Evaluating the Impacts of Increasing Housing Supply in Canada: A Sorting Model with Heterogeneous Households

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Evaluating the Impacts of Increasing Housing Supply in Canada: A Sorting Model with Heterogeneous Households

Executive Summary

Motivation and research questions

Housing affordability currently poses a significant challenge in Canada. This issue affects households across the entire income spectrum and is particularly notable in large cities. New housing supply improves affordability. This improvement happens through the filtering process, which is influenced by market dynamics and applicable to various market segments. CMHC has estimated that 3.5 million additional housing units would be needed on top of the current pace of construction to restore affordability by 2030. Yet, building new housing at different price ranges may affect households with various socioeconomic characteristics differently. Therefore, in this project, we examine the effects of different types of new construction on housing affordability, the provision of local amenities, and the welfare of households with different income levels.

We adopt the theoretical model in Nathanson (2020) for our analysis and calibrate it to the Toronto CMA. Households in the model choose a metropolitan area in which to work and live. When new housing is provided in the model, relatively higher-income households vacate their units to occupy newer ones; this makes their old units available to relatively lower-income households, improving the affordability of their housing and their welfare. However, new housing supply also incentivizes additional migration of households, which may augment the improvements in welfare and provision of amenities.

Key findings

In general, all new construction would improve housing affordability and benefit low-income households but make high-income households worse off. However, the magnitudes of these impacts would depend on the type of new construction.

New construction of only low-cost housing would be most effective at improving housing affordability, but would cause the largest out-migration of high-income households from the metro area and the largest in-migration of low-income households. Since fewer high-income households would remain in the metro area, local amenities would decrease, as would labor productivity, both of which would negatively affect low-income households who remain in that location.

In contrast, new construction of only middle-cost housing or a combined type of new supply would reduce the out-migration of high-income households and in-migration of low-income households. In turn, this would mitigate the negative impacts on the provision of amenities and labor productivity that appear when new supply is provided by constructing only low-cost

housing units. On the other hand, constructing only middle-cost units or a combined supply would keep housing demand more elevated, and thus improve housing affordability by less compared to constructing only low-cost housing units.

Lastly, new construction of only high-cost housing would induce the largest in-migration of high-income households to the metro area and the most out-migration of low-income households. The gains in welfare of low-income households would be offset by increasing house prices due to increased housing demand from in-migrating households with post-secondary education. Overall, increasing housing supply by adding only new high-cost units would result in the lowest welfare gains for low-income households compared to other options of increasing supply.

Although the construction of only middle-cost housing and combined supply have similar impacts on house prices, the combined supply induces lower welfare losses for high-income households and higher welfare gains for low-income households than the construction of only middle-cost housing. Thus, the provision of combined supply stands out as the preferred choice in terms of its impact on household welfare and housing affordability. However, constructing only middle-cost supply may be viewed as a reasonable alternative.

Only under certain hypothetical simulated conditions that are unlikely to be the case in reality, new supply of only low-cost, only middle-cost or combined supply could result in an improvement that makes all households, as well as rental property owners better off. However, increasing supply by constructing only high-cost housing cannot make everyone better off even under hypothetical conditions. This highlights that the often-assumed notion of any supply being good supply for increasing household welfare may be inaccurate.

A rapid change in economic conditions leading to the increased productivity of skilled workers in the metro area would trigger a decline in housing affordability and a gentrification where high-income households with a post-secondary education would crowd out low-income households without such a degree. The study considered four policy strategies to address rising housing prices caused by the productivity shock.[1] The analysis indicates that using new housing supply to mitigate the affordability challenges needs to be carefully designed to balance various tradeoffs.

The implications of this study extend to the industry, policymakers, and other stakeholders involved in addressing housing affordability challenges. It highlights the need for a nuanced and comprehensive housing supply strategy that considers the diverse needs of different income groups. By encouraging the construction of housing units in various cost segments of the market, policymakers can address affordability challenges effectively while minimizing adverse

[1] The analysis of policy strategy does not aim to examine the provision of new supply of a particular type. Instead, the analysis is based on computational choice of the combination of new supply types that optimize a particular desirable policy outcome.

effects on the availability of amenities, on productivity, and on the overall well-being of households and the community.

Évaluer les effets de l'augmentation de l'offre de logements au Canada :
un modèle de tri avec des ménages hétérogènes

Résumé

Motivation et questions de recherche

L'abordabilité du logement est un défi de taille au Canada à l'heure actuelle. Ce problème touche les ménages de tous les niveaux de revenu et est particulièrement important dans les grandes villes. L'offre de logements neufs améliore l'abordabilité grâce à un processus de filtrage. Ce processus est influencé par l'évolution du marché et s'applique à divers segments du marché. Selon les estimations de la SCHL, il faudrait 3,5 millions de logements de plus que le nombre de logements qui seraient construits au rythme actuel pour rétablir l'abordabilité d'ici 2030. Cependant, la construction de logements de prix variés peut toucher différemment les ménages selon leurs caractéristiques socio-économiques. C'est pourquoi, dans le présent projet, nous examinons les effets de la construction de divers types de logements sur différents facteurs : l'abordabilité du logement, l'offre de services et de commerces de proximité, et le bien-être des ménages de différents niveaux de revenu.

Nous adoptons le modèle théorique de Nathanson (2020) pour notre analyse et le calibrons en fonction de la région métropolitaine de recensement de Toronto. Dans ce modèle, les ménages choisissent une région métropolitaine où ils peuvent travailler et vivre. Lorsque des logements neufs sont offerts, les ménages à revenu relativement élevé quittent leur logement pour en occuper un plus récent. Leur ancien logement devient alors disponible pour les ménages ayant un revenu plus faible, pour qui l'abordabilité et le bien-être s'en trouvent ainsi améliorés. De plus, l'offre de logements neufs stimule la migration des ménages, ce qui peut favoriser l'amélioration du bien-être des ménages et de l'offre de services et de commerces de proximité.

Principales constatations

En règle générale, la construction résidentielle améliorerait l'abordabilité du logement et profiterait aux ménages à faible revenu, mais aggraverait la situation des ménages à revenu élevé. Toutefois, l'ampleur de ces répercussions dépendrait des types de logements qui sont construits.

La construction de logements à prix modique seulement serait le moyen le plus efficace d'améliorer l'abordabilité. Elle entraînerait cependant l'exode le plus important de ménages à revenu élevé de la région métropolitaine et l'afflux le plus grand de ménages à faible revenu. Comme moins de ménages à revenu élevé demeureraient dans la région métropolitaine, les commerces et services de proximité diminueraient, tout comme la productivité de la main-d'œuvre. Ces facteurs nuiraient alors aux ménages à faible revenu qui continuent de vivre à cet endroit.

En revanche, la construction de logements à prix moyen seulement ou d'une combinaison de logements réduirait l'exode des ménages à revenu élevé et l'afflux des ménages à faible revenu. D'une part, cette option permettrait d'atténuer les effets négatifs sur l'offre de services et de commerces de proximité et sur la productivité de la main-d'œuvre qui apparaissent lorsque seuls des logements à prix modique sont construits. D'autre part, elle maintiendrait la demande de logements à un niveau plus élevé. L'amélioration de l'abordabilité serait donc moindre que si l'on construisait uniquement des logements à prix modique.

Enfin, la construction de logements à prix élevé uniquement entraînerait la plus forte migration de ménages à revenu élevé vers la région métropolitaine et le plus grand exode de ménages à faible revenu. L'amélioration du bien-être des ménages à faible revenu serait contrebalancée par la hausse des prix des habitations, causée par la demande accrue chez les ménages migrants ayant un diplôme d'études postsecondaires. Dans l'ensemble, augmenter l'offre en n'ajoutant que des logements neufs à prix élevé se traduirait par la plus petite amélioration du bien-être des ménages à faible revenu, par rapport aux autres options d'augmentation de l'offre.

La construction de logements à prix moyen seulement et une offre combinée auraient une incidence semblable sur les prix des logements. Mais sur le plan du bien-être, l'offre d'une combinaison de logements est plus avantageuse que la construction de logements à prix moyen uniquement. En effet, elle amoindrirait la perte de bien-être pour les ménages à revenu élevé et améliorerait les gains en matière de bien-être pour les ménages à faible revenu. Ainsi, l'offre d'une combinaison de logements semble plus avantageuse en raison de son effet sur le bien-être des ménages et sur l'abordabilité du logement. Cependant, la construction de logements à prix moyen seulement peut être considérée comme une solution de rechange raisonnable.

Ce n'est que dans certaines conditions hypothétiques simulées – qui ont peu de chances de se produire dans la réalité – qu'il y a une amélioration de la situation de tous les ménages et des propriétaires de logements locatifs avec l'une ou l'autre des options suivantes : offre de logements à prix modique seulement, offre de logements à prix moyen seulement, ou offre combinée. Néanmoins, augmenter l'offre en construisant uniquement des logements à prix élevé ne peut pas améliorer la situation de tout le monde, même dans des conditions hypothétiques. Ces exemples montrent que la notion souvent admise selon laquelle toute offre est bonne pour accroître le bien-être des ménages pourrait être inexacte.

Une évolution rapide de la situation économique pourrait accroître la productivité des travailleurs qualifiés dans la région métropolitaine. Il en résulterait une baisse de l'abordabilité du logement et un embourgeoisement. En effet, les ménages à revenu élevé ayant un diplôme d'études postsecondaires afflueraient dans la région métropolitaine, qui se dépeuplerait des ménages à faible revenu n'ayant pas un tel diplôme. Dans l'étude en question, on examine quatre options stratégiques pour faire face à la hausse des prix du logement causée par le choc de productivité[2]. Selon l'analyse présentée, l'offre de logements neufs comme moyen d'atténuer les problèmes d'abordabilité doit être soigneusement planifiée pour bien équilibrer les avantages et les inconvénients.

