Examining Relationships Between Eliminating Parking Minimums and New Housing Construction Using a Terner Housing Simulator Tool

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INTRODUCTION

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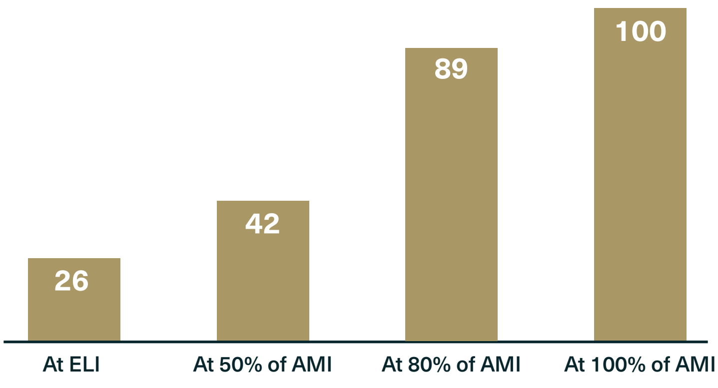
A Housing Supply and Affordability Crisis

According to the National Low Income Housing Coalition (NLIHC), there is a shortage of more than 134,000 homes across Colorado. This shortage is felt most acutely by low-income Coloradans, with nearly 90% of the lowest income households cost burdened. The housing shortage is so severe that it is increasingly affecting middle-income Coloradans working as teachers, nurses, and firefighters, threatening their ability to remain in the state. Figure 1, below, shows the uneven distribution of housing cost burden by Coloradans of different incomes according to NLIHC.

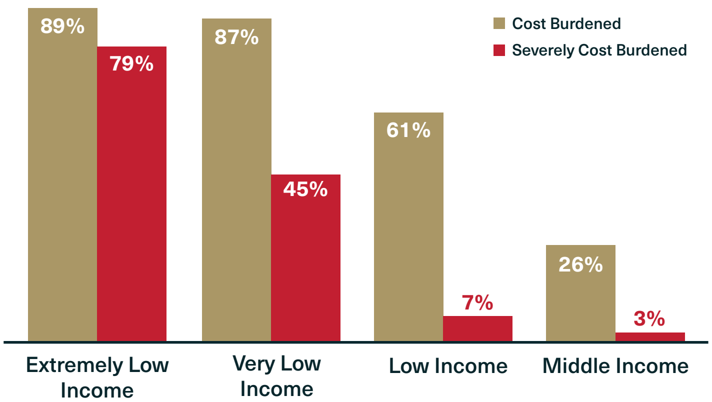
How do Parking Minimums Affect Housing Affordability?

Over the long term, excessive housing costs threaten the economic growth and prosperity of the state and the economic mobility of its residents. The high cost of providing parking - whether mandated by city ordinances or demanded by lenders or renters - contributes to higher housing costs. Land is expensive in high-demand cities like Denver, and dedicating part of a building's footprint to parking is costly. In fact, parking minimums carry both a direct cost (developers must pay to build the parking) and an indirect cost (dedicating land for parking limits the developable building envelope

AFFORDABLE AND AVAILABLE HOMES PER 100 RENTER HOUSEHOLDS



HOUSING COST BURDEN BY INCOME GROUP



Note: Renter households spending more than 30% of their income on housing costs and utilities are cost burdened; those spending more than half of their income are severely cost burdened.
Source: 2023 ACS PUMS

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possible on a given site, which often translates to fewer units).

Based in part on an outdated view that ‘modern’ cities would be automobile-oriented, cities around the country - including Denver - developed and passed zoning codes that create legal requirements for the number of parking spaces that new housing projects must include. These codes also mandate the number of spaces required for commercial, industrial, and retail buildings. Parking minimums were passed across the country in the 1950s and 1960s and were implemented alongside highway-building projects through American cities’ Central Business Districts. These highways were both justified by, and in turn promoted, sprawl and exclusionary zoning and land-use patterns. Planners’ mid-20th century urban-transport projects undermined cities’ environmental quality, walkability, and livability, particular for low-income communities and communities of color. Put simply, urban-transport projects were implemented alongside exclusionary zoning and restrictive land use policies to prioritize parking spaces over livable communities and more affordable homes.

