WHY FORMAL HOUSING ALTERNATIVES IN DEVELOPING COUNTRIES ARE INSUFFICIENT, INADEQUATE, AND UNAFFORDABLE: A MODEL OF THE PROCESS OF PRODUCTION OF THE BUILT ENVIRONMENT IN BOGOTA, COLOMBIA

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ABSTRACT

In this paper, I present a model of the articulations between the formal and informal mechanisms of housing production with the objective to analyze the causes of the rise and persistence of informal settlements in the developing world. The model is based on System Dynamics, a method of simulation that deals with complex systems characterized by dynamic behavior, and is tested using the case of Bogotá, Colombia, a city known by the prevalence of informal housing markets and its rich experience in the implementation of public policies to address informality. The final results and policy experiments show that informality arises from the inadequacy of a system of infrastructure financing based on tariffs and cross-subsidization and from the unintended consequences of classic interventions to deal with this problem such as settlement up-grading and the provision of public housing. A preventive policy based on dismantling these interventions and increasing the supply of land with urban services through a change in the system of infrastructure funding shifting the source of financing from cross-subsidies to property taxation is proven to be a more cost-effective method to mitigate the negative consequences of informality.

1. INTRODUCTION

Cities in the developing world lack most of the features of a formal planned urbanization: property titles, public services, and planning permissions. It has been estimated that 64 percent of the housing stock and 85 percent of the growth rate in the housing stock in the Third World is informal (Berner, 2001). In Latin America, for instance, between 25 percent and 60 percent of the population of the main cities was housed in this kind of development by the 1990s (Gilbert, 1998).

In this paper, I study the causes of this massive non-compliance with planning regulations by analyzing why formal mechanisms of housing production and land allocation have been unable to absorb the growing demand in developing countries. To this end, I study the articulation between the formal and informal mechanisms of housing production arguing that the key determinants causing the rise and persistence of informal settlements are the inadequacy of the system of infrastructure financing based on tariffs and cross-subsidization and the same public interventions that have been deployed to solve the problems related to informality.

The analysis is based on a System Dynamics simulation model of the process of housing production in Bogotá, Colombia. System Dynamics offers two advantages for modeling the formal-informal articulation. First, it allows a comprehensive approach because it deals with complex systems characterized by dynamic rather than static behavior, multiple interactions between internal and external elements, nonlinear relations, feedback, history dependence, adaptive agents, and trade-offs. Second, it allows the simultaneous analysis of quantitative and qualitative variables in contexts of little availability of 'hard' data. Moreover, the method has a long tradition of analyzing urban phenomena from the first Urban Dynamics Model proposed by

founder of the field (Forrester, 1969), to its subsequent adaptations and extensions (Schroeder, Sweeney and Alfeld, 1975; Mass, 1974; Chen, 1972) and to its more recent applications to the analysis of housing and urban public policies (Eskinasi, Rouwette and Vennix, 2009).

Bogotá, Colombia was chosen as a case study because of its historic prevalence of informal real estate markets and its rich experience in the implementation of different interventions to deal with informality. In addition, Bogotá is an interesting case study of informality, because rather than by invasion and squatting, its informal settlements are the product of 'pirate subdivisions'. This type of informal settlements are illegal parcelings of peripheral land sold by the legal owners without planning permission and without basic infrastructure to poor people who build their own houses through the process of self-construction (Doebele, 1977). Currently, this pattern is becoming more common throughout the developing world.

This paper is structured as follows. First, I summarize the model presenting its basic structure highlighting its theoretical and empirical basis and how its main elements are related with Bogotá's historical urban development. I also analyze the main feedback structures identifying their implications. Then, I present the main results of the simulation describing how the different elements of the structure interact to produce the dynamic generated by the model. Next, I report on the results and theoretical consequences of the eight core validation tests of system dynamics models as defined by Forrester and Senge (1980). Four of these tests evaluate model structure (structure and parameter verification, dimensional consistency, and extreme conditions), three tests evaluate model behavior (replication of the reference mode, behavior sensitivity, and behavior anomaly), and the remaining test evaluates both structure and behavior (boundary adequacy). Finally, I provide some conclusions regarding the dynamics of

informality and propose a policy to mitigate the problem showing its cost-effectiveness using the model. In addition, at the end of the dissertation I include an appendix in which I present the complete model structure and describe in a comprehensive way the equations, parameters, and historical data used to operationalize it.

2. THE MODEL

The model consists of three components: Housing Demand and Formal Supply; Urban Services Provision and Informal Housing; and Public Policies and Interventions. It covers 100 years from 1938 to 2038. This time framework was chosen for four reasons: first, given the durability of housing its dynamics are better understood over a long term. Second, as I will show subsequently, prior to 1938 informal housing was marginal in Bogotá. Third, using 1938 as initial year is convenient for initializing the model because a comprehensive census took place in Colombia during this year. Fourth, 2038 provides a symbolic milestone for testing the results of policies and interventions for improving the housing conditions in Bogotá because the city will celebrate its 500th year.

Housing demand and formal supply

This component describes the requirements of housing. Because the objective of the model is to capture the long term dynamics of the housing system, the demand is determined according to population forces rather than by short term market variations. As shown in Figure 1, the demand is categorized in three groups according to housing quality and household income: High-quality Housing (HH), Medium-quality Housing (MH), and Low-quality Housing (LH).

These categories correspond to the stratification levels used by Bogotá's Planning Department (SDP), which, since 1983, has divided the housing stock according to the quality of the housing and its surroundings in 6 strata: strata 1, 2 and 3 considered low-quality and substandard housing; stratum 4 considered middle-quality and standard housing; and strata 5 and 6 considered high-income or premium housing (SDP, 2005). Before 1983, each public utility company used its own criteria to classify the housing stocks and determine the levels of cross-subsidization of public services, a central concept for the model that will be introduced with more detail in the next section. The stratification is commonly used as a proxy for housing demand and household income (LONJA, 2005; Jaramillo, 2004; Molina, 2001).

As explained in detail in the appendix, the proportion of demanders per category (represented in the Figure 1 as the variables '% Demand for HH, MH, and LH') was estimated through the evolution of population per stratum in Bogotá. The incidence of low-quality housing is high: an estimated of 87.5 percent of the population in 1938 and a predicted of 89.6 percent in 2038. High-quality housing demanders, in contrast, are a minority going accounting for an estimated of 5 percent to 4.7 percent in the same time period. The main reason for this imbalance is the high degree of inequality in Colombia, a country that presents one of the worst distributions of income in the world. The Gini Coefficient in the seven largest urban areas in Colombia, for instance, was 0.48 in 1964, 0.52 in 1974, 0.48 in 1984 and 0.50 in 1994. In 2004 the Gini in Bogotá was 0.55 (DNP, 2009; Ocampo, 1994). In contrast, the average Gini in cities in the developed world is 0.35 (Mohan, 1994).

The demand for housing in each category is affected positively by population and negatively by household size. Since population has increased considerably in the city going from 335,512 in 1938 to 6,840,116 in 2005, housing need has increased

accordingly: more people means more demand. This tendency has been reinforced by the decrease in household sizes: less people per household means that more accommodations are needed. In effect, in 1964 the average household size was 6.2 persons, by 2005 it has decreased to 3.4 (DANE, 2009; Mohan, 1994).

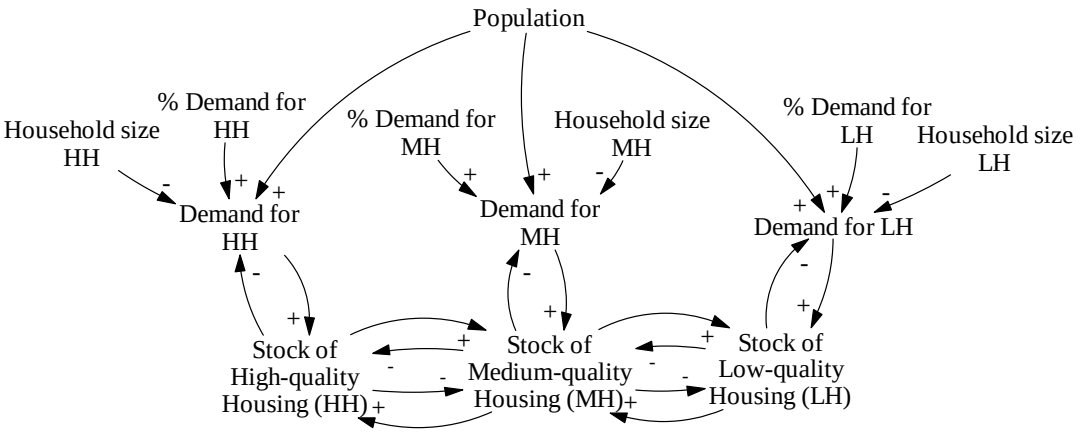

Figure 1 Housing Demand and Formal Supply

In the long term the housing stocks are determined by the demand and, as will be explained in the next section, by the capacity of the system to absorb that demand through the production of new housing. The demand and the housing stocks in each category interact through a balancing loop in which more housing demand incentivizes more stock and more stocks decrease the demand for housing by absorbing more households looking for accommodation.