Les conclusions de l'étude en question s'adressent au secteur du logement, aux décideurs politiques et aux autres parties prenantes qui s'efforcent de relever les défis de l'abordabilité du logement. Cette étude met en évidence la nécessité d'une stratégie nuancée et globale d'offre de logements qui tient compte des divers besoins des ménages ayant différents niveaux de revenu. En encourageant la construction de logements dans plusieurs gammes de prix, les décideurs peuvent remédier efficacement aux problèmes d'abordabilité tout en atteignant d'autres objectifs. Ils peuvent ainsi réduire au minimum les effets négatifs de la construction sur la disponibilité des services et des commerces de proximité, sur la productivité et sur le bien-être global des ménages et de la collectivité.

[2] L'analyse des options stratégiques ne vise pas l'offre de logements neufs d'un type particulier. Elle est plutôt fondée sur le choix calculé de combiner des types de logements neufs qui optimisent l'obtention d'un résultat stratégique particulier.

Abstract: This report examines the impact of increasing different types of housing supply, namely, low-cost, middle-cost, high-cost, and combined-cost units on households' welfare and on housing affordability in the Toronto census metropolitan area (CMA). To do so, it adopts and calibrates Nathanson (2020)'s sorting model in which households of different income levels choose homes based on their preferences and financial means. The model incorporates the filtering process in which the newly constructed housing units are bought by households with relatively higher income. This gradually allows older properties to become more affordable to relatively lower-income households over time. The study finds that the welfare of low-income households improves, whereas high-income households and rental property owners face declining welfare across construction scenarios. However, combined supply stands out as a more balanced choice, while middle-cost supply can be viewed as a reasonable alternative, since these options benefit most income groups and make house prices more affordable. The report also considers four policy strategies to mitigate a decline in housing affordability due to a hypothetical productivity shock and emphasizes the need for careful consideration of policies in order to balance various tradeoffs.

1 Introduction

Housing affordability currently poses a significant challenge in Canada. This issue affects households across the entire income spectrum and is particularly notable in large cities. The lack of housing supply has been documented to have contributed to rising housing unaffordability (CMHC, 2018), which calls for an expansion of housing supply. CMHC has estimated that Canada needs an additional 3.5 million new housing units on top of the current level of construction to restore affordability by 2030 (CMHC, 2023).

New housing supply gradually improves affordability. This improvement happens through the filtering process, which is driven by market dynamics and can be present in any segment of the market. Filtering is the gradual transition of housing units from relatively higher-income households to relatively lower-income households over time. This transition occurs as newer and more desirable housing units are built and bought by relatively higher-income households, making older units relatively less expensive and more affordable for lower-income households. At any price range, filtering increases accessibility to housing and affordability for those with relatively lower incomes.

However, how much new housing improves affordability and which categories of households benefit from filtering the most can differ depending on the type of new supply. Therefore, any housing-supply-related policy decisions need to be based on an understanding of how developing a certain type of new housing is going to impact such important elements as housing affordability, household welfare,[3] and the provision of local amenities.[4]

This report aims to examine those crucial questions by using an economic model in which households of various income levels choose homes of various prices and amenities based on their preferences and financial means. The model is a sorting model; i.e., in equilibrium, high-income households gravitate towards high-cost housing, and low-income households to low-cost housing. Thus, by building more housing, a filtering process emerges in which households with relatively higher incomes vacate their units to move to better ones, leaving their old units available to households with lower incomes (Rosenthal, 2014).[5]

The sorting model used in this report is adopted from Nathanson (2020). Nathanson's model is used as a baseline model and is calibrated with Canadian data from the Toronto CMA. In the model, households have different levels of education and different labor productivity. Households choose houses with different amenities and prices such that higher-income households live in higher-cost homes. Housing cost and quality is a multidimensional concept that refers to the physical condition of a house, its size and amenities, and the social environment in which the house is situated. On the other hand, house price refers, for renters, to annualized shelter costs, while, for owners, it is the user costs of housing multiplied by the owner's self-reported value of the house.

The report studies the impact of increasing the supply of different types of housing on house prices and on the welfare of different types of households, as well as that of rental property owners. Four types of new housing supply are examined: construction of only low-cost, only middle-cost, and only high-cost units, and construction of a mix of housing units of different price levels (i.e., combined new supply). The combined new supply in our study is a realistic feature that includes construction of an equal share of low-, middle- and high-cost housing.

The report also studies the impact of gains in the productivity of households with post-secondary education on the housing market and households and estimates the effects of several new housing supply policy strategies that aim at mitigating the decrease in housing affordability triggered by the productivity shock. The studied policy strategies for mitigating the productivity shock include those that achieve the *status quo* levels of construction as in 2015, the minimal number of new

[3] Welfare, in the context of this report, refers to a household's utility (satisfaction, happiness, and well-being) from consuming consumption goods and housing services.
[4] Amenities, for the purpose of this report, are understood as features of housing that determine its value other than physical structure and the land components of housing.
[5] This report does not seek to investigate the existence of the filtering mechanism in the housing system or delve into its operational aspects. Forthcoming research conducted by CMHC will provide empirical evidence regarding filtering in Canadian housing markets.

housing units constructed, the minimal construction cost, and the same mix of price ranges of new units as in 2015.

The report extends the existing knowledge in several ways. First, we calibrate Nathanson's model with Canadian data. Second, we study the effects of providing four types of new housing supply. Third, we estimate the impact of new housing supply on changes in total population, in- and out-migration, and the number of households of different education levels that make housing choices because of new supply. Finally, we investigate the effects of a productivity shock in favor of households with post-secondary education and explore potential supply-related policy strategies to tackle the resulting decline in housing affordability.

Highlights of key findings

Analysis shows that the type of housing that constitutes new supply matters. Constructing different types of new housing units results in different impacts on housing affordability and household welfare. In all scenarios tested, new construction can provide a potential solution to alleviate unaffordability. However, the changes in household welfare are not uniform. The welfare of low-income households improves, while the welfare of high-income households and rental property owners declines when new supply is provided. This is the case regardless of the type of new supply.

Construction of only low-cost units benefits low-income households without a post-secondary education and decreases the welfare of middle- and high-income households more than other types of new construction. Construction of only low-cost housing is also the most effective in reducing housing prices; however, it is associated with a few other effects. Namely, it:

- induces the largest out-migration of households with post-secondary education from the metro area and the largest in-migration of households without a post-secondary education into that area. This leads to the highest net loss in welfare of high-income households with or without a post-secondary education when compared to outcomes caused by other types of new supply;
- reduces amenities and total productivity of the metro area; and
- leads to the lowest growth in total population and the lowest number of low-income households gaining more utility by moving to houses of better quality. This means a lesser impact of filtering in improving the welfare of households with low income.

The construction of only middle-cost or only high-cost units, and the provision of combined new supply have similar welfare impacts, but the provision of only middle-cost units or combined supply reduces housing prices by much more compared to the provision of only high-cost units. New supply of only middle-cost units or new combined supply also leads to:

- less out-migration of households with post-secondary education and less in-migration of low-income households without a post-secondary degree compared to when new supply consists of only low-cost housing; and
- a higher total population of the metro area and a greater number of low-income households moving into housing of better quality compared to the situation when new supply is provided in the form of only low-cost housing.

Providing new supply in the form of only high-cost housing induces the largest rise in the population of the metro area and the least out-migration of households with post-secondary education, but it also leads to the least welfare gains for low-income households.

Although construction of only middle-cost housing and combined supply have a similar impact on house prices, combined supply induces lower welfare losses for high-income households and higher welfare gains for low-income households than construction of only middle-cost housing. Thus, the provision of combined supply stands out as a more optimal choice in terms of its impact on household welfare and housing affordability, as it benefits most income groups and makes house prices more affordable.

To validate the robustness of the above results, we restricted the construct of the sorting model to a few hypothetical cases when no migration in or out of the metro area is allowed or amenities are either: i) exogenous; or ii) determined by the share of the population with post-secondary education. The analysis shows that all households can benefit from any type of construction if there is no migration across cities or amenities are determined by external factors. However, when amenities rely only on population with post-secondary education, the supply of only high-cost new units does not make everyone better off, as the welfare of low-income households without a post-secondary degree falls, mainly due to the increase in house prices. The conclusion that the construction of only middle-cost units or combined supply represent the preferred choices of providing new supply also holds. The results of this robustness test highlight that the often-assumed notion that any supply is good supply, when it comes to increasing household welfare, may be inaccurate.

The analysis also simulated a productivity shock to understand the effectiveness of various supply strategies in reducing unaffordability and gentrification associated with rising house prices. A productivity shock caused by the increased productivity of households with post-secondary education results in a rapid rise in housing prices, especially in the low-cost segments of the housing market. Housing prices rise because of the increased housing demand of higher-income households; that demand is formed by a combination of a positive net in-migration of households with post-secondary education and an out-migration of low-income households without a post-secondary education. In the absence of new housing construction, rising housing prices push households with post-secondary education to shift their demand into lower-cost housing. This creates price pressures on the low-end segment of the housing market. Thus, the skill-biased productivity shock generates a certain degree of gentrification such that high-income households with post-secondary education crowd out low-income households without such education along the housing price continuum. Rentiers benefit from the productivity shock because house prices rise considerably.