Providing parking, especially for multifamily residential projects, is quite costly. Denver’s own Community Planning and Development office has stated that structured parking (parking located in multi-level structures) can cost as much as $50,000 per parking space and cause developable space to be used for parking instead of homes. Off-street surface parking lots are cheaper to build but require the dedication of valuable real estate to cars rather than to housing or other productive uses. In addition to direct costs, parking minimums also contribute to an overreliance on cars, traffic congestion, air pollution, and regulatory burdens for both the city and developers. This regulatory burden increases the cost of permitting, slows down the development of new housing units, and increases project uncertainty and risk, which results in fewer homes being built and increases their cost.

Reducing parking minimums can also create more options for renters by allowing them to pay only for the parking they actually use, a concept known as “unbundling”. When projects are required to oversupply parking, that additional cost of constructing each parking space - sometimes hundreds of dollars per month - gets passed on to every household in the project, including those without cars. Reducing municipal parking requirements can let developers unbundle parking from rent, so car-free or single-car

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households can choose properties with lower housing costs while drivers still have the option to lease a spot if they choose. This change reduces the parking cross-subsidy that disproportionately burdens lower-income renters, and aligns housing costs more closely with actual renter needs.

Although parking spaces typically will be included in a development when important to serve a project's purpose, mandatory parking regulations may require parking to be constructed even when, for example, shared parking is available in adjacent lots, ample parking is available on the street, or reduced parking is appropriate because of proximity to bus or light-rail transit. These zoning regulations dictate the number of parking spaces required based on building type and use, regardless of whether additional parking is actually needed, which imposes costs that impact housing production.

Measuring the Policy Impact of Eliminating Parking Minimums

But what are the measurable, quantitative effects of mandatory parking minimums on housing production in the City of Denver? In this white paper, we seek to answer this question by applying a novel Housing Policy Simulator tool developed in collaboration with Terner Labs, the nonprofit innovation arm of the Terner Center for Housing Innovation at the University of California, Berkeley. We model various scenarios associated with a range of economic conditions and developer and consumer preferences. The Simulator examines the 'developability' of parcels across Denver based on assumptions including, but not limited to, land values, market conditions (interest rate, cap rate, rent appreciation, vacancy rate, construction and operating costs, and many others) and uses an 'expected value' calculation to generate an estimated number of developable units citywide based on the city's status quo zoning and on potential changes to policy.

Findings indicate a modest, but positive, impact on multifamily housing production from eliminating city-mandated parking minimums. For example, one simulation assumed city parking requirements were eliminated in a moderately unfavorable economic environment with developers continuing to provide modest amounts of parking. In this simulation, expected multifamily housing production increases by over 460 marginal new units annually from a baseline of 3,682 expected units per year. This 13% increase represents a modest, but significant, impact on housing production, especially considering that this projected increase results from a single policy change.

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Roadmap

This white paper proceeds as follows: we first overview the methodology used as part of the Terner simulator tool in greater depth, noting key assumptions and limitations associated with this Denver-specific model. Next, we discuss the model's findings across a range of simulation environments and as a whole. A Discussion section explains some of the implications of this analysis for a policy change in Denver and considers additional benefits of eliminating parking minimums. And we conclude by exploring the potential of this Terner tool to model the impact of various public-policy changes on urban-development dynamics, in Denver and in other Colorado contexts.

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We modeled the relationships between changing city parking-minimum policies and the resulting production of multifamily residential housing in the City and County of Denver. Our models considered various degrees of city parking mandates (“policies”), estimates of developer responses to demand for parking (“Parking Demand Assumptions”), and economic and development conditions (“economies”). In this report, each model run that tests a unique combination of policies, Parking Demand Assumptions, and economies is referred to as a Scenario.