The housing stocks in each category also interact through two sets of balancing loops: filtering and gentrification. Filtering down is the general process by which aged housing is downgraded from a higher to a lower quality level caused when new units displace old ones or when owners fail to invest enough in maintenance to keep the

units at the higher quality level. Gentrification is the particular process by which some housing units are upgraded from a lower to a higher quality level usually caused by a change in location preferences or by a shortage in supply at the higher level. Since filtering and gentrification work in opposite directions, the first increases the stocks in the lower categories and the second increases the stocks in the higher categories, the outcome of this trade-off will depend on specific local factors. As discussed in the appendix, in Bogotá's case both filtering and gentrification are marginal because the tendency is to demolish old high quality units and replace them with new high quality units preventing the consolidation of filtering and making gentrification unnecessary.

Urban services provision and informal housing

The stocks of housing in the long run are not only determined by the demand but also by the capacity of system to generate enough units to absorb the requirements generated by the population dynamics. This capacity is determined by resource constraints. The key limitation to housing production in the developing world is the scarcity of land with urban services. One of the reasons why housing has been called 'the impertinent commodity' is its dependence on urban services such as water, sewerage, electricity, and telecommunications. Since these services require considerable investments and are subject to economies of scale, individual actors are generally unable to reproduce by themselves the necessary conditions for housing production requiring the intervention of centralized collective providers to supply land with these infrastructures (Jaramillo, 1995; Topalov, 1984). The Formal Housing Supply and Informal Housing component describes the process of production of urban services in Bogotá, highlighting the incentives that create scarcity of improved land in the city.

Utility companies in Bogotá have been designed as commercially-oriented and self-sustainable agencies that combine the notion that services should be financed exclusively by their users and the idea that tariffs should be defined according to income in a redistributive fashion (Jaramillo, 1995). This combination has been achieved by means of a system of cross-subsidization in which high-income households pay tariffs that are higher than the average long term cost of service provision to contribute to cover the deficit produced by low-income users who pay tariffs that are considerably lower than the average long term cost.

The structure of the Formal Housing Supply represented in Figure 2 shows how the supply of urban services for low-quality housing depends positively on the number of high-quality housing units: more high-quality housing means more cross-subsidies, more services for low-quality housing, and more units in this category. It is important to note that the supply of urban services for low-quality housing is not directly related with the supply of medium-quality housing, this is because tariffs for this last group have been designed to be equal to the average long term cost of provision which means that this category does not subsidize, and is not subsidized by, other categories.

Figure 2 also shows two additional sources of services for low-quality housing: cross subsidies from other uses and transfers from the general budget. The first is an important source since commercial and industrial uses pay tariffs that are even higher than the ones paid by high-income households. Moreover, their consumption is also higher and can increase at higher rates; in this model it was assumed that the consumption of these uses grew at the same pace of the GDP in the country (which has been 4.31 in average in the last 50 years [GRECO, 2002]). The second source has been less important since the intent of the cross-subsidization system was to limit financial transfers from the general budget and generate self-sufficient agencies.

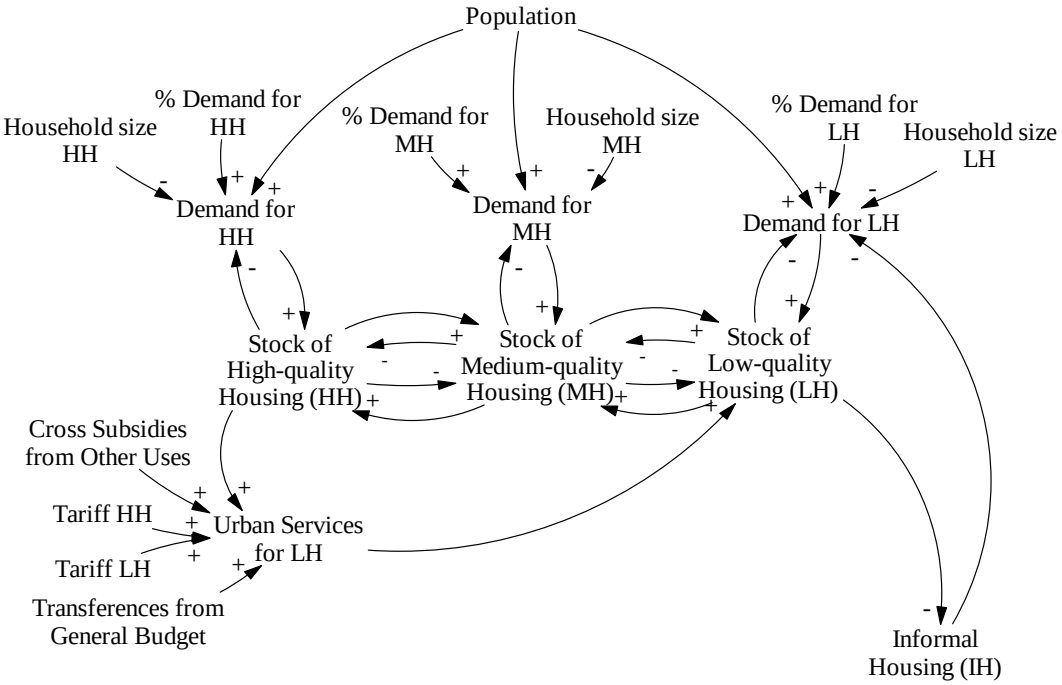

Figure 2 Housing Demand, Formal Supply, Urban Services Provision, and Informal Housing

As can be expected, higher tariffs for services in the high-quality category will increase the supply of services for low-quality housing through more cross-subsidization. Also, higher tariffs for the lower category will also mean more supply of services because the subsidy needed per unit is lower and, therefore, the contributions from high-income households will cover more low-quality units. During most of the 20th century the redistributive character of cross-subsidies in Bogotá increased as tariffs for the higher categories grew and tariffs for the lower categories decreased (Gilbert, 2007; Coing, 2005; Mohan, 1994). However, as explained in more detail in the appendix, the pace of growth of the tariffs in the higher category was slower than the pace of the decrease in the lower category. Therefore, the provision of urban services for low-quality housing decreased gradually as the increase in the contributions from the high-quality stock was consumed by higher subsidies per low-quality unit.

In 1994, a new law governing the system of cross-subsidies was enacted. The main objective of Law 142 of 1994 was to improve the efficiency of the provision of urban services in Colombia through privatization and higher competition. To that end, contributions and subsidies were drastically limited by decreasing high-quality housing tariffs and increasing low-quality housing tariffs to levels close to the average long term cost of provision. According to the law, the decrease in contributions from high-quality housing should be gradually covered by the general budget of the municipality through transfers to the utility companies. The problem is that the increase in budgetary transfers has not been sufficient even though some monies have been especially earmarked to this end (Gilbert, 2007). The results of this change have been considered highly regressive since the percentage of income spent on services in low-income households has increased substantially (Coing, 2005). Moreover, the decrease in tariffs for high-quality housing has been almost three times faster than the increase in tariffs for low-quality housing. This means that the supply of services for the lower category is decreasing more rapidly than before.

A key implication of the system of cross-subsidization that has characterized the production of urban services in Bogotá is that utility companies have been incentivized to provide infrastructure without delay for high- and medium-quality developments since, in strictly commercial logic, these consumers will not generate a deficit. Services for low-quality developments, in the other hand, are only provided when the availability of cross subsidies guarantees that the provision for this category is not going to generate deficits. This incentive, added to the fact that the contributions from the high-quality category have been insufficient to cover the demand and have decreased through time, has produced a deficit of urban services that has limited the supply of formal low-quality housing.

Since the growth of the stock of formal low-quality housing has not been able to keep up the pace with the growing demand for units in this category, many low-income households have been pushed to informal housing: self-built accommodations constructed in land with no infrastructure or planning permission.

This component represents the articulation of the stock of formal low-quality housing, the stock of informal housing, and the demand for housing in the lower category through a reinforcing loop: if the formal stock decreases (below what it would otherwise have been) the informal stock increases since more people are pushed to informality. As the informal stock increases the demand for housing decreases since some households find an alternative accommodation, this in turn, decreases the pressure of the demand for more formal units.

Public policies and interventions

Although informal housing has eased the deficit of low-quality units, the results have created many negative outcomes such as substandard housing, sprawl, overcrowding, and marginalization. For these reasons, different public policies have been designed and implemented to decrease the incidence of informality and its effects. Figure 3 complements the model structure by including the most important interventions: Up-grading, Demolition and Relocation, Public Housing, and the policy of Minimum Requirements. In the remaining of this section, I will describe in general terms each one of these policies paying particular attention to their costs as they compare to the average long term cost of providing services for a formal unit.