The described outcomes of the productivity shock may also be seen as a scenario in which there is no policy response and no new housing supply is provided. We then consider four policy strategies to address rising housing prices caused by the productivity shock.[6] The results of the analysis indicate that a strategy consisting of using new construction to mitigate a decline in housing affordability needs to be carefully designed to balance various tradeoffs.

- Maintaining the *status quo* levels of new construction as they were in 2015 curtails the out-migration of low-income households without a post-secondary education, although it is not sufficient to reduce the out-migration to zero. It also moderates the increase of house prices caused by the productivity shock by almost one half; however, it does not restore the pre-shock affordability levels.

- We explore three other policy strategies that aim to stem the out-migration of low-income households without a post-secondary education and offset the decline in housing affordability. We sought to identify the amount of new supply that makes it so that the combined effect of the productivity shock and new construction makes no household in the metro area worse off.

    - The option to construct the minimal number of housing units necessary to reduce the out-migration of low-income households without post-secondary education to zero would require an increase in housing supply of over 70% compared to the *status quo* levels. Moreover, this policy option would largely (but not completely) offset the increase in house prices triggered by the skill-biased productivity shock. However, the quality of new housing would be much lower than in the *status quo* case.

    - The option of providing new supply that results in minimal costs can offset the appreciation of house prices and leads to a 79% decline in construction costs compared to the *status quo* option. Although this policy option makes low-income households better off, high-income households are worse off compared to the policy option of constructing the minimal number of units.

    - The option of maintaining the mix of new supply as it was observed in 2015 can completely offset price appreciation caused by the productivity shock and make

[6] The analysis of policy measures does not aim to examine the provision of new supply of a particular type. Instead, the analysis is based on computational choice of the combination of new supply types that optimizes a particular policy scenario.

most households better off, but it comes with the highest construction cost compared to the other options.

The report is organized as follows. Section 2 describes the sorting model with heterogeneous households, as well as the equilibrium definition and characterization. Section 3 presents data, model estimation and calibration. Section 4 studies the impacts of various types of construction. Section 5 illustrates the effects of a skill-biased productivity shock and evaluates policy strategies to address the resulting decline in housing affordability. Section 6 concludes.

2 Model environment

The theoretical framework is according to Nathanson (2020). The next two sections provide a description of the model environment and the equilibrium characterization. The model economy includes T census metropolitan areas (CMAs) indexed by t. In a metropolitan area t, houses are classified by a composite measure: housing cost, $q_{j,t} > 0$, where $j \in \Psi\{0, \dots, J_t\}$ and $q_{j,t}$ is strictly increasing in j. In line with previous literature (Keall et al., 2010), housing cost, $q_{j,t}$, refers to the physical condition of a house, as well as the cost of the social environment in which the house is situated. Thus, housing cost is a multi-dimensional concept. Housing is indivisible, measured by $h_{j,t} > 0$. Housing is traded in competitive markets at price $p_{j,t}$.

The economy includes rentiers and households. Rentiers are endowed with all the housing stock and consume a composite non-housing good c with a normalized price of 1. The housing market is perfectly competitive and thus rentiers take house prices as given. Their decisions consist of choosing the quantity of housing units to sell and the quantity of non-housing goods to consume subject to a budget constraint.

Households are heterogeneous in terms of education, $e \in \{L, H\}$, labor productivity, $z > 0$, and taste for each city t, ϵ_t. For each $e \in \{L, H\}$, the distribution of labor productivity, z, is $\tilde{n}_e(z)$. The support of $\tilde{n}_e(z)$ is convex, and the lower bound of the support of $\tilde{n}_e(z)$ equals zero. Moreover, $\tilde{n}_e(z)$ is continuous, and $\int_0^\infty \tilde{n}_e(z)dz > 0$.

Let $n_{e,t}(z)$ denote the measure of households with education e and labor productivity z living in city t. The population of households with education e in city t is $N_{e,t} = \int_0^\infty n_{e,t}(z)dz$. The total population in city t is given by $N_t = N_{L,t} + N_{H,t}$. The total labor productivity of education e in city t is $Z_{e,t} = \int_0^\infty z n_{e,t}(z)dz$. The population in each city is strictly positive, *i.e.*, $N_{e,t} > 0$.

2.1 Households

The preferences of households consist of non-housing consumption c, housing cost q, city amenities a, and an idiosyncratic taste for a city ϵ. The taste for each city, ϵ, follows an extreme value distribution, Gumbel distribution, as suggested by McFadden (1973, 1977) for location choices whose errors follow Gumbel distributions. Following Glaeser and Gottlieb (2009), Gennaioli et al. (2013), and Reed (2003), the household utility function is Cobb-Douglas:

$$u_e(c, q, a, \epsilon) = c^{\beta_{c,e}} q^{\beta_{q,e}} a^{\beta_{a,e}} exp(\beta_{\epsilon,e}\epsilon) \quad (1)$$

where parameters $\beta_{c,e}, \beta_{q,e}, \beta_{a,e}, \beta_{\epsilon,e} > 0$ for each $e \in \{L, H\}$. This functional form captures the fact that non-housing and housing consumption are complementary, and the share of housing expenditure is stable across cities and time. The taste shock ϵ captures heterogeneous preferences across education groups and allows to limit household mobility across cities in response to changes in utility from non-housing consumption, housing cost, and amenities (Kline and Moretti, 2014; Hsieh and Moretti, 2019).

Following the endogenous growth literature (Romer, 1990), amenities depend on exogenous characteristics of a city and the relative population of households with education *H*:

$$a_t = \tilde{a}_t \left(\frac{N_{H,t}}{N_{L,t}}\right)^{\gamma_a} \quad (2)$$

where $\tilde{a}_t > 0$ and $\gamma_a \geq 0$ for each *t*. When $\gamma_a > 0$, city amenities increase in the population of high-education households. Several observations justify this setup. High-income households with post-secondary education are sorted in the model into high-cost homes, which generate high property-tax revenue to finance local amenities. See Nathanson (2020) for further discussions.

The labor market is competitive, and the labor price of education *e* in city *t* is $w_{e,t}$. A household's income is $y_{e,t} = w_{e,t}z$. For given house prices, labor prices, and amenities, each household chooses a city *t*, non-housing consumption *c*, and housing cost *q* subject to the budget constraint, $c + p_{j,t} \leq w_{e,t}z$. Here, housing is indivisible, and each household can consume only one unit of one type of house.

2.2 Firms

Firms in city t produce the non-housing consumption good *c* with labor inputs of different education levels according to the production function:

$$F_t(Z_L, Z_H) = \left(\left(A_{L,t}Z_L\right)^{\rho} + \left(A_{H,t}Z_H\right)^{1-\rho}\right)^{\frac{1}{\rho}} \quad (3)$$

where $A_{e,t}$ is production technology, Z_e labor input for $e \in \{L, H\}$ and $0 < \rho \leq 1$. Firms take $A_{e,t}$, as given and choose labor inputs Z_e for $e \in \{L, H\}$. With this labor-augmented production function, the resulting profits, $F_t(Z_L, Z_H) - Z_L w_{L,t} - Z_H w_{H,t}$, are distributed to the rentiers in city *t*.

Production technology $A_{e,t}$ governs labor productivity and depends on exogenous characteristics as well as the metropolitan area's population:

$$A_{e,t} = \tilde{A}_{e,t} N_t^{\gamma N} \left(\frac{N_{H,t}}{N_t}\right)^{\gamma_H} \tag{4}$$

where $\gamma_N \geq 0, \gamma_H \geq 0, \tilde{A}_{e,t} > 0$ for each *t*. When $\gamma_N > 0$, productivity increases when city population rises, and the relative share of education groups remains constant. When $\gamma_H > 0$, productivity increases in the share of high-education households in the city. Thus, labor mobility affects both a city's amenities and productivity.

2.3 Equilibrium

An equilibrium consists of house prices $p_{j,t}$, labor prices $w_{e,t}$, an amenity level a_t, productivity levels $A_{e,t}$ and a population distribution $n_{e,t}(z)$ for each *e*, *j*, and *t* such that: (i) households optimally choose *t* and *j*; (ii) the housing market clears for each cost level, $q_{j,t}$; (iii) firms in each *t* maximize profits; and (iv) equations (2) and (4) hold.

Given population measures $N_{L,t}(z)$ and $N_{H,t}(z)$, local equilibrium holds when house prices and wages clear housing and labor markets, while households, rentiers, and firms in *t* optimize. Define indirect utility as:

$$v_{e,t} = f(x) = \begin{cases} 0, & if\ w_{e,t}z < \min_{j \in J_t} p_{j,t} \\ \max_{j \in J_t} u_e(w_{e,t}z - p_{j,t}, q_{j,t}, a_t, 0), & otherwise \end{cases} \tag{5}$$

The indirect utility $v_{e,t}(z)$ is set to 0 if household income is lower than the lowest housing cost such that the household cannot afford living in metropolitan area *t*. Otherwise, households maximize utility subject to constraints. Then, in equilibrium, households (with *e* and *z*) are allocated across metropolitan areas as:

$$n_{e,t} = \frac{\tilde{n}_e(z) v_{e,t}(z)}{\sum_{t'=1}^{T} v_{e,t'}(z)} \tag{6}$$

Intuitively, a metropolitan population increases in the utility that households can enjoy relative to other metropolitan areas and increases in the distribution of labor productivity.