We employed a novel application of the Terner Labs Housing Policy Simulator (“The Simulator”) for our models. The Simulator, powered by MapCraft Labs’ analytics and mapping software, allows researchers to simulate how various policy reforms could affect the financial feasibility of housing development - specifically market-rate, multifamily rental development (the Simulator does not model single-family housing, condos, or subsidized affordable housing development). It models a comprehensive range of potential multifamily developments on a site, the financial feasibility of each possible development, and the likelihood of development for the most profitable option. Users can then toggle between policy options and compare the potential impact on future development.

The Simulator estimates annual multifamily housing production by combining real estate pro formas - the financial calculations underlying a project that determine whether it is feasible - with local land use and regulatory information, as well as the probability that a given development will happen based on past trends. The Simulator looks at possible multifamily developments with a wide range of potential characteristics on all developable parcels in the city. By adjusting the parameters for one simulation relative to another - such as the city parking requirements and/or assumed number of included parking spaces - the Simulator can estimate how housing production might change in response to that adjustment.[1]

The Modeling Process

Our multi-disciplinary and multi-institution team - including Terner Labs staff alongside University of Denver faculty from the Sturm College of Law, Korbel School of International Studies, and Burns School of Real Estate - collectively developed the Denver-specific model via an inclusive process involving a wide variety of stakeholders. Developers, policy experts, city officials, regulators, and others reviewed and discussed assumptions. For each assumption, there were multiple iterations, including focus groups, and numbers were changed based on feedback.

[1] Please see **Appendix A** for detailed methodology on the Terner Housing Policy Simulator

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We likewise developed a wide variety of model inputs and assumptions to capture a range of potential outcomes.

The Model In Brief

The Simulator estimates the total expected number of units permitted annually in multifamily, market-rate rental developments in Denver. This resulting expected-value number is a function of several calculations:

- For each parcel, the Simulator first conducts a simple and generic building massing to determine the maximum allowable building envelope and estimate the largest unit count that can fit on each parcel. This maximum unit count is first constrained by physical characteristics of the parcel (lot size, certain existing features limiting developable area), then constrained by local land use and development regulations (e.g., maximum building heights, floor area, density limitations, municipal parking requirements).
- Next the Simulator calculates the type of development (e.g., small multifamily, high-rise apartment building) and corresponding number of units with the strongest financial performance in the Simulator's pro forma, called the "optimal development." The financial calculations use assumptions (e.g., economic conditions, development timelines, fees, construction costs, operating revenue) that are constant across all simulations, as well as parameters that we manipulate from one simulation to the next (i.e., parking inclusion). Note that in all simulations, we assume developers provide the minimum share of below-market-rate units required by the Expanding Housing Affordability (EHA) ordinance at the required level to avoid in-lieu fees and linkage fees and receive incentives. In high-market areas, we assume 15% of units are offered at 70% AMI, and in typical-market areas, we assume 12% of units are offered at 70% AMI.
- The Simulator next estimates the probability that the optimal development might actually be developed in the future. This probability is based on a statistical analysis of historical development data for Denver. This analysis quantified the relationship between the financial metrics of a potential development (from the Simulator's pro forma) and whether a new development was actually built on a given parcel. Based on these statistical relationships, the Simulator applies a probability that the optimal development will be permitted in the future.
- In a given scenario, the "expected number of units" to be developed on each parcel is the number of units in the optimal development multiplied by the associated probability of development. For example, a parcel with an optimal dwelling unit count of 100

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and a development probability of 10 percent has an expected number of units of 10. The expected number of units that would be developed citywide is the sum of the expected number of units for all parcels.

We then estimate the effect of adjustments to zoning-mandated parking minimums and assumed "developer-provided" parking inclusion by comparing the expected number of units between different simulations—for example, using a city's current parking minimums versus a potential elimination of city-mandated parking minimums.