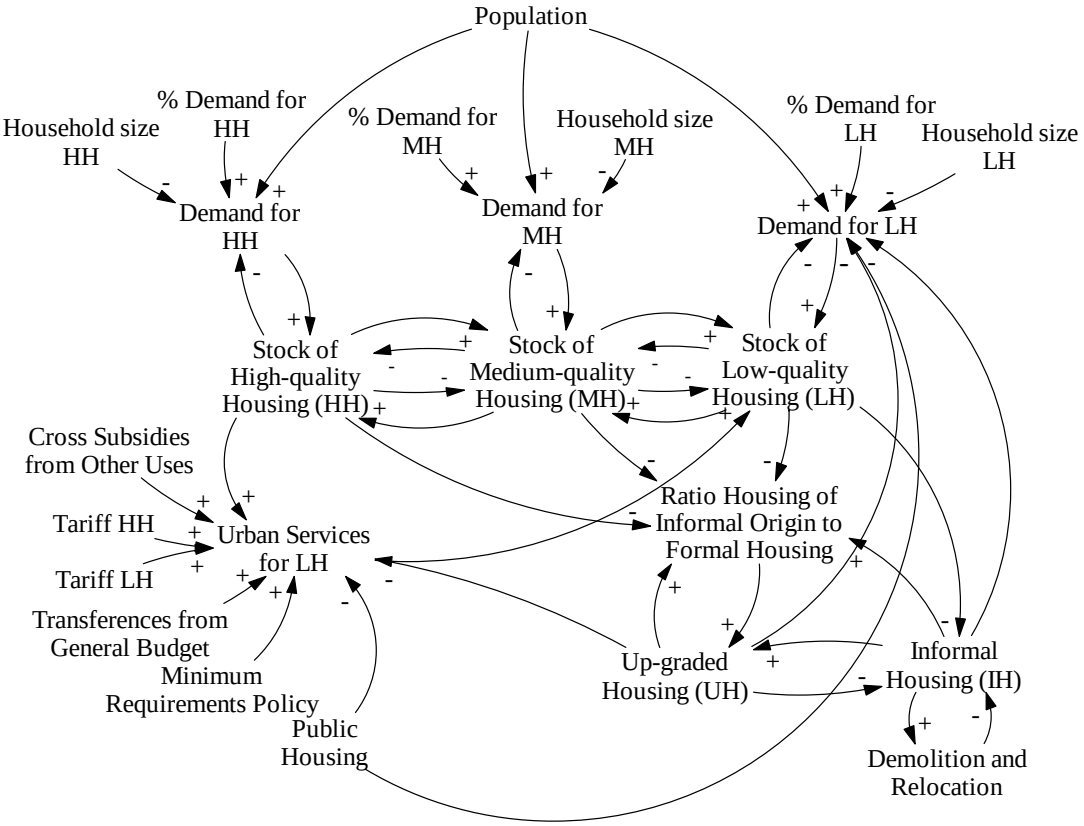

Figure 3 Housing Demand, Formal Supply, Urban Services Provision, Informal Housing, and Public Policies and Interventions

Up-grading is the provision of services and infrastructure to informal settlements. As figure 3 shows up-grading is represented in the model through the stock of up-graded housing (UH). Since this stock originates from informal housing, it creates a balancing loop where more informal housing creates more up-grading replacing informal units with up-graded units, all other things being equal.

However, up-grading is considerably more expensive than a planned urbanization because it replaces the traditional pattern of site planning - service provision - housing construction - occupation, with the pattern of occupation - housing construction - service provision - site planning (Baróss, 1990).

Because the infrastructure is provided when houses have been already built the cost of up-grading a unit can represent as much as three times the cost of the trunk service provision for a formal unit (Cities Alliance, 2006; Aristizabal and Gomez, 2002; Roda, 2000). For this reason, up-grading creates an important reinforcing loop for informal housing by decreasing the provision of urban services below what it would otherwise have been. This, in turn, decreases the stock of formal low-quality units, increases informal housing, and increases the need for more up-grading.

Although allocating scarce resources to the process of up-grading is more expensive for the municipality, it is, nonetheless, pushed onto the agenda by politicians, informal settlers, and other actors that profit from the system of informality. This social pressure for up-grading is captured in the model by the effect of the ratio of informal housing to total housing. The intuition is that as the proportion of informal housing increases, the pressure to up-grade becomes stronger.

Up-graded housing is also related positively to this effect since it can be expected that as more housing is up-graded, the remaining informal units will push harder for the same treatment. This creates another important loop reinforcing up-grading. It is important to highlight, however, that public utilities in Bogotá have always protected their commercial orientation from political interference requiring politicians and residents to pay partially for the extra-cost through transfers from the general budget and higher tariffs (Gilbert and Ward, 1985, 1982).

Demolition and relocation is an outflow for the stock of informal housing produced by an alternative intervention practiced when it is not possible to up-grade the units. With this policy the municipality gives a payment to the informal settlers recognizing the improvements achieved through the process of self-construction. In some cases the

municipality also offers technical assistance, a subsidy, and access to credit in order to facilitate the process of finding an alternative accommodation in the formal market.

As explained in the appendix, the incidence of this policy is not significant since it is usually only applied with units that are located in zones of high hazard risk. Another important characteristic of this policy is that it is more expensive than up-grading representing up to 5.5 times the cost of providing services through the formal process (Roda, 2000). However, it is important to note that this intervention does not affect the provision of services for low-quality housing since it is funded entirely from the public budget and is operated by the same municipality and not by the utility agencies.

The provision of public housing is a preventative policy intended to provide a formal alternative for low-income households to discourage informal development. More than 150,000 public units have been produced in the city in the last century, with particular intensity in the decades of the 1960s, 1970s, and 1980s when almost 130,000 units were built. In addition, almost 50,000 units have been constructed by the public sector for middle- and high-income strata in particular public employees and members of the army (*Secretaría del Habitat and Universidad Piloto de Colombia*, 2008; ICT, 1997; Saldarriaga, 1996).

In contrast to public housing programs in the developed world, public units in Bogotá have been produced for sale and not for rent. This characteristic has important implications in terms of the demand and in terms of the costs of the policy. Regarding the demand public housing units have always been appropriated by the higher tier of the low-income demand and have not reached the poorest of poor (Mohan, 1994; Gilbert and Ward, 1982). As for the costs, the housing authorities have been able to recover some part of the costs through the sale price. However, the costs related to the

trunk services provision, the secondary (domestic) services provision, the housing subsidy, and written-off debts (which were considerable during the period of maximum production) have not recovered in the majority of the cases (ICT, 1997).

For this reason, the costs of providing a public unit could represent more than 6 times the cost of trunk services provision for a formal unit (Roda, 2000). For utilities the cost is 2.33 times the cost of providing formal housing since it only includes both the trunk and domestic provision. The extra-cost (the difference between 6 and 2.33) is usually covered by the budget of the housing authorities. Since public housing diverts resources, decreasing the supply of services for low-quality formal units below what it would otherwise have been, it affects negatively the availability of services and, therefore, decreases the provision of formal housing as shown in Figure 3. But at the same time by providing an alternative for some low-income households it decreases the demand helping to ease the pressure for new low-quality stock.

The policy of minimum requirements was an attempt to increase the formal housing supply by way of relaxing planning standards. The basic idea was to provide lots with a very basic infrastructure to low-income households so they could replicate the pattern of self-construction within a formal and legal framework. The policy was first implemented as a pilot test in public projects financed by the Alliance for Progress in the 1960s and then in large scale for the total production of formal housing in 1972 when a law regulating the minimum requirements was enacted (Saldarriaga, 1996).

At the beginning, the policy provided modest results because the procedures for granting permission to ‘minimum requirement developments’ were very time consuming and complicated (Mohan, 1994). After additional regulations were enacted in 1979 to promote and facilitate implementation, a considerable portion of the

demand was absorbed through this mechanism (Molina, 1990). However, the results of the minimum requirements policy began to be criticized based on concerns that it was replicating the pattern of substandard housing producing urban environments characterized by extremely high densities and lack of public spaces (Ceballos, 2005). In 1990 the policy started to be watered down and disappeared completely in the new urban plan of 1997.

As shown in figure 3 the minimum requirement policy increased the supply of services for low-quality housing because it decreased the average long term cost of provision by allowing the progressive development of infrastructure with lower technical specifications. The actual decrease in the cost of provision is difficult to calculate since the requirements changed over the years but it can be estimated that at its peak the policy could have decreased the average long term cost by as much as 30 percent (see appendix 1).

3. THE RESULTS

To run the model until the year 2038 it is assumed that all the trends evidenced for the last year with available data (2005 for most variables related to population and 2010 for variables related to policies) maintain the same behavior in the future. In this way, population, which is modeled as an exogenous variable, continues increasing at the present rate reaching more than 11 million for the last year of simulation. Figure 4 presents the evolution of the population estimated by the model (Base Run) comparing it with the actual data from census sources (Reference Mode).

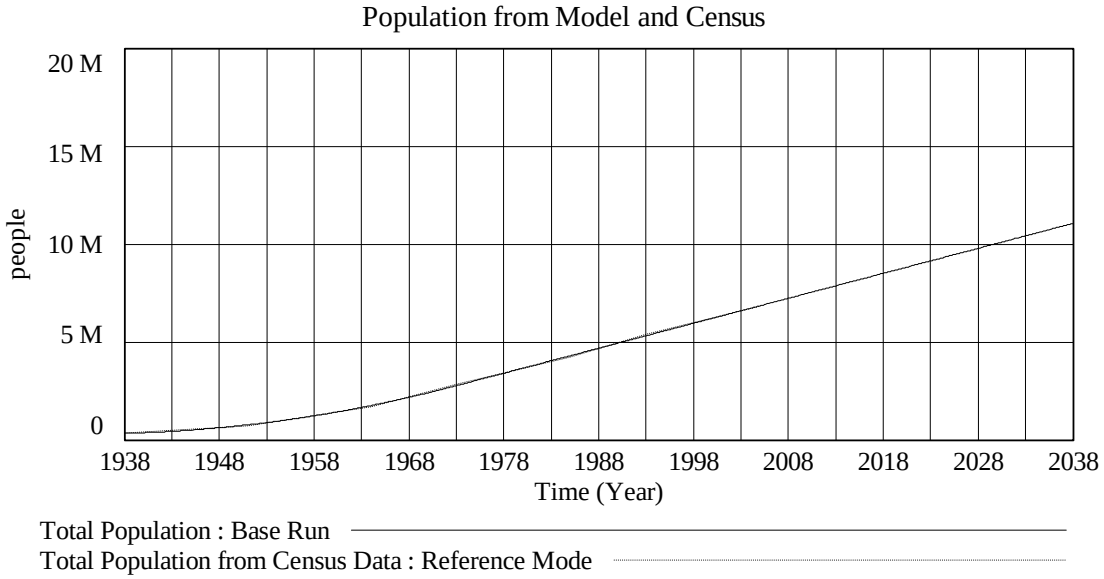

Figure 4 Simulated Behavior of Population in Bogotá from 1938 to 2038 from Model and Census Data

The increase in the population produces an increase in every category of the demand including the demand for high-quality housing (HH). Since this category has no restriction in terms of availability of services, the supply increases according to the demand. This increment in high-quality housing is important because, all other things being equal, it will result in more public services for low-quality housing (LH). The degree to which this happens will depend on the relative behavior of the tariffs and in other public policies.