From a firm's optimization problem, we have:

$$w_{e,t} = \left(\left(A_{L,t} Z_{L,t}\right)^{\rho} + \left(A_{H,t} Z_{H,t}\right)^{\rho} \right)^{\frac{1}{\rho}-1} A_{e,t}^{\rho} Z_{e,t}^{\rho-1} \tag{7}$$

Wage is the marginal product of labor inputs. In equilibrium, there exists a lowest $j_{0,t} = \sup\,(j \in J_t | \sum_{j'=j}^{J_t} h_{j',t} \geq N_t)$ such that $p_{j,t}$ strictly increases over $j \geq j_{0,t}$ and equals zero if $\sum_{j=j_{0,t}}^{J} h_{j,t} > N_t$, and housing demand equals zero for $j < j_{0,t}$ and $h_{j,t}$ for $j > j_{0,t}$. When the housing stock of a metropolitan area exceeds the metro population, then the price of the house with the lowest cost $p_{j_{0,t},t} = 0$. The prices of higher-cost units solve the system that equates household demand for these units to the rentiers' endowments.

The following two equations admit a unique solution for the endowment cutoffs and house prices:

$$\left(w_{e,t}z_{e,j,t} - p_{j,t}\right)^{\beta_{c,e}} q_{j,t}^{\beta_{q,e}} = \left(w_{e,t}z_{e,j,t} - p_{j-1}, t\right)^{\beta_{c,e}} q_{j-1,t}^{\beta_{q,e}}, \tag{8}$$

$$h_{j,t} = \sum_{e\in\{L,H\}} \int_{z_{e,j,t}}^{z_{e,j+1,t}} n_{e,t}(z)dz \tag{9}$$

for each $j > j_{0,t}$, $z_{e,j,t}$ is the greatest lower bound of labor productivity *z* among households of education *e* choosing $q_{j,t}$ and $z_{e,J+1,t} = \infty$. The *j* that maximizes utility for a household is the one for which $z \in \left(z_{e,j,t}, z_{e,j+1,t}\right]$. This *j* pins down indirect utility via (5). To solve $\left\{z_{e,j,t}\right\}_{j=j_{0,t}+1}^{J_t}$ and $\left\{p_j\right\}_{j=j_{0,t}+1}^{J_t}$, we rewrite (8) and (9) as:

$$z_{e,j,t}\left(p_{j,t}, p_{j-1,t}\right) = \frac{p_{j,t} - \delta_j^q p_{j-1,t}}{\left(1 - \delta_j^q\right) w_{e,t}} \tag{10}$$

$$N_t - \sum_{j'=j}^{J_t} h_{j',t} = \sum_{e\in\{L,H\}} \int_0^{z_{e,j,t}\left(p_{j,t},p_{j-1,t}\right)} n_{e,t}(z)dz \tag{11}$$

Where $\delta_j^q = \left(\frac{q_{j-1}}{q_j}\right)^{\frac{\beta_{q,e}}{\beta_{c,e}}}$. Note $p_{j_{0,t},t} = 0$. With this, we adopt the way to solve the system of equilibrium conditions as is in Section 3 of Nathanson (2020).

3 Data, estimation and calibration

3.1 Data

We use the household-level data from the hierarchical file, 2016 Census Public Use Micro Files (PUMFs). This data provides non-aggregated data covering a sample of 1% of Canadian households. The file enables the study of individuals in relation to their census families, economic families, and households. We limit the sample to the 2016 Toronto CMA, the largest metropolitan area in Canada. We derive the variables for the Toronto CMA from PUMF Census 2016 hierarchical file. The following lists the variables used in this study:

- ***hhinc***: disposable income for market basket measure (MBM) of economic family for all persons
- ***htype***: True if the primary household maintainer has a post-secondary or above degree

- ***p***: household shelter cost, directly from PUMF
- ***weight***: household weight, constant for all observations

We aggregate all persons in a housing unit into a single household observation, *i*, and exclude from the sample those households who are in subsidized housing. The household income, y_i, is the summation of total personal income for all members of the household. We also exclude about 6% of households who do not have education information for their primary household maintainer. We then assign $e_i = 1$ if the household's primary maintainer has a post-secondary degree, and 0 otherwise. The annual price of the housing unit, p_i, is calculated as 12 times the monthly shelter cost for renters and ϕ times the self-reported value of the house for owner-occupants, where ϕ is the user cost of housing and given by:

$$\phi = r^g + \tau^p + \delta + r^p - g^e$$

where

- $\gamma^g = 0.020233$: ten-year government bond return in 2016
- $\tau^p = 0.00666$: average property tax rate of the Toronto CMA in 2016. It is the average property tax rate across all municipalities in the Toronto CMA
- $\delta = 0.025$: depreciation rate following Harding, Rosenthal and Sirmans (2007)
- $r^p = 0.02$: risk premium following Flavin and Yamashita (2002)
- $g^e = 0.02547523$: expected capital gain, which is calculated as the real average growth rate of MLS house prices in the Toronto CMA over the last three decades.

To satisfy Assumption 2, we assume renters who do not pay rent (or with monthly rent equal to $1) live in the lowest-cost housing units, j_0, with $p_{j_0} = 0$. We exclude about 2% of households with extremely low income relative to their house value: $y_i < 0.2p_i$.[7] Finally, to capture new units built in 2015 (one year before the survey), we use a random 20% sample of those dwellings built between 2011 and 2016.[8]

Table 1 lists summary statistics, with weighted means calculated using household weights available in the data. In the estimation sample, owner-occupants have the highest income and education levels, while the renters with zero rent have the least. Rent and home values for new construction are nearly the same as the corresponding units in the estimation sample. The number of new units as a share of total units in the estimation sample is 1.6%.

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[7] We do this to have well-defined income cutoffs by house value ranges.

[8] In the PUMF data, period of construction is presented as five-year categories.

Table 1: Summary Statistics

	Estimation sample			New construction	
	No-pay renters	Renters	Owners	Renters	Owners
Income	\$45,264	\$63,112	\$115,806	\$74,109	\$101,745
Education	0.39	0.59	0.61	0.72	0.70
Rent	-	\$16,002	-	\$19,743	-
Home value	-	-	\$611,229	-	\$611,516
Annualized value		\$16,002	\$28,361	\$19,743	\$28,374
Weighted observations	6,826	535,850	1,179,412	10,118	18,008

Note: "Annualized value" for owner-occupied units is calculated as the product of self-reported value of the house and the user cost of housing specified above.

3.2 Independently determined parameters

The inverse elasticity of substitution between labor with and without a post-secondary degree is estimated to be about 0.7 in several labor economics papers. This inverse elasticity corresponds to $1-\rho$ and thus r = 0.3. Combes and Gobillon (2015) find that the typical estimate in the literature of the elasticity of productivity with respect to population density lies between 0.04 and 0.07. We set $\gamma_N = 0.055$, the midpoint of this range. Moretti (2004) estimates that log output in an industry within a metropolitan area rises about 0.0055 when the share of the population with post-secondary education in other industries in the same area rises by one percentage point. Interpreting this estimate as 100 times the derivative of log productivity with respect to N_H/N, we obtain 0.55 = $\gamma_H N/N_H$. The shares of the population with post-secondary education in the two years (1982 and 1992) in the sample in Moretti (2004) are 0.161 and 0.191.[9] Then setting N_H/N equal to the average gives g_H = 0.0968. The share of the population with post-secondary education and its income share are calculated directly using the estimation sample.

3.3 Estimating income distribution

To estimate housing-price and housing-stock cutoffs, we partition households in housing units into 50 quantile bins according to their house price, p_i, placing equal numbers of households in each bin. No-pay renters occupy the lowest bin, j = 0, so that $J = \{0, \dots, 50\}$. The price of each bin is the sample average: $\hat{p}_j = \sum_i g_i \delta_{i,j} p_j \,/ \sum_i g_i \delta_{i,j}$, where g_i is the household weight, and $\delta_{i,j}$ is a dummy for whether household i is in bin j. For j > 0, the housing stock estimate is $\hat{h}_j/N = \sum_i g_i \delta_{i,j} \,/ \sum_i g_i$, which is approximately constant by model construction.

The income distributions, f_L and f_H, are specified as double Pareto-lognormal, a four-parameter family that Reed (2003) and Reed and Jorgensen (2004) propose to characterize income

[9] We need to use the values from Moretti (2004) to be consistent with its estimates.

distribution. We jointly estimate these eight distributional parameters and $\varsigma = \left(\frac{\beta_{q,L}}{\beta_{c,L}}\right) / \left(\frac{\beta_{q,H}}{\beta_{c,H}}\right)$, which governs the relative taste for housing versus non-housing consumption across the two education groups. We denote the nine parameters by θ and conduct the estimation as follows.

- Given θ, use the following two equations to solve for $\{y_{L,j}, y_{H,j}\}_{j=1}^{50}$:

$$y_{H,j} = \hat{p}_{j-1} + \frac{\hat{p}_j - \hat{p}_{j-1}}{1 - \left(\frac{y_{L,j} - \hat{p}_j}{y_{L,j} - \hat{p}_{j-1}}\right)}$$

$$\sum_{j'=j}^{50} \frac{\hat{h}_j}{N} = \frac{N_L}{N} \int_{y_{L,j}}^{\infty} f_L(y) dy + \frac{N_H}{N} \int_{y_{H,j}}^{\infty} f_H(y) dy$$

- Compute the model moments as follows:

$$\bar{y}_{L,j}(\theta) = \frac{\int_{y_{L,j}}^{y_{L,j+1}} y f_L(y) dy}{\int_{y_{L,j}}^{y_{L,j+1}} f_L(y) dy}$$

$$\bar{y}_{H,j}(\theta) = \frac{\int_{y_{H,j}}^{y_{H,j+1}} y f_H(y) dy}{\int_{y_{H,j}}^{y_{H,j+1}} f_H(y) dy}$$

$$\bar{e}_j(\theta) = \frac{\frac{N_H}{N} \int_{y_{H,j}}^{y_{H,j+1}} f_H(y) dy}{\frac{N_L}{N} \int_{y_{L,j}}^{y_{L,j+1}} f_L(y) dy + \frac{N_H}{N} \int_{y_{H,j}}^{y_{H,j+1}} f_H(y) dy}$$

- where $\bar{y}_{e,j}(\theta)$ is the average income among households of education *e* choosing housing at cost q_j, $\bar{e}_j(\theta)$ the share of households choosing q_j who have education *H*.