Differences in the expected number of units under each scenario can result from a combination of two types of changes. First, the optimal development on a parcel could change, resulting in a different number of units. For example, the optimal development for a given parcel might have 10 units for the baseline scenario, but it could increase to 15 units if reduced parking spaces would allow for construction of a larger building. Second, the estimated financial metrics and associated probability of development could change. For example, the optimal development for a given parcel might be 10 units for both scenarios, but the probability of development might increase from 5 to 10 percent if the construction costs per dwelling were reduced when fewer parking spaces are built compared to baseline.[2]

Simulated Scenarios

To understand the multifamily housing dynamics in Denver resulting from changing parking minimum policies, we tested a total of 75 scenarios - five potential parking policies tested across five economic environments and three sets of assumptions for developer-driven parking inclusion. The three sets of assumptions for developer-driven parking inclusion are especially important. In **Parking Demand Assumption 1**, we do not assume any developer provision of parking on new projects beyond what is explicitly required by the zoning code. So if the scenario simulates the full removal of the zoning code requirement, under Parking Demand Assumption 1 no parking spaces are included on any project. Our goal with this scenario is to set an "upper bound" on the potential impacts of changing parking minimum policy. In **Parking Demand Assumption 2**, we assume that demand for parking will result in developers providing approximately 0.86 parking spaces per unit, even if the zoning requirement is set or simulated at a lower ratio. This number is approximately the average amount of parking provided in 119 completed and proposed residential and mixed-use projects in Denver between 2020-2022 that were not subject to parking requirements. And finally, in **Parking Demand Assumption 3**, we use a more dynamic

[2] Please see **Appendix B** for a list of key assumptions that informed the Simulator model.

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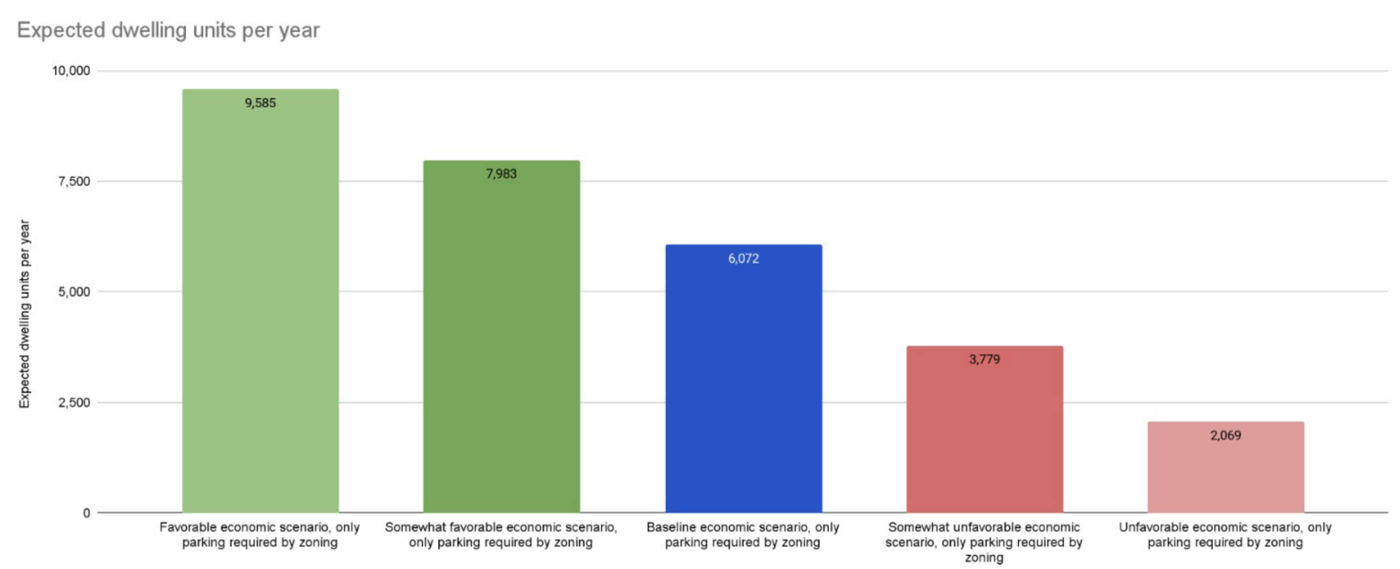
estimate of developer-provided parking, varying the estimate by geography (assuming at least 0.5 parking spaces per unit in locations within 0.5 miles of a light rail station, and 1.0 parking spaces per unit everywhere else), again even if the zoning requirement is set or simulated at a lower ratio. Further research could segment Simulator assumptions for developer-driven parking provision by income level, neighborhood, or proximity to other modes of transit like Bus Rapid Transit (BRT) or regularly scheduled bus service.