Figure 5 shows the services support function, a representation of the number of low-quality units that can be serviced per high-quality unit. This number decreases at the beginning of the study period as the redistributive character of tariffs increases (and the subsidy for each unit in the lower category increases), since fewer units will be supported by the contributions from high-quality units. However, after 1958 it starts to increase because of the extra-support provided by commercial and industrial uses and grows considerably during the 1970s and 1980s due to the decrease in servicing costs

produced by the policy of minimum requirements. During the 1990s the support is affected negatively by the dismantling of this policy and the changes introduced by Law 142 of 1994. After 2010, the year in which is assumed that the tariffs will achieve their targets according to the mentioned law, the support increases again pushed by the increase in consumption of commercial and industrial uses. The services support function is calculated exogenously from data about tariffs and the cost of provision as explained in the appendix.

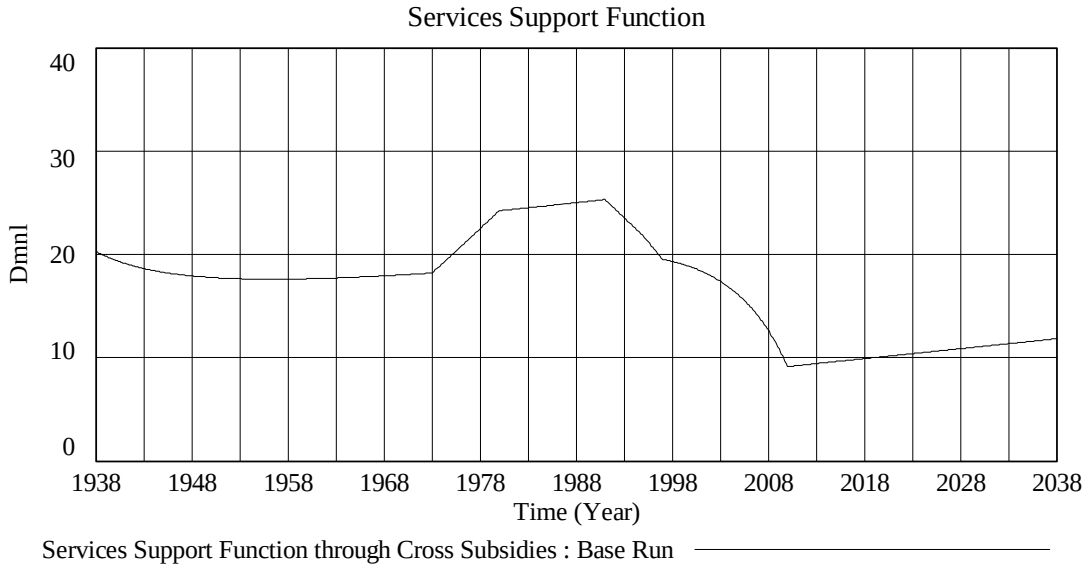

Figure 5 Simulated Behavior of the Services Support Function: a representation of the number of low-quality units that can be serviced per high-quality unit**.**

The total number of new low-quality units that can be potentially serviced per year also depends on the transfers from the general budget to the utility companies. As described in the previous section, Law 142 in 1994 increased these funds to compensate for the decrease in the contributions from high-quality housing. In the later years, the percentage of transfers in the budget of the main utilities has reached 50 percent compared to less than 5 percent before the implementation of the law.

Figure 6 shows the total number of low-quality units that could be provided with services through funds from cross subsidies and from the general budget. The sum of these numbers, however, is not equal to the effective production of low-quality housing because this support is affected negatively by the production of public housing and the pace of up-grading as these policies drain resources from the utility companies. For this reason the actual feasible production of low-quality housing is lower.

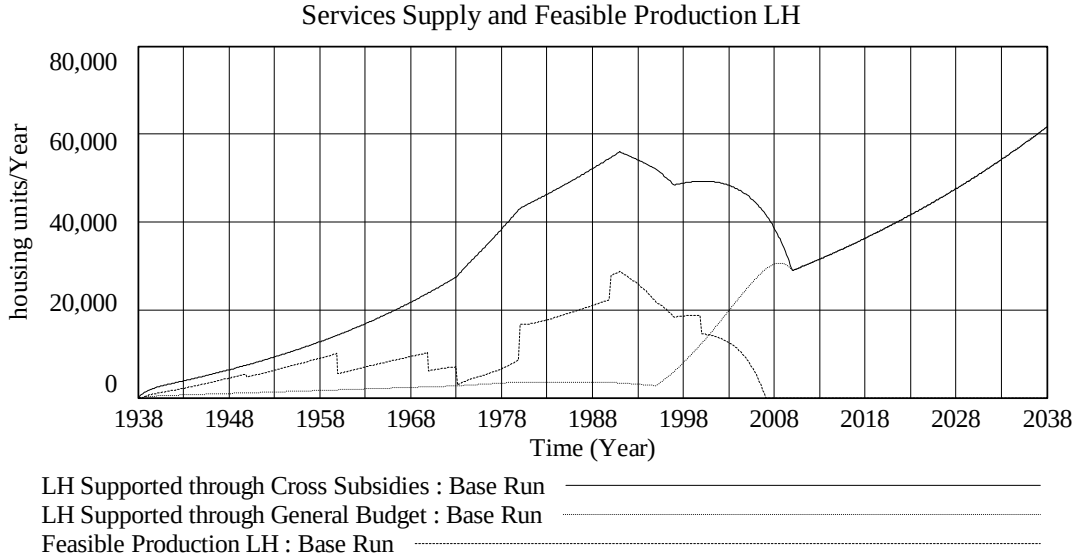

Figure 6 Simulated Behavior of Services Supply and Feasible Production of Low-quality Housing

Because public housing and up-grading are more expensive than the provision of a low-quality unit, these policies crowd-out an increasing number of formal housing resulting in a reinforcing effect in which more informal units are produced, more units are up-graded, fewer services are available for low-quality formal production, and more households are pushed to informality. Figure 7 shows the behavior of public housing production (an exogenous variable in the model), informalization (an endogenous variable), and up-grading (an endogenous variable). Public housing

production has an uneven pattern because it was estimated by dividing the actual number of public units built per decade into the number of years (no annual information was available). This causes the broken pattern of the feasible production variable in figure 6. It is also important to note that the growth of informality decreased during the 1980s due to the minimum requirements policy as some authors have suggested (Molina, 1990). However, the decrease in the services support function, caused by the elimination of this policy and the changes of Law 142 of 1994, produced a considerable increase in the rate of informalization during the 1990s, which resulted in more pressure for up-grading and more crowding-out of services for low-quality formal units. That explains why the feasible production in this category reaches zero around the year 2008 as was shown in figure 6.

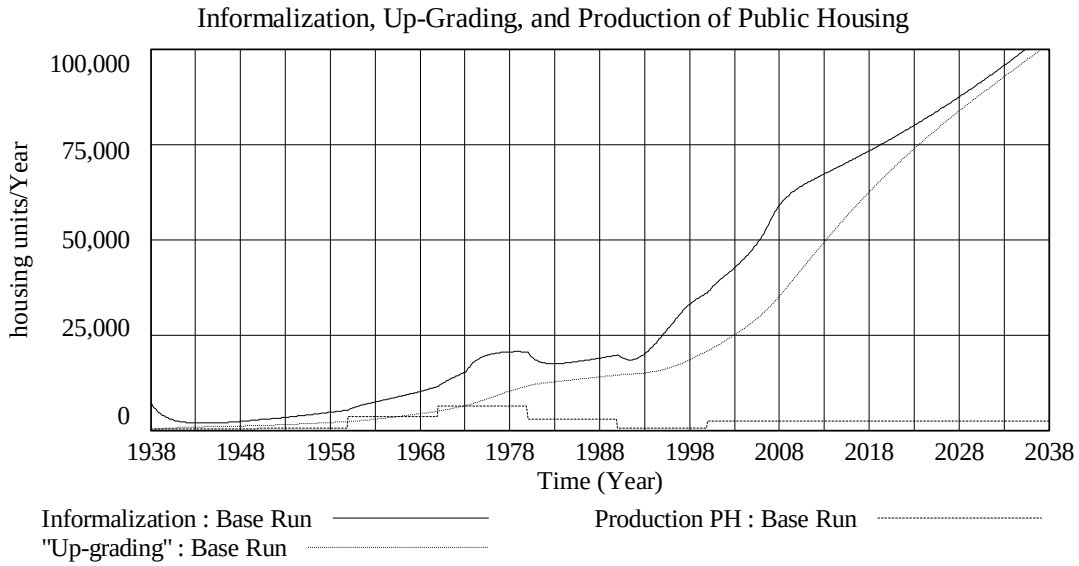

Figure 7 Simulated Rates of Informalization, Up-Grading, and Production of Public Housing