- The following moment conditions equate empirical realizations of these conditional expectations to their model-based counterparts:

$$E\delta_{i,j}(1 - e_i)\left(y_i - \bar{y}_{L,j}(\theta)\right) = 0$$

$$E\delta_{i,j} e_i \left(y_i - \bar{y}_{H,j}(\theta)\right) = 0$$

$$E\delta_{i,j}\left(e_i - \bar{e}_j(\theta)\right) = 0$$

- Estimate θ via two-step generalized method of moments (GMM) by Hansen (1982), using the diagonal inverse of the sample variances as the weighting matrix. This estimator chooses the θ that best fits the joint distribution of income, education, and housing cost in the data.

Finally, we follow the method provided in Section 4.5 of Nathanson (2020) to refine $\{\beta_{c,e}, \beta_{a,e}, \gamma_a\}$ to ensure that instabilities do not affect comparative statics. Please see the Appendix for detailed steps.

3.4 Parameter table and model fit

Table 2[10] reports parameter values including independently calibrated parameters, estimated parameters using GMM, and computed parameters for stability. Over 60% of households had post-secondary education in the Toronto CMA in 2016. These households account for an income share of 67%. The estimated value for relative housing taste is $z = 1.36$, indicating that households without post-secondary education value housing versus non-housing consumption relatively more than households with post-secondary education. The estimated migration elasticities to amenities and non-housing consumption, $\beta_{c,L}, \beta_{a,L}, \beta_{c,H}$ and $\beta_{a,H}$, imply that households with post-secondary education value amenities versus non-housing consumption more than households without post-secondary education do. The spillover elasticity is $\gamma_a = 1.36$, which is higher than 1.08 in Glaeser and Gottlieb (2009), but lower than 2.6 in Kline and Moretti (2014) due to the stability criterion imposed.

[10] In Table 2, "college" indicates post-secondary education, while "non-college" means without a post-secondary education.

Table 2: Parameter Values

Parmeter	Value	Description
		Parameters determined independently
ρ	0.3	1 - inverse elasticity of sub b/t college and non-college labor
ϕ	0.0464	User cost of housing in Toronto CMA
γ_N	0.055	Elasticity of productivity w.r.t population density
γ_H	0.0968	Elasticity of productivity w.r.t high type ratio
N_H/N	0.601	College population share
Y_H/Y	0.669	College income share
		Parameters determined by GMM estimation
a_L	6.2182	α of f_L, income distribution for non-college
b_L	2.9463	β of f_L, income distribution for non-college
ν_L	11.3724	ν of f_L, income distribution for non-college
τ_L	0.2401	τ^2 of f_L, income distribution for non-college
a_H	5.1157	α of f_H, income distribution for college
b_H	3.6400	β of f_H, income distribution for college
ν_H	11.5794	ν of f_H, income distribution for college
τ_H^2	0.2198	τ^2 of f_H, income distribution for college
ζ	1.3626	Relative housing taste, non-college over college
		Parameters for stability
$\beta_{c,L}$	2.2724	Non-college migration elasticity to consumption
$\beta_{a,L}$	0.2730	Non-college migration elasticity to amenities
$\beta_{c,H}$	1.4278	College migration elasticity to consumption
$\beta_{a,H}$	1.0659	College migration elasticity to amenities
γ_a	1.3658	Amenity spillover elasticity

Figure 1 displays household income and housing values by education group from the model and the data. Circles represent the model results, while crosses come from the data. The model matches the empirical income quite well. Given housing value, the income of households with a post-secondary degree is generally higher than that of those without a post-secondary degree. The income gap increases with housing value.

Figure 1: Goodness of fit: Income by education group

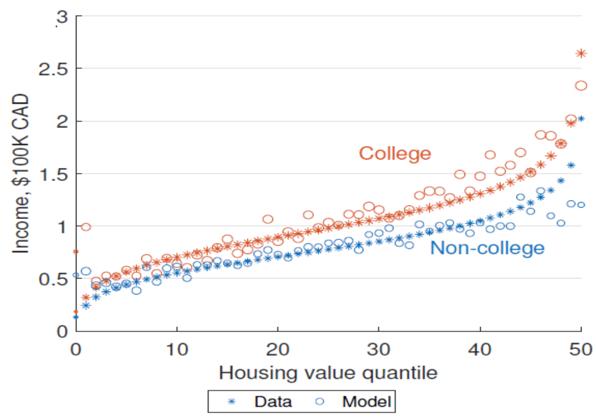
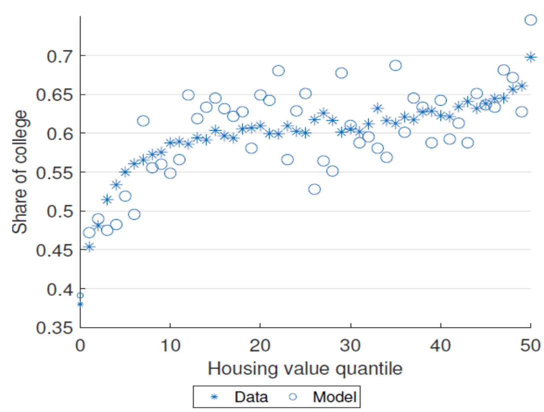


Figure 2 displays the share of households with post-secondary education with respect to housing value. The model fits the data well. The share of households with post-secondary education in Toronto is 60% and the distribution of the share of households with post-secondary education with respect to housing value is quite even in Toronto. For example, around 60% of households with post-secondary education reside in houses with the average value in Toronto.

Figure 2: Goodness of fit: Shares *of households with post-secondary education*



4 Effects of increasing housing stock

In this section, we estimate the effects on welfare and equilibrium house prices by respectively increasing the housing stock in the 20th, 50th, and 80th percentiles of the housing cost or housing value distribution. We also consider the effects of introducing a combined mixture of new housing. Constructing housing of cost q_j means to increase housing stock h_j. More specifically, the 20th percentile represents low-cost construction, the 50th middle-cost construction, the 80th high-cost construction, and combined construction implies an equal share of all these construction types. We first present the baseline model and then extension results with different parameters and assumptions.

4.1 Baseline construction effect

We first estimate the respective effects of low-, middle- and high-cost construction on welfare and house prices. In addition, we estimate the effects of a *combined construction* with an equal share of one third in bins 10, 25 and 40, respectively. In these experiments, we will increase the housing stock in the Toronto CMA by 1.36%, the construction intensity in the data, in the chosen bins. We aggregate household welfare effects across education groups and income quartiles. We report the welfare effect of local rentiers, who are assumed to exclusively own the entire housing stock. We also report the effect of construction on average house prices.

The baseline results are reported in Panel A of Table 3. First, construction has heterogeneous effects on different education groups and across different income quartiles. High-, middle- and combined-cost construction have similar impacts. All types of construction make low-income households better off. For instance, the welfare of households without a post-secondary degree in the lowest income quartile rises from 4.50% to 5.46%. However, low-cost construction helps these households the most, as the welfare change reaches 5.46%.

High-income households are worse off with any type of construction, but they are at their worst with low-cost construction. Second, rentiers are worse off with any type of construction. Finally, low-cost construction reduces the average house price the most, by 7.2%, middle-cost construction by 6.87%, and high-cost construction by 3.25%.

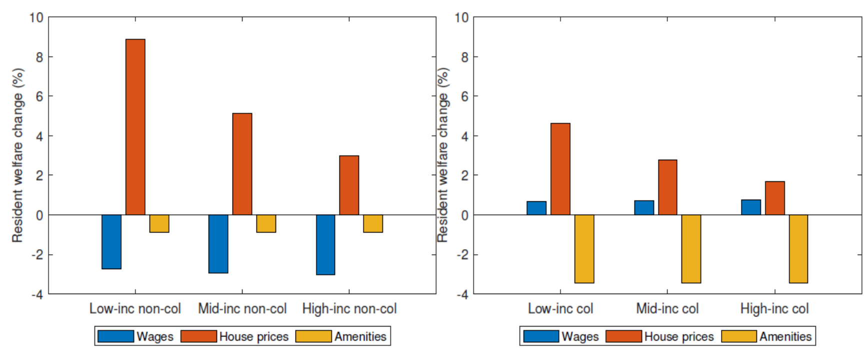
Table 3: Effect of construction on household welfare (%)