Accounting for Economic Uncertainty - Economic Scenario Planning

In line with research on Exploratory Scenario Planning (XSP) by the Lincoln Institute of Land Policy, we also modeled projections for five possible sets of economic conditions and development environments (favorable, somewhat favorable, baseline, somewhat unfavorable, unfavorable). Economic conditions and development fundamentals like construction costs, financing costs, operating costs, rent growth, and vacancy rates have a major effect on the feasibility of development.

STATUS QUO POLICY SIMULATIONS VARY UNDER DIFFERENT ECONOMIC SCENARIOS



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As seen in the figure above, there will be significantly more housing development in favorable economic conditions than unfavorable, and this is true across all policy frameworks.[3] As we will see in the full results below, however, the percentage increase - and usually the marginal increase as well - in multifamily housing units resulting from parking reform is much larger in unfavorable economic conditions than favorable ones, all else being equal.

Model Limitations

The Simulator output should be examined at the aggregate level for the City and County of Denver, and not used to predict behavior at the level of individual parcels, or even in individual city zones or neighborhoods. The reason for this is that the Simulator uses expected value calculations and marginal-economic analyses but cannot consider some unique attributes of individual parcels or neighborhoods. For example, a specific parcel might seem to be quite suitable for development but might be located on a former landfill; the model would not likely be able to account for this if the attribute is not already capitalized into the parcel's land value or into land-use or zoning regulations. Additionally, a specific Denver district might have unique neighborhood-organization politics or environmental constraints. If these hyper-local attributes are not captured in assumptions related to land use and zoning, or development pro-forma dynamics, these would not be captured by the Simulator.

[3] Please see **Appendix C** for details on economic scenarios

Additionally, the Simulator considers retrospective market and societal conditions but cannot dynamically 'predict' future economic changes or changes to demography or cultural or lifestyle preferences. As discussed above, this can be partially addressed by using economic scenario planning to approximate housing outcomes under a variety of market conditions, but the individual economic scenarios are necessarily static.

Finally, we are not predicting how developer behavior is likely to change, nor forecasting how many parking spaces they will opt to build in a given project as a response to changing requirements. Rather we assume several levels of parking inclusion relative to zoning and/or the historic average and run scenarios with each set of Parking Demand Assumptions. This is an important caveat because parking inclusion is not solely determined by cost of provision. Developers, lenders, and investors are also motivated to ensure their project is attractive to renters and can be quickly leased without substantial rent concessions, and so they try to anticipate renter demand. Many lenders and investors, therefore, impose their own parking standards as a pre-condition for their investment in a project. It is difficult to quantitatively model some of these more 'soft' dimensions like lender risk tolerance, perceptions of leasability, and cultural attitudes and renter preferences around cars and driving.[4]

[4] **Appendix D** provides additional guidance on limitations and interpreting results from the Simulator.