The growth of informalization and up-grading results in a rapid increase in the stock of housing of informal origin (defined as the sum of the stocks of informal housing [IH] and up-graded housing [UH]). This trend intensifies in the 1990s to the point that

around the year 2003 these stocks overcome the housing stock of formal origin (the sum of high-quality [HH], medium-quality [MH], low-quality [LH], and public housing [PH]) as the main housing source in the city. Figure 8 represents this trend showing that before 2003 the stock of housing of formal origin was bigger than the stock of housing of informal origin and that this difference increased in the 1980s as a result of the decrease in informality produced by the minimum requirements policy. However after the 1990s due to the elimination of this intervention, the changes introduced by Law 142 of 1994, and the increase in up-grading, the situation is reversed with the stock of formal origin hitting a plateau and staying around 1 million units for the rest of the simulation. The stock of informal origin, in contrast, grows exponentially reaching more than 3 million units in the year 2038.

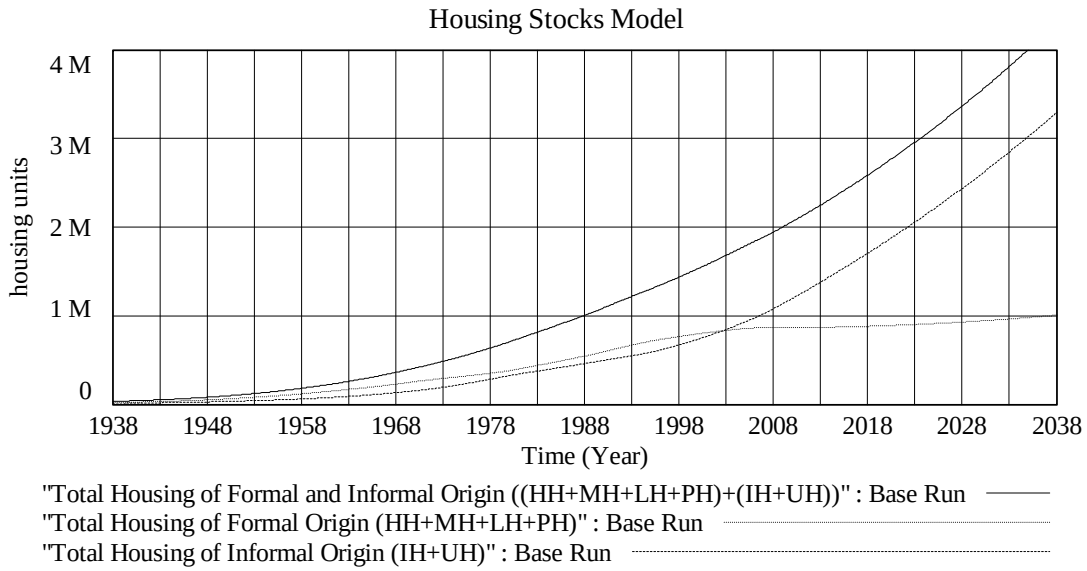

Figure 8 Simulated Behavior of Formal and Informal Housing Stocks

The increase in informality eases the pressure of the demand for low-quality housing. As figure 8 shows the number of households in this category of the demand increases throughout the period of simulation reaching more than 4 million in 2038 due to the

increase in population, the decrease in household size, and the change in the proportion of population demanding this type of accommodation. However, most of this latent demand is absorbed by informal housing reducing the actual demand for formal low-quality housing to around half million.

Figure 9 Simulated Behavior of Low-Quality Housing Demand and Desired Stock

Nonetheless, as figure 10 shows this form of absorbing the increasing housing need is very expensive. In this diagram, the costs of provision of low-quality housing for the public sector (through public budget and cross subsidies) and for low-income households (through tariffs) are represented as the sum of the costs generated by the formal stock, the up-graded stock, and the public housing stock in terms of the number of long term average costs (LTAC) of providing a formal low-quality unit that could have been covered according to the relative costs explained in the last section. These costs increase exponentially, both for the public sector and for low-income households, and their sum, defined as the accumulated total social cost, reaches more than 10 million in 2038. This means that the pattern of absorbing the deficit through

up-grading and public housing is clearly inefficient, since the resources that are allocated to these ends surpass the resources that would have been needed for absorbing the demand through the provision of services for formal housing. In effect, in the long term the 10 million of average costs that the current policies totaled in 2038 would have been more than enough to absorb a demand of 4 million. This inefficiency will be studied with more detail in the next sections.

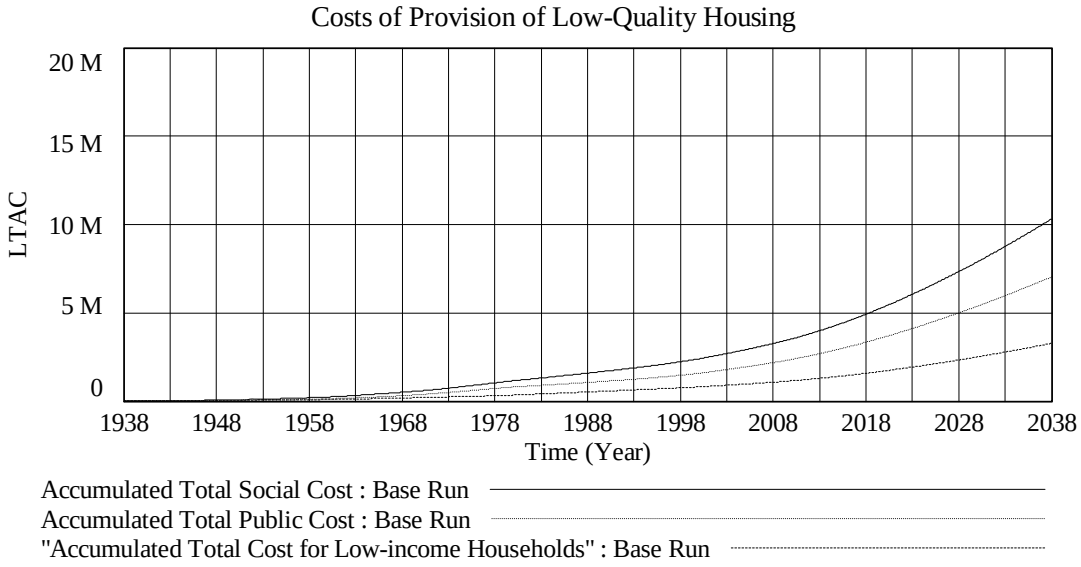

Figure 10 Simulated Behavior of Costs of Provision of Low-Quality Housing

4. MODEL EVALUATION

Structure and parameter verification, and dimensional consistency

The structure verification test involves comparing the model with the quantitative and qualitative knowledge of the real-world system. The parameter verification test requires that model constants correspond conceptually and numerically to real-world empirical observations (Forrester and Senge, 1980). Hence, these tests require that the

model assumptions do not contradict the accepted understanding of the problem in theoretical and empirical terms. The model described in this paper can be considered robust in both accounts since it was built taking into account all the relevant literature (see the appendix) and its structure represent real-life and tangible variables commonly used in housing analysis. Moreover, as described in the appendix, most parameter values were estimated using available historical data and when this was not possible they were defined using qualitative information supported by the literature and they were tested for sensitivity.

The dimensional consistency test involves evaluating if the units of the variables maintain the coherence throughout the mathematical operations defined in the model's equations (Forrester and Senge, 1980). The model passes this test since no 'scaling' parameters (constants with no real-life meaning) are included in the structure. Moreover, the built-in software tool verifies that units are consistent.

Extreme conditions

This test evaluates the implications for the overall behavior of the model when variables and parameters are changed for improbable maximum and minimum values (Forrester and Senge, 1980; Sterman, 2000). The model is also robust to this test because the simulation of unrealistic conditions produced consistent responses in the dynamics of the system.

Figure 11, for instance, shows how the stock of housing of informal origin responds to some extreme conditions. When the services support function for low-quality housing from high-quality units, commercial and industrial uses, and the general budget is set to zero, informality increases, compared to the Base Run, since this and public housing would be the only ways to absorb the demand. When public housing or up-

grading are set to zero, informality decreases since the provision of services in these policies is more expensive than in the case of formal low-quality units. When the percentage of high-quality demanders is set to 20 percent (up from an initial condition averaging 5 percent) and the percentage of low-quality demanders is set to 40 percent (down from an initial condition averaging 87 percent) informality decreases since there is more supply of services for low-quality housing and less demand. When the population is set to zero, the stock of informal origin is zero for the entire simulation since there is not demand for housing in the system.