Income quartile:	Non-college 1	Non-college 2	Non-college 3	Non-college 4	College 1	College 2	College 3	College 4	Rentiers	Average price
Panel A. Baseline										
20th	5.46	1.59	-0.03	-1.33	1.96	0.37	-0.53	-1.37	-4.62	-7.2
50th	4.91	1.80	0.24	-1.09	1.66	0.38	-0.30	-1.14	-4.00	-6.87
80th	4.50	1.67	0.61	-0.69	1.55	0.39	-0.23	-0.84	-3.25	-3.25
Combined	4.95	1.68	0.27	-1.04	1.69	0.38	-0.35	-1.11	-3.96	-6.87
Panel B. Exogenous amenities										
20th	2.58	1.22	0.65	0.26	1.74	1.25	0.87	0.58	-0.67	-2.10
50th	2.23	1.45	0.86	0.38	1.54	1.20	1.01	0.68	-0.30	-2.10
80th	2.02	1.34	1.21	0.69	1.45	1.13	1.00	0.85	0.22	-2.08
Combined	2.28	1.34	0.91	0.45	1.58	1.19	0.96	0.70	-0.25	-2.10
Panel C. Exclusively-college amenities										
20th	0.54	0.95	1.15	1.42	1.65	1.89	1.91	2.01	2.30	1.79
50th	0.13	1.17	1.39	1.60	1.45	1.87	2.09	2.17	2.80	1.94
80th	-0.14	1.05	1.74	1.94	1.35	1.81	2.10	2.39	3.42	2.06
Combined	0.18	1.06	1.43	1.65	1.48	1.86	2.03	2.19	2.84	1.93
Panel D. Local services										
20th	5.49	1.61	-0.01	-1.32	1.86	0.36	-0.56	-1.39	-4.69	-7.28
50th	4.90	1.81	0.26	-1.07	1.65	0.38	-0.30	-1.14	-4.02	-6.88
80th	4.43	1.66	0.64	-0.64	1.55	0.39	-0.20	-0.80	-3.19	-6.45
Combined	4.94	1.69	0.29	-1.01	1.68	0.38	-0.35	-1.11	-3.96	-6.86
Panel E. No migration										
20th	20.82	11.45	8.00	5.10	10.81	6.96	4.87	2.94	-9.32	-13.78
50th	20.90	12.04	8.49	5.41	10.81	7.06	5.13	3.11	-9.21	-14.07
80th	20.90	12.10	9.01	5.86	10.81	7.06	5.17	3.35	-8.88	-14.21
Combined	20.85	11.85	8.49	5.45	10.80	7.02	5.05	3.13	-9.13	-14.01

The baseline results have several important implications. First, considering the impacts both on welfare and house prices, middle- and combined-cost construction types stand out as balanced choices in that they benefit most income groups and make house prices more affordable. Moreover, our findings suggest that combined-cost construction, which is closer to the construction mix provided in practice, has lower welfare losses for high-income households and higher welfare gains for low-income households. Combined-cost construction has the same impact on house prices. Thus, combined-cost construction is slightly preferable to middle-cost construction. Second, low-cost construction benefits low-income households and reduces house prices the most, but its gains are marginal compared to combined- and middle-cost construction. Most of all, combined- and middle-cost construction benefits middle-class households more than low-cost construction does. Lastly, high-cost construction seems to have similar welfare impacts as combined- and middle-cost construction, but its impact on housing affordability is less than half that of combined- and middle-cost construction. Combined- and middle-cost construction benefit low-and middle-income households more than high-cost construction does.

To clarify the mechanism behind these results, we decompose the welfare effect of combined-cost construction for different education and income groups. As shown in Figure 3, low-income households without post-secondary education benefit from construction because the effect from the falling prices of their housing dominates the effects of changes in wages and amenities. The same pattern is observed for low-income households with post-secondary education and middle-income households with or without post-secondary education, but to a lesser extent. High-income households without post-secondary education lose welfare mainly because of losses in wages and amenities, while high-income households with post-secondary education lose mainly because amenities decline. Due to the decline of amenities, few high-income households move to the metropolitan area in response to the middle-cost construction. Existing households move up the cost ladder to occupy it. As a result, housing becomes cheaper, which improves the welfare of low-income households. More low-income households move to the city. If most of these low-income households do not have post-secondary education, then metro amenities will decline; if most of these low-income households have post-secondary education, metro amenities could be unchanged or even increased.

Figure 3: Components of welfare effect of combined percentile construction



We further explore the effects of all types of construction on the metro population, migration and the sorting process. We report these effects of low-, middle-, high- and combined-cost construction in Table 4. Starting with low-cost construction: low-cost construction raises the metro population by 0.75%. The housing stock of the 20th percentile expands by 1.36%. However, low-cost construction leads to a brain drain with the highest out-migration of households with a post-secondary degree. For a simple illustration, 100 new low-cost units lead to in-migration of 90 households, of which 74 do not have a post-secondary degree and 16 have a post-secondary degree. These 100 new units induce out-migration of 35 households, of which 7 do not have a post-secondary degree and 28 have a post-secondary degree. The net in-migration of households without a post-secondary degree is 67, while the net outflux of households with a post-secondary degree is 12, which means a net migration of 55 households (100 ´ (0.75/1.36) = 55), freeing up new units for 45 existing residents, on a net basis. During the sorting process, 8 households from the bottom quarter of income move up the cost ladder. Among the migrants, 71 households are from the bottom quartile. Among them, 59 do not have a post-secondary degree, and 12 have a post-secondary degree. Thus, low-cost construction induces the migration of low-income households without a post-secondary degree and a brain drain of the post-secondary population.

Middle-cost construction expands the housing stock of the 50th percentile by 1.36%, raises the metro population by 0.81%, and has lower brain drain than the low-cost construction. For 100 new middle-cost units, 86 new households move to the city. Among these migrants, 71 households have no post-secondary degree and 15 have a post-secondary degree. These 100 new units induce the out-migration of 27 households, among whom 5 do not have a post-secondary degree and 22 have a post-secondary degree. The net in-migration for households without post-secondary education is 66, while the net outflux of households with post-secondary education is 7, which means a net migration of 59 households (100 ´ (0.81/1.36) = 59), freeing up new units for 41 existing residents on a net basis. During the sorting process, 91 households from the bottom quarter of income move up the cost ladder. Among the migrants, 64 households are from the bottom quarter of income. Of these households, 53 do not have a post-secondary degree and 11 have a post-secondary degree. Compared with low-cost construction, middle-cost construction reduces the migration of low-income households without a post-secondary degree and the brain drain of the population with post-secondary education; it also helps more households to move up to the cost ladder.

High-cost construction expands the housing stock of the 80th percentile by 1.36%, raises the metro population by 0.85%, and induces almost no brain drain. For 100 new high-cost units, 82 new households move to the city. Among these migrants, 68 households have no post-secondary degree and 14 have a post-secondary degree. These 100 new units induce the out-migration of 19 households, among whom 3 do not have a post-secondary degree and 16 have a post-secondary degree. The net migration of households without post-secondary education is 65, while the net outflux of households with post-secondary education is 2, which means a net migration of 63 households (100 ´ (0.85/1.36) = 63), freeing up new units for 37 existing residents on a net basis. During the sorting process, 84 households from the bottom quarter of income move up the cost ladder. Among the migrants, 59 households are from the bottom quartile, and 49 of them do not have a post-secondary degree, while 10 do have a post-secondary degree. Compared with low- and middle-cost construction, high-cost construction reduces the migration of low-income households without post-secondary education and the brain drain of the population with post-secondary education.

Interestingly, combined-cost construction produces very similar results to middle-cost construction. The only difference is that it has fewer households moving up the cost ladder than middle-cost construction. The main reason why combined-cost construction has similar effects to those of middle-cost construction is because the effects of constructing low- and high-cost housing offset each other. The remaining effects are quite similar to those of middle-cost construction alone.

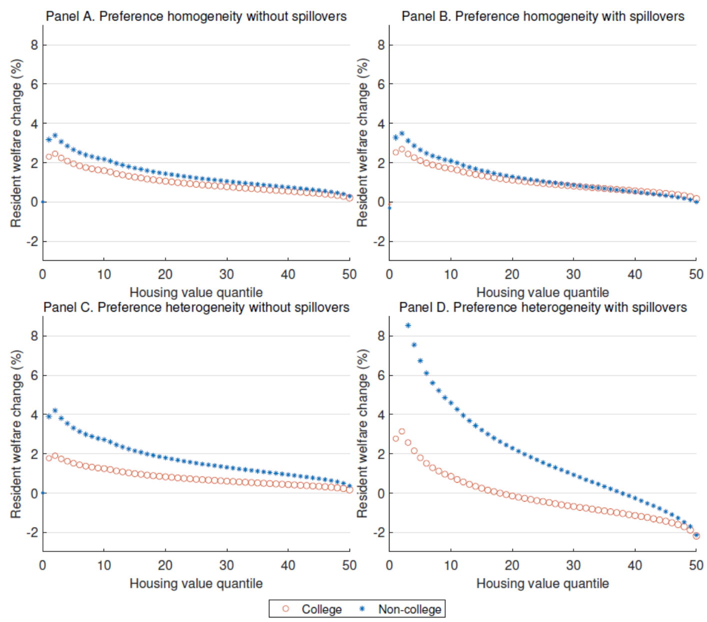
Table 4: Number of household per 100 newly built units

	Low-cost 20th			Middle-cost 50th			High-cost 80th			Combined		
	Non-college	College	Total	Non-college	College	Total	Non-college	College	Total	Non-college	College	Total
In-migration	74	16	90	71	15	86	68	14	82	71	15	86
Out-migration	7	28	35	5	22	27	3	16	19	5	22	27
Net-migration	67	-12	55	66	-7	59	65	-2	63	66	-7	59
Pop-growth rate			0.75%			0.81%			0.85%			0.81%
Available units for existing households, net			45			41			37			41
Move-up from bottom quarter			8			91			84			61
Move-up from bottom half			26			116			108			83
Migrants (bottom 25%)	59	12	71	53	11	64	49	10	59	54	10	64
Migrants (bottom 50%)	73	15	88	69	13	82	63	14	77	68	14	82

We further explore the channel through which building a certain type of housing affects welfare. With limited space, we only consider the case of low-cost construction. We explore two critical channels: spillovers and the differential preferences of households with and without a post-secondary education. As shown in Figure 4, the baseline with heterogeneous preference and spillovers appears in Panel D.