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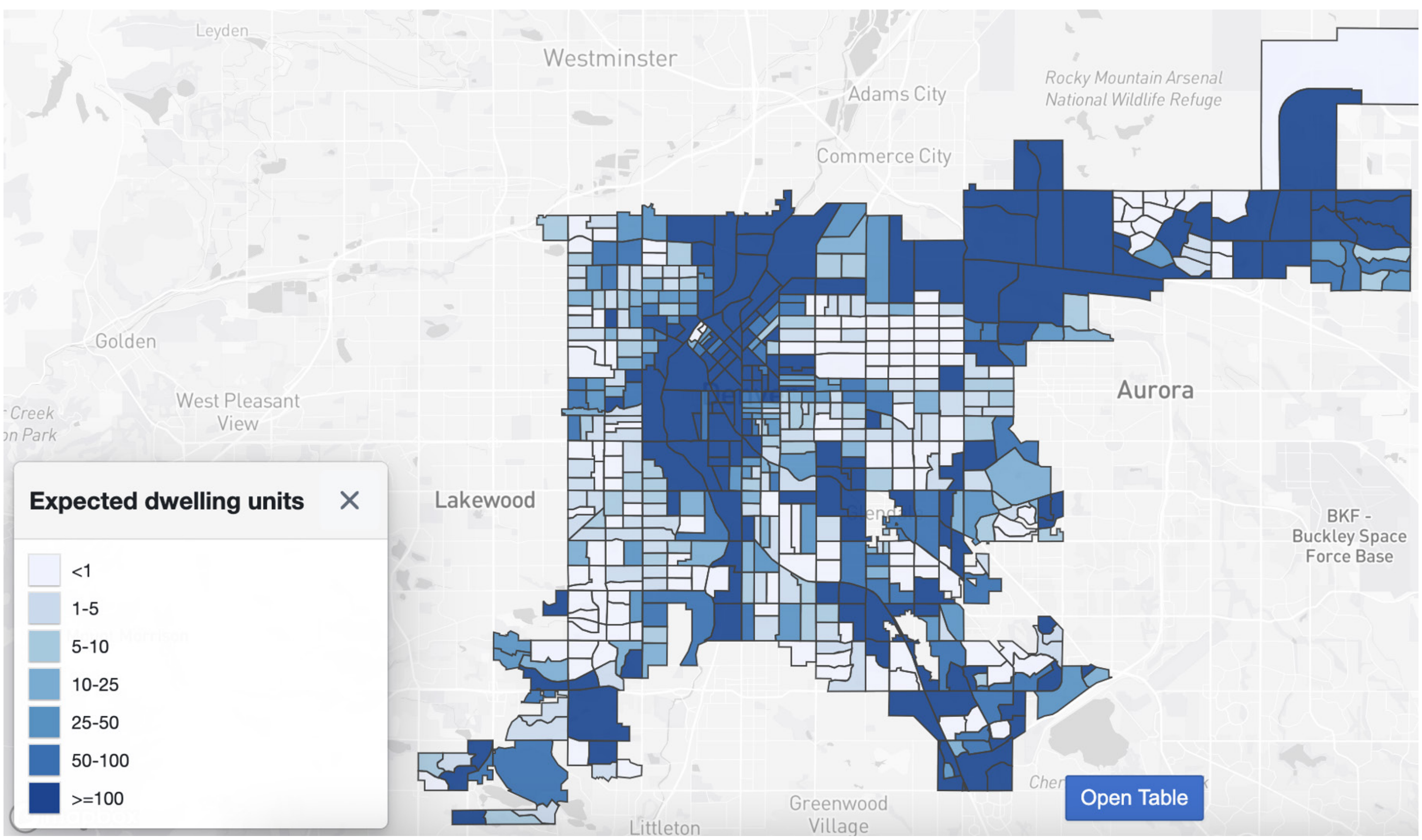
The map below shows status-quo development likelihood across the city of Denver under baseline assumptions. Note that expected development varies by neighborhood in Denver, and this is the case across all Scenarios. Based on land values, zoning and regulation, and financial feasibility, the parts of the city most likely to see housing development in the coming years are Central Denver, Cherry Creek, and Northeast Denver.

Findings across the three distinct sets of developer-provided parking assumptions

Parking Demand Assumption 1: Developers do not include parking unless required.