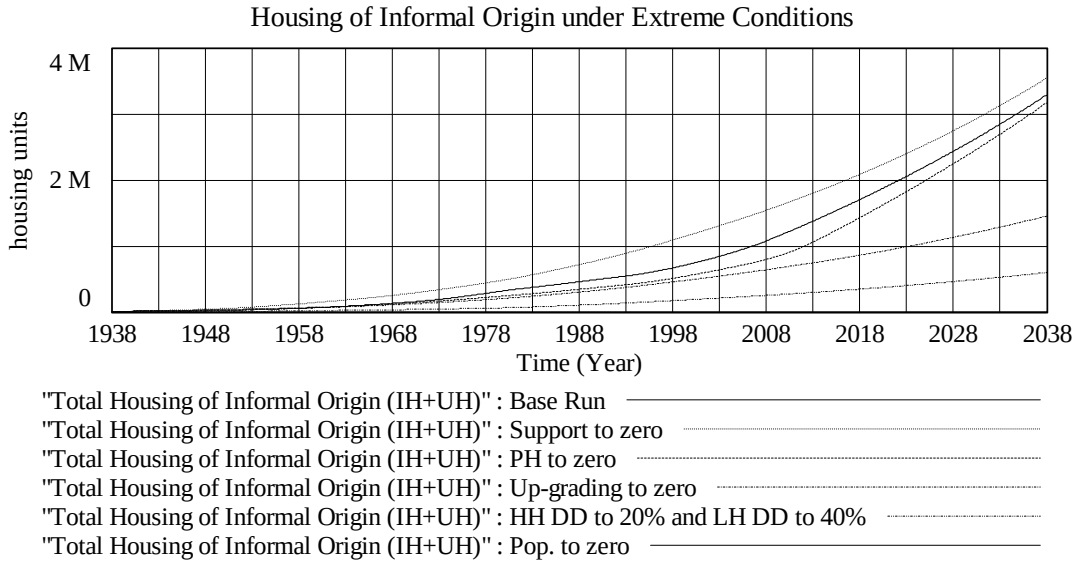

Figure 11 Simulation of Extreme Conditions Tests

It is important to note that these tests can work as counterfactual analyses. They show, for instance, that although public housing and up-grading are interventions that clearly aggravate the problem, their elimination does not eliminate informality completely, so, from a policy perspective, their dismantling would have to be complemented with other interventions. Also, the fact that informality is very responsive to the percentage of households per category of the demand shows that a more equitable distribution of

income could have prevented the rise and persistence of informal settlements in the city since more units will generate contributions and less will demand subsidies.

Replication of the reference mode

This test, also known as behavior-reproduction test, entails the comparison of the results of the model with the observed behavior of the real system (Eskinasi, Rouwette and Vennix, 2009; Forrester and Senge, 1980). In this case the main outcome variables, the housing stocks, were compared with real data and estimations produced by other authors. Figure 12 shows the total housing stock generated by the model (Base Run) compared to census data (Reference Mode). In general terms, the model replicates the overall behavior although it overestimates housing units and misses the timing of an apparent inflexion point after 1993. The implications of these omissions will be considered at the end of this section.

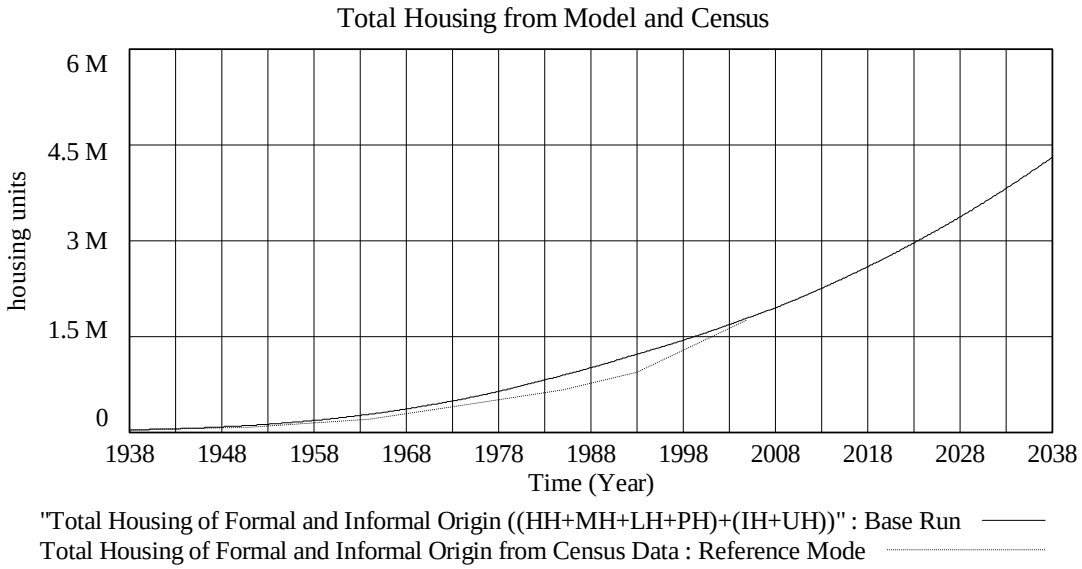

Figure 12 Behavioral Reproduction Test: Simulated Total Housing from Model and Census Data

The censuses do not distinguish between formal and informal housing. For that reason a method proposed by Jaramillo (1980) is used to disaggregate the housing stock per category. This method estimates the number of informal units by subtracting the planning permissions granted in intercensal periods from the total stock in each census. Figure 13 presents the comparison of the housing stock of informal origin generated by the model (Base Run) with the estimations produced using census data and Jaramillo's method (Reference Mode). As was the case with the total stock the model overestimates the stock, in particular during the 1980s. However, the model reproduces the general behavior although an inflexion in the reference mode after the 1990s is captured by the model with a delay.

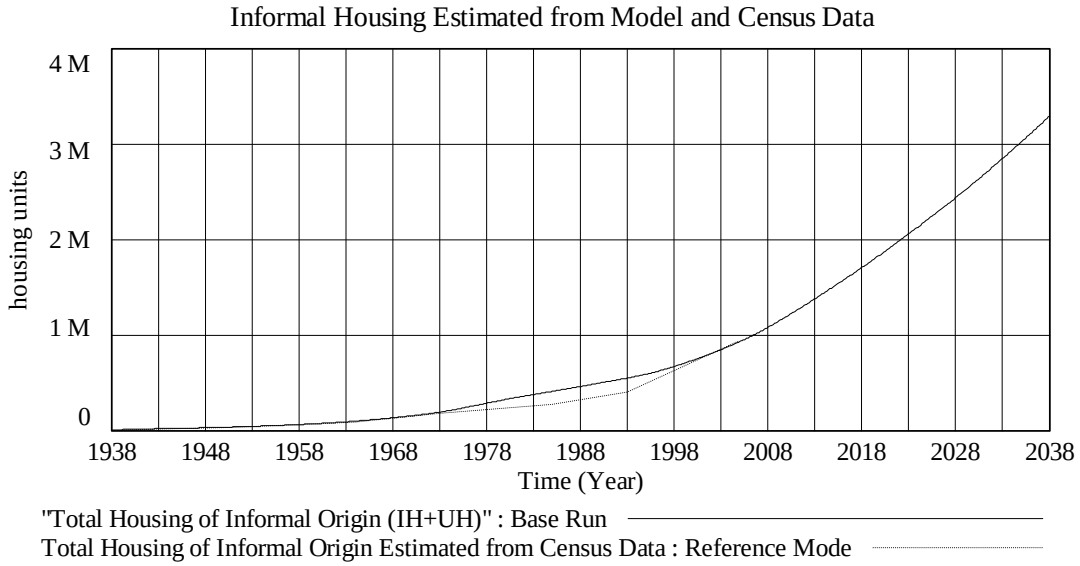

Figure 13 Simulated Informal Housing from Model and Census

Figure 14 compares the stock of formal housing generated by the model (Base Run) with the estimations produced by census and Jaramillo's method (Reference Mode). Once again the model overestimates the formal stock and presents an inflexion during the 2000s that is not captured by the observed data.

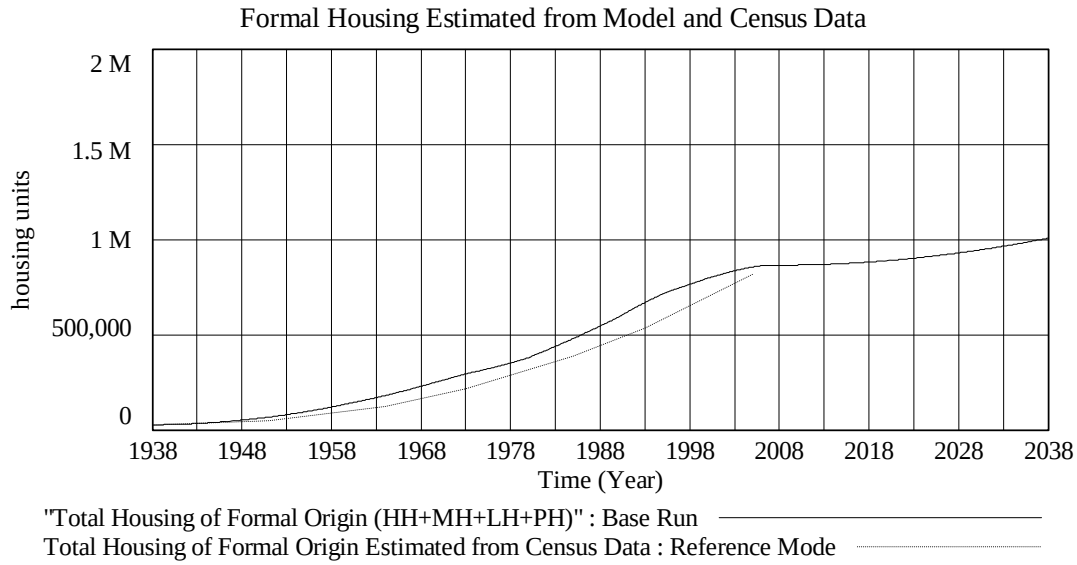

Figure 14 Simulated Formal Housing from Model and Census

The differences between the behavior generated by the model and the reference mode could indicate that the structure should be expanded to include more variables of the demand and supply of housing. For example, the overestimation of the total housing stock can be the result of the absence of macroeconomic variables that affect the housing market such as economic growth, interest rates, or inflation. An overestimated housing demand resulting from these omissions could be the reason for the overestimation of the stock of informal origin during the 1980s and the overestimation of the stock of formal origin during the entire comparison period.