In Panels A and C, we turn off all spillovers by setting $\gamma_N = \gamma_H = \gamma_a = 0$ and r= 1, in which case amenities and wages no longer depend on the city population. In Panels A and B, we eliminate preference heterogeneity by setting $\beta_{a,L}$ and $\beta_{a,H}$ to their average value in the city before the construction. In these two cases, the migration response to amenities and non-housing consumption is identical across the two education groups. In each panel, we plot the average welfare response among households of each education group in each bin. Low-cost construction benefits low-income households without a post-secondary degree much more in Panel D than any other panel. The high-income households are affected much more in this panel as well. In fact, without spillovers (Panels A and C), everyone benefits from construction. Thus, the strong distributional effect of low-cost construction relies on the combination of urban spillovers and preference heterogeneity.

Figure 4: Effect of 20th percentile construction on resident welfare



4.2 Extensions

The remaining panels in Table 3 explore welfare and affordability effects of construction under different parameters and assumptions. In Panel B, $\gamma_a = 0$ so that amenities are exogenous and no longer depend on the composition of city households. Every household benefit from all types of construction. Rentiers benefit from high-cost construction but lose slightly with low- and middle-cost construction. All types of construction reduce house prices by around 2%. While low-cost construction continues to improve low-income households' welfare more than the other two types of construction, it is outperformed by the other two types of construction respectively for middle- and high-income households. Although middle-cost construction benefits low-income households slightly less than low-cost construction does, it benefits other groups of households more than the other two types of construction. To a certain extent, middle-cost construction is still preferred with exogenous amenities. Finally, combined construction performs in a similar way to middle-cost construction. With exogenous amenities, the welfare gain for low-income households without post-secondary education is only half as much as in the baseline model. Thus, the endogeneity of amenities amplifies the benefit of construction for low-income households without post-secondary education. It also amplifies the impact of new construction on house prices.

In Panel C, we consider an alternative to the baseline amenity specification: $a = \tilde{a}N_H^{y}$. The share of population without a post-secondary degree in the metro area no longer affects amenities; the amenities are determined by only the share of population with post-secondary education. Both low- and middle-cost construction types make all groups better off, including the rentiers. The reason why even the rentiers are better off is because new construction in this scenario raises house prices. Among these two types of Pareto-improvement construction under the assumption that amenities are determined exclusively by the population with post-secondary education, middle-cost construction still, overall, outperforms low-cost construction. Interestingly, low-income households without post-secondary education are worse off with high-cost construction because they must compete more for housing against high-income households and households with post-secondary education, whose migration is stronger in this scenario.

In Panel D, we add to the model local supply of services by households without post-secondary education. As in Nathanson (2020), we split the non-housing consumption into the consumption of manufactured goods and the consumption of services provided by households without post-secondary education such that $\beta_{cs,e} \log c_s + \beta_{cm,e} \log c_m$, with $\beta_{cs,e} + \beta_{cm,e} = \beta_{c,e}$. Here, c_s denotes the consumption of services provided by households without post-secondary education, and c_m denotes the consumption of manufactured goods produced by firms in the baseline model. Households consume only local services provided by other households in the metro area. After defining the equilibrium as in the baseline, we set $\beta_{cs,L} = 0$, meaning that only households with post-secondary education consume services. This assumption gives the greatest chance of offsetting the negative effect of construction on households with post-secondary education. We estimate $\beta_{cs,H}$ by calculating the ratio of the total wage and salary earnings of workers without post-secondary education in service occupations in the Toronto CMA to the aggregate income less housing costs of households with post-secondary education. We calculate $\beta_{cs,H}$ as 9.2%. As shown in Panel D, we have similar results to the baseline. The main conclusion remains that middle-cost construction is overall a better solution in balancing welfare and affordability.

Finally, Panel E turns off cross-metro migration. Construction now makes all households better off, but makes the rentiers worse off than the baseline because house prices fall the most. Considering welfare alone, high-cost construction is preferred. However, once housing affordability is considered, middle-cost construction is still slightly preferable.

To sum up, combined-cost construction and middle-cost construction in the baseline model benefit both low- and middle-income households and reduce house prices as much as low-cost construction. They stand out as balanced construction in terms of welfare and affordability. This conclusion is robust to changes in various parameters and assumptions. High-income households and households with post-secondary education lose from all types of construction because amenities decline, while the rentiers lose when housing prices drop. Once we shut down endogenous amenities or make amenities rely only on population with a post-secondary degree, or shut down inter-metro migration, all households benefit from any type of construction. The baseline results remain valid after adding local services to the model. Thus, high-income households and households with post-secondary education lose from construction because all types of construction cause the ratio of population with and without post-secondary education to drop, which decreases amenities consumed by households. With a larger population with post-secondary education, the welfare loss of high-income households and the population with post-secondary education is lower than in a city with a smaller population with post-secondary education. Overall, new combined-cost or middle-cost construction in the Toronto CMA improves the welfare of low- and middle-income households and makes housing more affordable and has a lesser impact on high-income households and households with post-secondary education than low- and high-cost construction.

5 Policy experiments to address a decline in affordability

In this section, we first examine the effects of a productivity shock that raises house prices. Then we experiment with various policies to assess how effective these policies are in reducing the welfare losses associated with rising house prices.

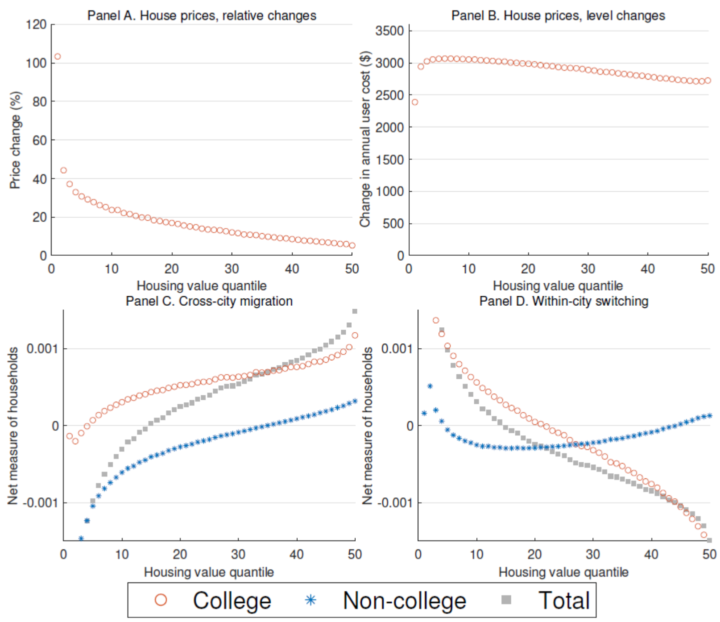
5.1 Effects of a skill-biased productivity shock

In this subsection, we study the effect of a skill-biased productivity shock on housing prices without any policy intervention. The exogenous productivity shifters for L and H labor are $\delta_{A,L}$ and $\delta_{A,H}$. We set their values at -0.0157 and 0.0038 as in Nathanson (2020). These values mean that households with post-secondary education become more productive upon shock, and households without a post-secondary degree become less productive.

Figure 5 plots the house price and population changes that occur in response to this shock. As shown in Panels A and B, house prices sharply increase relative to their initial value. The largest price appreciation occurs in the lowest housing-cost bins. The remaining panels C and D explain why price appreciation is concentrated in low-cost segments.

Panel C shows the net measure of households moving into each bin from outside the city. As a result of the skill-biased productivity shock, the high-cost bins receive an influx of households with post-secondary education, while households without post-secondary education move out of the low-cost bins. The skill-biased shock in favor of households with post-secondary education generates a decline in housing affordability such that a sharp rise in house prices is associated with an out-migration of low-income households without a post-secondary degree. However, it is puzzling that house prices of low-cost segments of the housing market increase so much when there is an out-migration of low-income households.

Figure 5: Effect of a skill-biased productivity shock on housing markets



Panel D provides the answer to changes in housing demand within the city. As shown in Panel D, the combined switching effect in gray cancels the combined migration effect in Panel C. Without new construction, households with post-secondary education switch down into the low-cost bins. As shown in Panel B, the slope of house prices with respect to cost is quite constant. Only the slope between the lowest bins increases much because the demand to switch into these bins is strong. This skill-biased productivity shock generates gentrification such that high-income households with a post-secondary degree crowd out low-income households without a post-secondary degree.

5.2 Policy effectiveness

We conduct a series of policy experiments addressing the decline in affordability caused by the productivity shock. Table 5 analyzes the effectiveness of various policies. As shown, Panel A reports the population changes of households without post-secondary education in each income quartile, Panel B gives the same information for households with post-secondary education, while Panel C summarizes house price and quantity changes from each policy option.

Table 5: Effect of a skill-biased productivity shock under different policies (%)

	Construction policies				
	None	2015	Unit-minimizing optimum	Cost-minimizing optimum	2015 quality optimum
Income quartile:	(1)	(2)	(3)	(4)	(5)
Panel A. Non-college population change					
Income quartile					
1	-8.94	-4.48	0.27	2.28	0.89
2	-2.30	-0.66	0.17	0.10	1.26
3	0.71	0.98	0.45	0.03	1.30
4	3.47	2.46	0.89	0.15	1.32
Panel B. College population change					
Income quartile					
1	0.45	2.13	4.01	4.78	4.09
2	3.44	3.83	3.84	3.32	4.27
3	5.10	4.74	3.87	3.19	4.33
4	6.82	5.66	4.06	3.19	4.34
Panel C. Housing market changes					
Average price	16.94	8.97	2.33	0.41	0.49
Median price	13.48	7.14	2.38	0.73	0.31
Rentier welfare	12.54	8.19	3.18	1.19	3.41
Housing units	0.00	1.37	2.41	3.13	2.96
Construction cost	0.00	1.41	1.07	0.68	3.04
Construction quality	-	0.00	-56	-79	-

Note: "Construction cost" gives the total value of new housing as a share of the value of existing housing, using pre-shock prices. "Construction quality" gives the average value of new housing relative to the average value of new housing in 2015, using pre-shock prices.