This assumption is illustrative only, as it only shows the maximum possible impact of the parking reform. It does not assume any voluntary provision of parking



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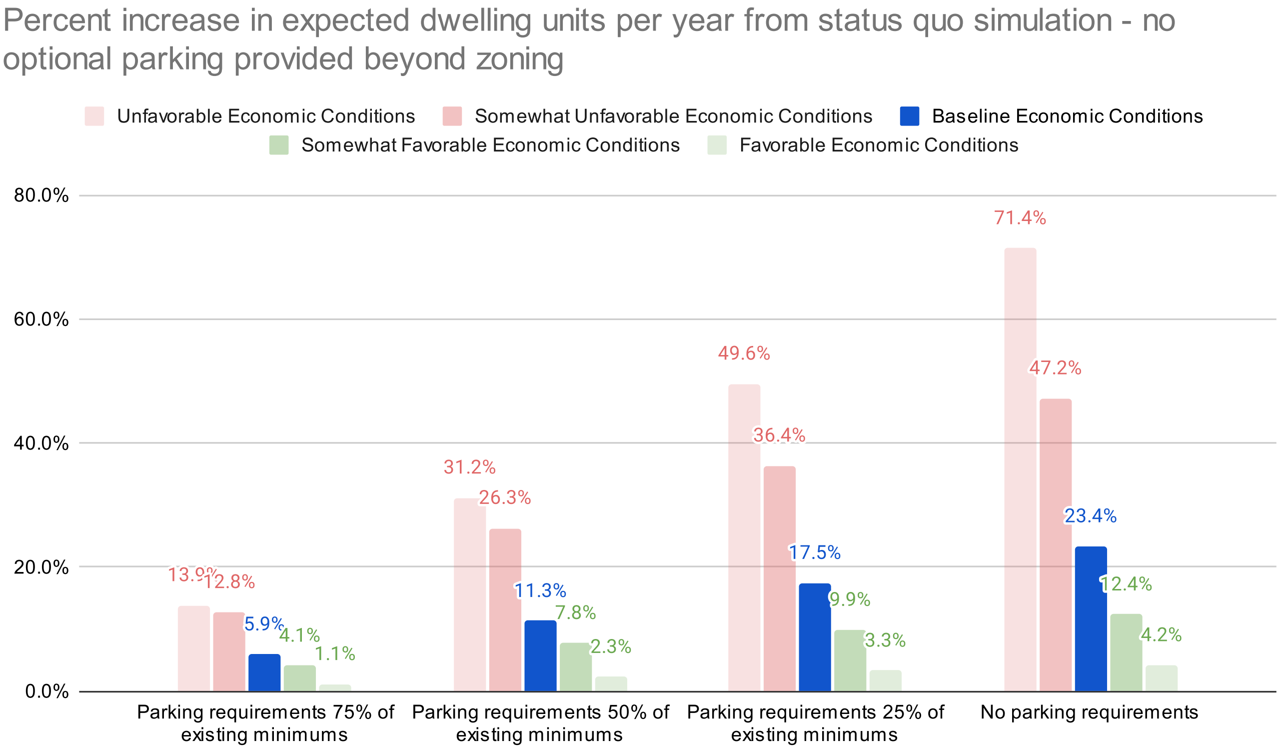
by developers as would be expected based on prior experience (in Denver and in other cities) and feedback from developers. However, despite this drawback this assumption does help set an "upper bound" on the potential impact of parking reform. It demonstrates that under no Scenario will eliminating parking minimums result in unprecedented amounts of new multifamily housing being built. Rather, the largest annual unit increase even with this "upper bound" assumption is 1,785 new units (under somewhat unfavorable economic conditions) - or about 17% of Denver's recent permitting peak (10,525 units in 2017).

REDUCED PARKING CAN NUDGE MORE PROJECTS INTO HIGHER DEVELOPMENT PROBABILITIES



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Parking Demand Assumption 2: Developers include at least 0.86 spaces per unit.