However, this can also be related to the absence of variables in the model representing other policies implemented by the national and municipal governments. For instance, a policy of promotion of the commercial building sector, based on financial incentives and mortgage reform, implemented during the period from 1982 to 1986 could be the reason for the decrease in informality in the reference mode during the 1980s.

Likewise, the fact that the reference mode is not showing symptoms of the inflexion in the growth of the formal stock, as simulated in the model during the 2000s, could be related to an extraordinary increase in public investment in infrastructure that was possible thanks to the privatization and decapitalization of public companies. Indeed, some authors have already warned that the expansion of public services achieved in Bogotá in the last years will not be sustainable in the near future (Gilbert, 2006).

Nonetheless, the model can be considered adequate since it complies with the particular behavior-reproduction tests suggested by Forrester and Senge (1980): symptom-generation, frequency-generation and relative-phasing, multiple-mode, and behavior characteristic. First, the model generates endogenously 'the symptom': informal housing. Second, it captures periodicities of fluctuations between variables. Third, it is able to generate more than one mode of behavior when conditions are changed, and the new behaviors are consistent with the logic of the model. Fourth, it shows observed patterns, and this, rather than showing the exact time of the event, is what should be expected in system dynamics models (Forrester and Senge, 1980).

In particular, the model generates endogenously the important characteristics of the dynamics of the reference mode. First, it simulates that the stock of informal origin overcomes the formal stock during the intercensal period of 1993 and 2005 to become the main source of housing in the city. Second, it estimates consistently the relative weights of formal and the informal housing as percentage of the total stock and this can be a better measure of the appropriateness of a system dynamics model than a point-by-point prediction of the absolute values (Forrester and Senge, 1980). Third, the model accurately estimates endogenously a consistent decrease in the average time for up-grading (the period of time between the initial stages of informal settlement and up-grading) a pattern that has been reported in the relevant literature (*Secretaría del*

Habitat and Universidad Piloto de Colombia, 2008). Table 1 shows the behavior of the main variables for the reference mode and the model according to census years.

Table 1 Relevant Variables According to Model and Reference Mode

Year	Variable	Reference Mode		Base Run	
		Value	%	Value	%
1938	Population	335,512		335,512	
	Total Housing from Census Data	30,045	100	30,045	100
	Formal Housing Stock Estimated	27,375	91.11	27,375	91.11
	Informal Housing Stock Estimated	2,670	8.89	2,670	8.89
1951	Population	722,100		767,681	
	Total Housing from Census Data	75,559	100	103,846	100
	Formal Housing Stock Estimated	47,195	62.46	67,042	64.56
	Informal Housing Stock Estimated	28,364	37.54	36,804	35.44
1964	Population	1,692,844		1,757,550	
	Total Housing from Census Data	207,055	100	278,167	100
	Formal Housing Stock Estimated	121,802	58.83	180,202	64.78
	Informal Housing Stock Estimated	85,253	41.17	97,965	35.22
1973	Population	2,861,913		2,769,540	
	Total Housing from Census Data	396,856	100	486,974	100
	Formal Housing Stock Estimated	214,614	54.08	294,521	60.48
	Informal Housing Stock Estimated	182,242	45.92	192,453	39.52
1985	Population	4,225,649		4,299,540	
	Total Housing from Census Data	664,135	100	888,873	100
	Formal Housing Stock Estimated	388,750	58.53	479,984	54.00
	Informal Housing Stock Estimated	275,385	41.47	408,889	46.00
1993	Population	5,386,134		5,319,540	
	Total Housing from Census Data	941,286	100	1,217,646	100
	Formal Housing Stock Estimated	534,384	56.77	669,549	54.99
	Informal Housing Stock Estimated	406,902	43.23	548,097	45.01
2005	Population	6,840,116		6,849,540	
	Total Housing from Census Data	1,758,344	100	1,785,339	100
	Formal Housing Stock Estimated	816,382	46.43	855,332	47.91
	Informal Housing Stock Estimated	941,962	53.57	930,007	52.09

Behavior sensitivity*, *behavior anomaly, and boundary adequacy

The behavior sensitivity test evaluates if changes in uncertain parameters cause a failure of the model to replicate the reference mode (Forrester and Senge, 1980). As

stated in the description of the parameter verification test, most of the constants in this model are supported by historical data (see the appendix). However, it was not possible to find reliable data on the rates of filtering, gentrification, and demolition for each housing stock. These values were defined according to qualitative information found in the relevant literature and tested for behavior sensitivity using the built-in optimization and sensitivity tools in the software.

The results of this test show that the behavior of informality is sensitive to this set of parameters and that it is possible to find a combination that reduces substantially the stock of informal housing, all other things being equal. However, the system does that by minimizing the outflows and maximizing the inflows to the stock of low-quality housing to levels that are not plausible in the real world. Moreover, finding a sensitive parameter does not invalidate a model since, in general, "both real systems and models of real systems shown behavior sensitive to a few parameters" (Forrester and Senge, 1980: 223).

The behavior anomaly test examines if the behavior of all the variables in the model, including secondary and auxiliary variables, present incongruencies (Forrester and Senge, 1980). This test is important because it could be possible to replicate the reference mode of the main variables with a model that generates abnormal behavior in the rest of the structure. This is not the case in this model because all the variables correspond to real-life concepts and their behavior present rational dynamics in terms of the information available and the assumptions included.

The boundary adequacy test evaluates if expanding the structure of the model by endogenizing variables alters its behavior (Forrester and Senge, 1980). This test is an iterative process in which the modeler constantly challenges the limits of the model by

adding the necessary structure to include variables and concepts that were previously considered exogenous, or that were not considered at all (Sterman, 2000). In this model the structure was expanded from initial versions to include the internal dynamics of the informal stock, the tariff structure, the policy sector, and the calculation of the costs.

However, there are still some exogenous variables that could be endogenized to enhance the understanding of the system. For instance, the reference mode replication test suggested that it could be useful to complement the structure of housing demand and supply with variables related to the short-term dynamics of the market. Likewise, in the current model public housing is determined exogenously when in reality it should correspond to some perception of public officials about the housing deficit. It is important to note, nonetheless, that none of these expansions would alter the policy conclusions and recommendations produced by the model, a key requirement of the boundary adequacy test as defined by Forrester and Senge (1980).

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

The analyses in previous sections suggest several determinants of informal settlements: a growing demand for low-quality housing, a system of provision of public services based on cross-subsidization that cannot keep up with the pace of the demand because of the imbalance of contributions and subsidies, and public policies that aggravate the problem by consuming more scarce resources and crowding-out potential formal units.

Solving the problems associated with informal urbanizations requires addressing these causes directly. In terms of the growing demand for low-quality housing produced by

the rapid pace of urbanization there is not much that can be done in the short term. Although the growth rate of the population in Bogotá has been decreasing in the last decades, the city still receives a considerable number of migrants from rural areas and minor cities.

This phenomenon is more acute in Bogotá than in other Latin American cities not only because of a strong natural growth rate but also because of the armed conflict that has afflicted Colombia during the last 40 years. For instance, during the first semester of 2010 the city received 18 displaced families per day and between 1997 and 2009 the total population arriving to Bogotá in these conditions was 274,376 (El Tiempo, 2010). This population by itself is enough to be considered a large city in the United States.

Moreover, policies to mitigate rural-to-urban migration in Latin America have not been effective as the experience of promotion of growth poles in the 1950s and the 1960s showed. And even in the case that these interventions could actually work their results might not be desirable because they could affect economies of agglomeration and the overall productivity of the economy.

The system of provision of urban services based on cross-subsidization, on the other hand, could be improved through policies to increase contributions and decrease individual subsidies, so more low-quality units could benefit, but these interventions produce unintended consequences. For instance, increasing tariffs for high-quality housing incentivizes utility companies to prioritize the provision of services for this category of the demand and supply low-quality housing only residually. Increasing tariffs for low-quality housing is regressive and could generate an unaffordable burden for low-income households.

A better income distribution that increases the number of households contributing to the system and decreases the number of households receiving subsidies could also solve the problem but is unlikely in the short-term. Other interventions that increase the support of services for low-quality housing through decreasing the average cost of provision such as the minimum requirements policy could be more effective but they affect living conditions condemning lower segments of the demand to inadequate and insufficient public areas and infrastructures.

