	13	0.812	0.010	0.794	0.832
Location 16	13	0.734	0.009	0.720	0.753
Location 17	13	0.763	0.007	0.755	0.777
Location 18	13	0.794	0.009	0.783	0.815
Location 19	13	0.812	0.009	0.799	0.834

*Notes: This table show the descriptive statistics for bilateral distances calculated using the Structural Similarity Index. The first row displays the results for all pairs of images within Sunton (13 images). The remaining rows display the results for each point (numbers correspond to locations shown in Figure B1) with all images in Sunton.*

## C Alternative explanations

**Technological and input constraints.** The cost of construction materials might be high in Africa (see [Beirne and Kirchberger, 2021](#)). These factors can affect the sizes of structures but they cannot lead to heterogeneous outcomes observed in my collected data, where I observe many buildings with five or six stories that were completed within a year. High material costs alone cannot explain the slow construction speeds. One needs to assume that basic materials, such as stone and cement, are rationed and only some households have quick access to them. Moreover, there should be very large gaps between market and rationed prices so that remaining households prefer to incur the opportunity cost and wait for several years. Technologies are also unlikely to be the driving factor because slow construction is observed in the case of very basic structures, the construction of which requires only materials and manual labor.

**Taxes.** Property taxes also can create incentives to leave buildings unfinished. According to ([Keen and Slemrod, 2021](#)), in Greece, there is a 60 % tax reduction for unfinished buildings. In Kenya there are three types of property related taxes: land rent; the stamp duty (on transactions); and the capital gains tax ([Franzsen and McCluskey, 2017](#)). Among those, the most relevant is the land rent/tax. It is calculated based on the value of land rather than on the value of the building or its condition. Thus, the tax evasion motive cannot be the reason behind the preponderance of unfinished buildings.<sup>11</sup> In some other African countries the tax base includes improvements on land and depending on the exact valuation procedure that can create incentives to leave buildings unfinished. However, even under such taxation regimes, there are cases, such as Siera Leone, Uganda and Liberia, where property listings are not complete or have been updated more than two decades ago ([Franzsen and McCluskey, 2017](#)). According to the authors in Kenya land valuation rolls date back to the early 1980s.

**Property rights.** Informality and land rights are also important factors affecting households' planning and construction decisions. As was highlighted, in Sunton the share of corrugated iron sheet buildings is very small (3%) and this area does not appear on the maps of informal neighborhoods discussed in [Henderson et al. \(2021\)](#). The lack of land rights and high risk of demolition can lead households to build temporary structures from cheap materials in order to minimize expected losses. Meanwhile, in Figure A1 we observe a building, in which substantial amounts of resources have already been invested and the demolition or expropriation of this building will imply large losses for the owner. There is no reason to expect that the completion of this building will increase the likelihood of demolition/expropriation. At the same time, if the owner finalizes the unfinished story, which will require a modest investment, relative to the amount already invested, then he/she can expand the living space. It is critical to stress that the building in Figure

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<sup>11</sup>[Kelly \(2004\)](#) reports that, although the Rating Act (1972) allows local authorities to tax either land or land and improvements, all property Rates in Kenya are levied only on land.

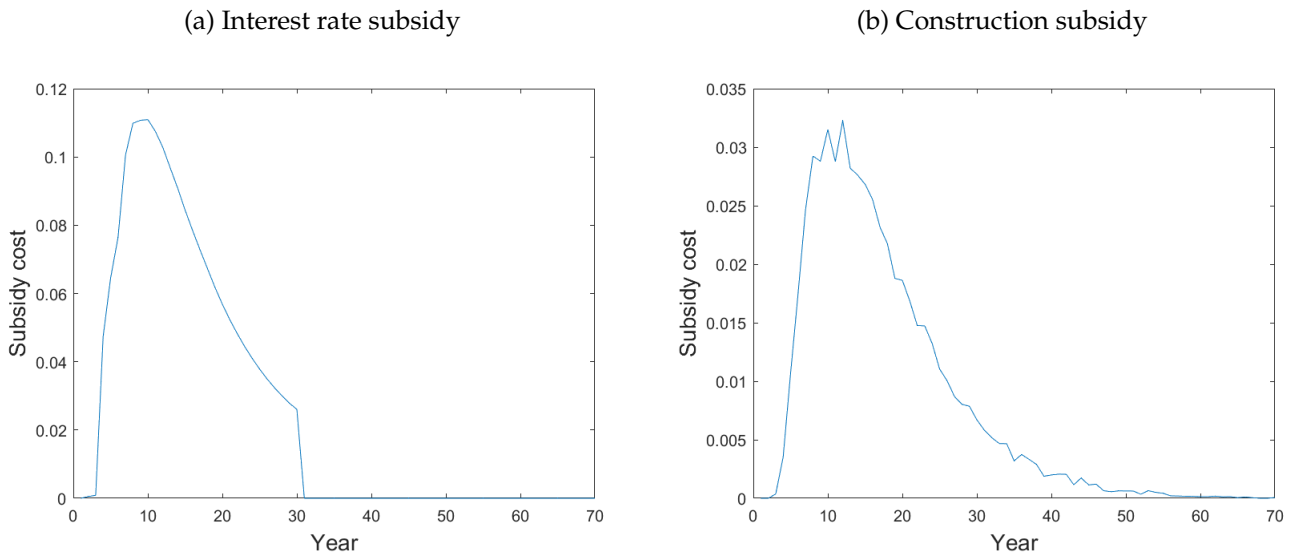
A1 is not an exception in terms of its size. In my collected sample, the average unfinished building has 2.39 stories which is slightly higher than the average for finished buildings (2.36).

The fact that most unfinished buildings already have substantial investments in them, allows me to rule out the possibility that they are structures erected by squatters, with the hope of claiming property rights in the future. These types of settlers face high risk of demolition/expropriation and they are likely to make minimal investments. Moreover, squatters are more likely to have low income levels and are likely to plan to build smaller buildings. The fact that the average unfinished building has fewer stories than the finished one runs against this line of thinking.

Both street and satellite images provide further evidence that authorities have control over the neighborhood. Almost all land plots are equally-sized and located next to each other, streets run parallel to each other and have 90 degree intersections (see Figure A2). These are strong signs that the neighborhood was designed by the authorities and they controlled the process of plot sales/allocation. The neighborhood also has powerlines along all its streets without unregulated and intersecting web of connections (Figure A1). From this perspective it is also important to highlight again that the analysis focuses on a very small area (see Figure A2) and large differences in construction speeds can be observed for buildings located immediately next to each other.

## D Additional figures

Figure D1: Subsidy costs



Notes : These figures plot the cost schedules for subsidy policies described in Section 4.4.