Results in column (1) correspond to the baseline case in Figure 5 when there is no policy response. In line with Panel C of that figure, the low-income population without post-secondary education declines while the population with post-secondary education increases at all income levels. House prices rise by 16.94% on average, with a median increase of 13.48%. There is no change in the housing stock by assumption. The rentiers benefit from rising house prices following the skill-biased shock.

Column (2) presents the case where construction matches the data for 2015 as a *status quo* case. From 2015 to 2016, housing stock in the Toronto CMA increased by 1.37%. This level of construction curtails the out-migration of low-income households without post-secondary education but is not enough to reduce it to zero. In the lowest income quartile, the out-migration is reduced by half, from -8.94% in the baseline without a policy response, to -4.48%. This level of construction also increases the migration of middle-income households with post-secondary education but reduces the migration and welfare of high-income households, from 6.82% in the baseline, to 5.66%. House price growth falls to 8.97% and 7.14% for the average price and median price, respectively. Thus, the *status quo* construction reduces average and median house prices by 8% and 6.3%, respectively.

Columns (3) to (5) present answers in different ways to the question of how much construction is necessary to stem the out-migration of low-income households without post-secondary education. We search for a set of construction amounts, $\delta_{h,j}$, so that the combined effect of the productivity shock and construction makes no household in the city worse off. Such an outcome represents a Pareto improvement over the baseline without a policy response. Low-income households without post-secondary education no longer leave the city.

Column (3) presents the minimal number of new housing units necessary to achieve this objective. As shown in Panels A and B, no low-income households leave the city and low-income households are better off than in the baseline of no policy response. However, high-income households are worse off than in the *status quo* case because the cost of new housing is 56% lower in column (3) than column (2). The construction cost is computed as the average price of new housing in the pre-shock equilibrium. This minimal construction increases the housing stock by 2.41%, an increase of 76% from 1.37% in data. In terms of affordability, this level of construction reduces average and median house prices by 14.6% and 11.1%, respectively. The construction cost is 1.07% of the value of existing housing stock, lower than 1.41% in the *status quo* case in column (2).

Column (4) presents the minimal number of new housing units, but whose construction leads to the lowest construction cost, indicating the solution moves towards lower-cost housing. The construction cost in column (4) is only 0.68% of the housing stock, which is lower than the 1.07% in column (3). The cost of construction is 79% lower than the 2015 level. While cheaper to implement, this policy option makes low-income households better off but high-income households worse off than in column (3). This level of construction almost wipes out the increase in housing prices from the productivity shock. The housing stock is expanded by 3.13%, which is even higher than in column (3).

Column (5) adds a cost constraint so that the cost distribution of new construction matches data in column (2) but solves for the total quantity of construction eliminating out-migration. The resulting optimum improves every household's welfare from column (3). It also improves the welfare of all households except for the low-income households when compared to column (4). It also almost wipes out housing price gains from the shock by increasing the housing stock by 2.96% with a higher construction cost of 3.04% of the housing stock. Though it is more costly to implement, many households are better off with this policy option compared to the one that involves low-cost construction.

To sum up, the construction alternatives shown in columns (2) to (5) represent construction policy options with trade-offs. Compared to the baseline of no policy response, none of these solutions is a Pareto improvement such that everyone is better off. *Status quo* cannot stem the out-migration of low-income households or offset house price appreciation caused by the skill-biased productivity shock. Low-cost construction improves the welfare of low-income households but harms middle- and high-income households. Maintaining the cost as in data with a combination of low-, middle- and high-cost construction (i.e., column (5)), is preferred by most households and it can make housing affordable.

6 Conclusion

The housing affordability challenge arises whenever house price appreciation significantly outpaces the increase of household income. Construction of new housing may hold the key to resolving affordability challenges. As has been documented (CMHC, 2018), the lack of housing supply has contributed to fast-rising house prices in Vancouver and Toronto. Thus, increasing housing construction could fundamentally help solve unaffordability issues. While it may seem that construction of any type of new housing would help, little is known in terms of the effects of new construction on housing affordability, welfare, and amenities across households of different income levels. This report aims to fill in that gap by calibrating and extending the model developed by Nathanson (2020) with Canadian data.

We obtain the following main results from the modeling analysis, which lead to important considerations for policymaking:

First, the type of new housing construction matters. Construction of only low-cost housing benefits low-income households, while inducing the out-migration of households with post-secondary education and therefore the decline of both amenities and productivity in the metro area. Construction of only high-cost housing does not induce the out-migration of households with post-secondary education, but is the least effective in terms of reducing house prices and improving affordability. The types of new supply associated with more balanced benefits are: either providing a combination of equal quantities of low-, middle- and high-cost housing; or constructing only middle-cost housing. Most households in various income groups are better off when new supply is provided by constructing either combined supply or only middle-cost housing. Those two types of supply make housing nearly as affordable as does the provision of only new low-cost housing, but are also associated with additional benefits. This result therefore supports the argument for increasing the so-called "missing middles" (*i.e.*, duplexes/triplexes, row homes, and low-rise apartments) in Canadian cities.

Second, under only certain conditions (which are rather unlikely to be the case in reality), new housing construction can result in an improvement that makes everyone better off (i.e., a Pareto improvement). All households benefit from any type of construction if amenities are exogenous or there is no migration across cities. Except for the construction of only high-cost new housing, all types of construction make all households better off, even rental property owners, if the change in the average education level of the population does not affect amenities. Thus, endogenous amenities may alter the conclusion in some studies that any housing supply would increase household welfare and productivity.

Finally, a skill-biased productivity shock in favor of households with post-secondary education would trigger a decline in housing affordability and gentrification such that high-income households with post-secondary education crowd out low-income households without such education. Among several policy options we considered, the *status quo* approach with the levels of construction as observed in 2015 helps to reduce house prices but cannot stem the out-migration of low-income households without a post-secondary education. Levels of construction that create the minimal number of new housing units or construction associated with minimal construction cost would mostly offset the appreciation of house prices triggered by the skill-biased productivity shock but induce a large decline in amenities (due to a large decline in housing costs). Levels of construction that aimed to maintain the same mix of new supply as was recorded in 2015 can solve the affordability challenges and is preferred by most households. However, this approach induces a much higher construction cost. Therefore, our study shows that the use of new construction to mitigate affordability challenges needs to be carefully designed to balance various tradeoffs.

Appendix

Parameters for stability

We refine $\{\beta_{c,e}, \beta_{a,e}, \gamma_a\}$ to ensure stable equilibrium:

1. Equation system

$$\partial \log n_e(z) = \partial \log v_e(z),$$

$$\partial \log v_e(z) = \left(\frac{\beta_{c,e} y_e(z)}{y_e(z) - p_j}\right)(\partial \log w_e)^{(0)} - \left(\frac{\beta_{c,e}}{y_e(z) - p_j}\right)(\partial p_j)^{(0)} + \beta_{a,e}(\partial \log a)^{(0)},$$

$$\delta_{h,j} = \sum_{e \in \{L,H\}} \left(\partial N_{e,j}^{int} + \partial N_{e,j}^{ext}\right),$$

$$(\partial \log a)^{(1)} = \gamma_a \partial \log N_H - \gamma_a \partial \log N_L,$$

$$(\partial \log w_e)^{(1)} = \partial \log A_e + (1 - \rho)\frac{Y_{\sim e}}{Y}\partial \log\left(\frac{Z_{\sim e}}{Z_e}\right) + (1 - \rho)\frac{Y_{\sim e}}{Y}\partial \log\left(\frac{A_{\sim e}}{A_e}\right).$$

   a. Initial perturbations to house prices p_j, wages w_e, and amenities *a* are labeled with superscript (0), which induce population changes via (1) and (2). These migration responses then change $\{p_j, w_e, a\}$ though (3), (4) and (5).
   b. The linear system defines a matrix *M*: $\left\{(\partial p_j)^{(0)}, (\partial \log w_e)^{(0)}, (\partial \log a\,)^{(0)}\right\} \rightarrow \left\{(\partial p_j)^{(1)}, (\partial \log w_e)^{(1)}, (\partial \log a\,)^{(1)}\right\}$.

c. The matrix is required to be stable, meaning that all of its eigenvalues have negative real parts.

   i. Draw 10,000 times from Kline and Moretti (2014) sampling distribution for *y*.

   ii. Allocates the estimates of $\beta_{w,e}$ from Kline and Moretti (2014) to $\beta_{q,e}$ and $\beta_{c,e}$:

$$0.57 = (1 - e^{rent})\left(\frac{\beta_{c,L}}{\beta_{w,L}}\right) + e^{rent}\left(\frac{\beta_{c,H}}{\beta\_(w,H)}\right)$$

$$\varsigma = (\frac{\beta_{q,L}}{\beta_{c,L}})/(\frac{\beta_{q,H}}{\beta_{c,H}})$$

   iii. Where e^{rent} is the share of renters with post-secondary education, which is 0.588 calculated using 2016 Census. Note 0.57 reflects that renters in the Toronto CMA spend 43% of their income on housing.[11]

   iv. Use the mean of the estimates ψ under which M is stable.

11 We use 12 times monthly shelter cost for renters. For owners, it is user cost multiplied by the self-reported value of the house. To be consistent, the income is the total household income.

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