Dismantling expensive public policies that deteriorate the capacity of the system to provide services for a formal urbanization, such as up-grading and public housing, will contribute to mitigate informality only if the saved resources are actually allocated to generate more formal housing that is affordable and adequate for the needs of the demand.

In summary, a successful policy should incentivize utility companies to provide services to low-quality housing in a way that is both redistributive and financially sustainable. And it should do all of that in the short term. Based on the model presented in this paper I propose a policy that meets all these criteria through two main elements. The first is to change the system of financing services by increasing the amount of individual subsidies to the levels prior to the Law 142 of 1994 and shifting the sources of subsidies from tariffs to property taxation. The second is to change the nature of the policies to deal from informality by dismantling interventions like up-grading and public housing and instituting a policy to provide lots with basic infrastructure ex-ante.

Shifting the sources of subsidies from tariffs to property taxation can incentivize utility companies to expand infrastructure and provide services to low-quality housing

faster because the municipality will cover the difference between the tariff and the average long term cost of provision. This type of arrangement has been successfully implemented in different cases in which there are an interest to increase private supply. For example, housing vouchers designed to promote private housing by covering the difference of what low-income households are willing and able to pay and the market rent have proven to be a more cost-effective system to provide affordable housing in the United States than direct public provision (Newman and Schnare, 1997).

This system of provision of subsidies can also be more progressive than a system of redistribution based on tariffs since the demand for property tends to be more elastic with respect to income than the demand for services (Rojas and Gonzalez, 1998). In effect, according to my own calculations when household income increases from the average for stratum 1 to the average for stratum 6 the consumption of water increases 0.26 for each extra unit of income whereas the consumption of housing, measured by area, increases 0.41. This effect could be stronger if we take into account that the demand for property is less elastic to price than the demand for services and therefore the prices paid in the upper strata tend to be higher than in the lower strata. The progressiveness of a system based on the property tax is even more important in Latin American cities because of their characteristic unequal distribution of land (Uribe and Bejarano, 2008).

Moreover, the resources to fund subsidies generated in this system have the potential to increase quickly in the near future since the revenue from property taxation in Bogotá, as well as in other Latin American cities, is still very low in international terms. For instance the revenue from property tax represented only 0.57 percent of the city's Gross Regional Product (a measure of the size of the economy) when in OECD

countries it represents up to 2.12 percent of the Gross Domestic Product (Uribe and Bejarano, 2008) and in some cities of the United States can reach 4 percent of the Gross Regional Product (Smolka, 2003).

On the other hand, replacing up-grading and public housing interventions with the provision of lots with basic infrastructure will not only prevent the crowding-out effect produced by the higher cost of the traditional policies but also will assure that the solution is adequate and affordable. Indeed, informal settlements have been dubbed as 'architecture that works' because they offer a housing alternative that allows low-income persons to acquire an asset by transforming labor into capital through the process of self-construction (Turner, 1976). Also, informality allows the gradual transformation of physical spaces according to the need of the households expanding accommodations as the family grows or adding more rooms to generate extra income from rental or commercial activities (Abramo, 2007; Gilbert, 1999; Doebele, 1977). The provision of lots with basic infrastructure will allow low-income households to maintain these benefits but avoiding the high costs of settlement up-grading for the municipality.

The basic conditions for this policy are simulated in the model starting in 2010. From this year the tariff for services for low-quality housing is cut in half, the support for urban services from the general budget is increased 3.7 times assuming that property taxation increases up to the level of OECD countries and that this extra revenue is earmarked for public infrastructure. In addition, public housing and up-grading are eliminated. Table 2 summarizes the parameter changes for the purposes of policy analysis.

Table 2 Summary of Parameter Changes for Policy Analysis

Parameter	Modification in 2010
Tariff for low-quality housing	Multiplied by 0.5
Low-quality Housing supported from general budget	Multiplied by 3.7
Annual Up-grading	Set to zero
Annual Production of Public Housing	Set to zero

Figure 15 compares the outcomes of this policy (Policy in 2010) with the projection of the current conditions (Base Run). As represented in the graph the supply of formal housing increases substantially overcoming housing of informal origin in less than 15 years. By 2038 the implementation of the proposed intervention would produce almost 1.5 million formal units more than the current interventions.

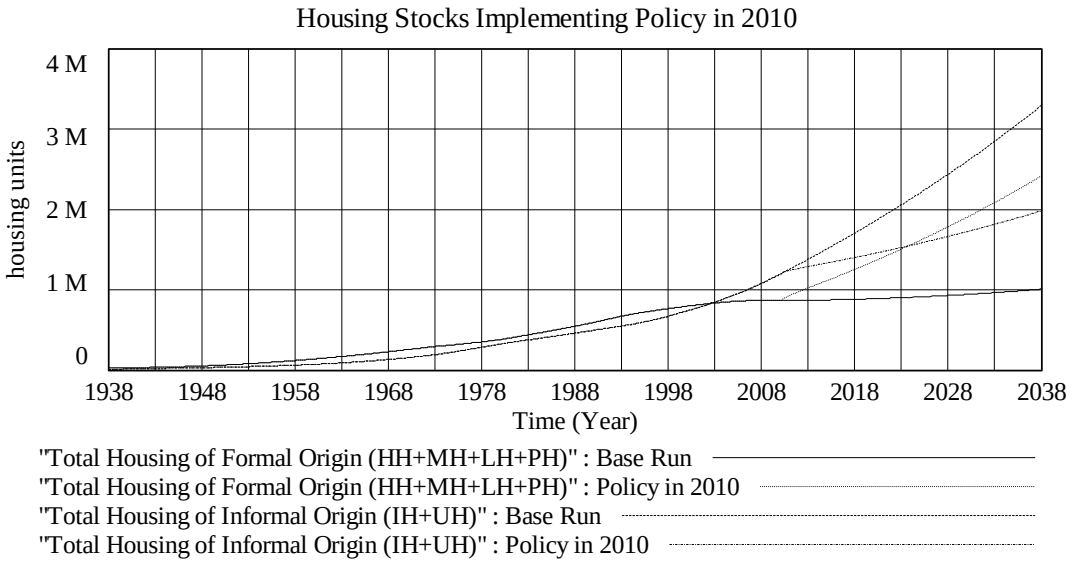

Figure 15 Simulated Formal and Informal Housing with Policy in 2010

Moreover this policy will achieve these positive results with fewer resources. The accumulated cost for the public (Accumulated Total Public Cost) through cross-subsidies and the general budget could decrease to almost half of that of the current

policies. The costs for low-income households (Accumulated Total Cost for Low-income Households) also decrease since the tariffs are defined in a more redistributive fashion. Figure 16 represents the costs for the public and the costs for low-income households with policy (Policy in 2010) and compares them with the original situation (Base Run).

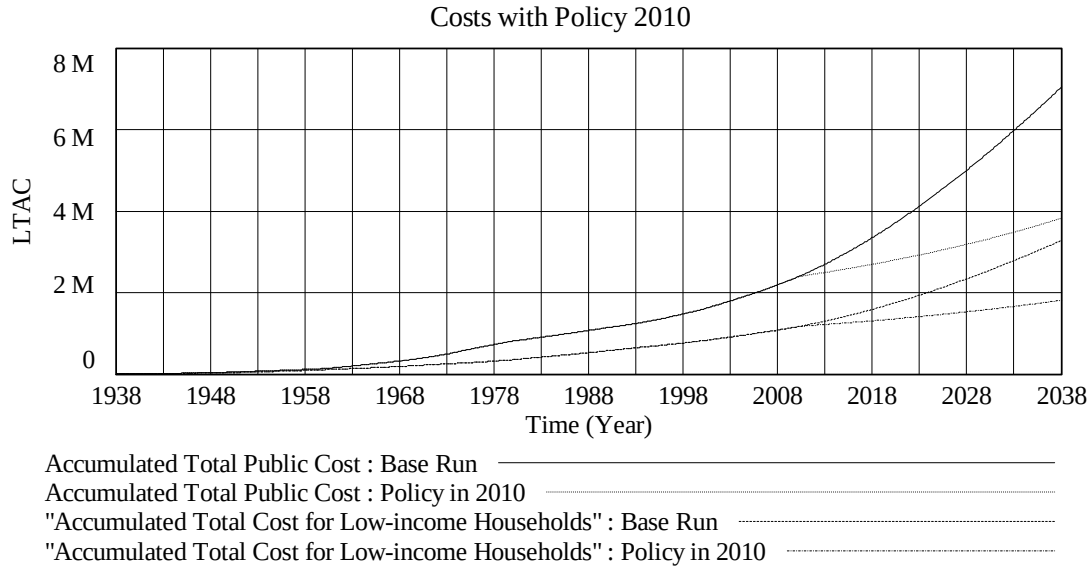

Figure 16 Simulated Costs of Low-income Housing Provision with Policy in 2010

These results suggest that it could possible to commemorate the 500th anniversary of Bogotá with a more livable, progressive, and financially sustainable environment. Although the current system has been in the making for decades it is possible to keep its positive characteristics and mitigate its negative incentives with simple measures if there is enough political will to do it. For instance, shifting the sources of funding for the provision of services from cross-subsidies to property taxes and replacing policies like up-grading and public housing with the provision of lots with infrastructure are realistic, but effective, interventions that can be implemented in the short term to solve the problems of informality in the city.

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