In this assumption, we estimate the developer will include approximately 0.86 spaces per unit, even if mandates are removed. This number is based on the average parking ratio from 119 completed and proposed residential and mixed-use projects in Denver, from 2020-2022, that had no parking requirements. In other words, on average, developers in Denver over that period built approximately .86 spaces per unit in those areas of the city without any parking mandates. Notably, the effect-size magnitude increases in the worst economic conditions, because in challenging economic times, the housing projects that include less parking are more likely to pencil than projects that include parking. By contrast, in more favorable economic conditions, more projects pencil overall and the number of projects that are made feasible by reducing the amount of parking required represents a smaller percentage increase over the baseline. Note that the benefit of reducing parking minimums is identical in three of the policy scenarios below; this is because this Parking Demand Assumption forces all projects to include at least 0.86 parking spaces per unit regardless of city mandates, so it somewhat artificially shows no marginal benefit to more significant city reforms. Additionally, since this Parking Demand Assumption is the most parking-intensive scenario modeled, it shows diminishing returns to reduced parking requirements in the most unfavorable economic conditions - this is because the economic conditions can be poor enough that projects are not feasible even with only 0.86 parking spaces per unit. These diminishing returns in negative economic conditions are seen in Parking Demand Assumptions 1 and 3 as well, when we modeled even more deeply negative economic scenarios.

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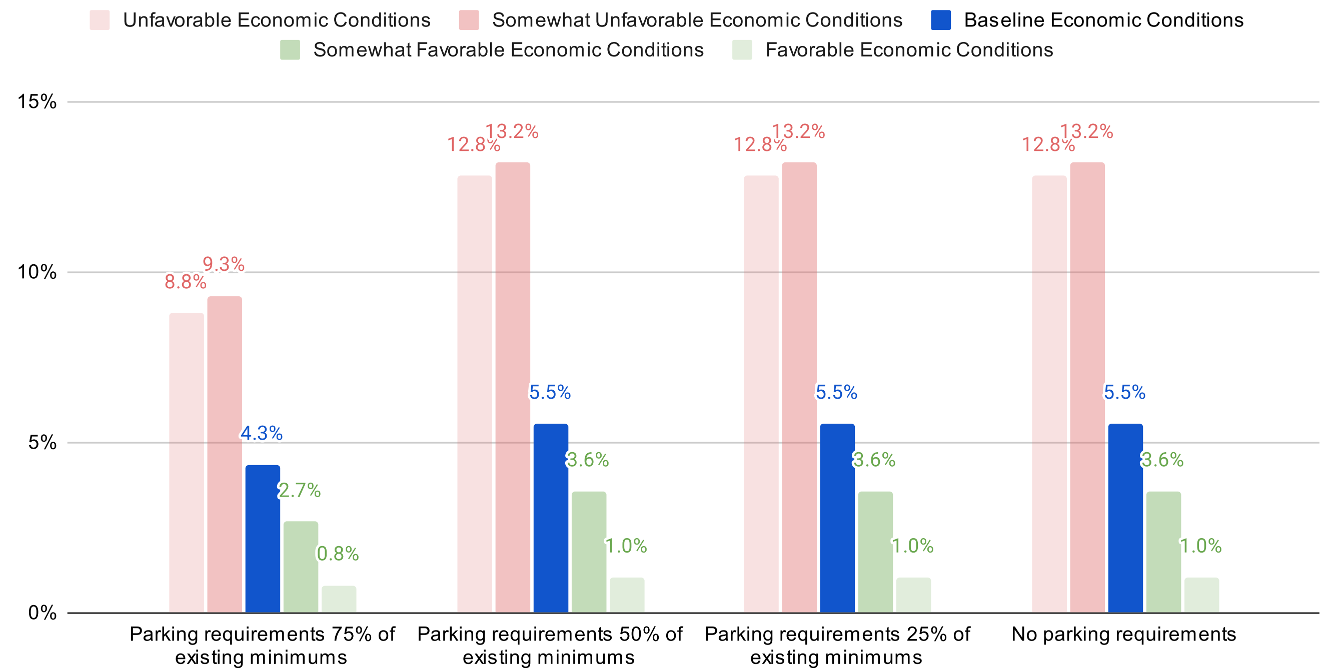
THOSE EFFECTS ARE REDUCED IF WE ASSUME DEVELOPERS WILL BUILD PARKING ANYWAY

Percent increase in expected dwelling units per year from status quo simulation - 0.86 optional parking provided



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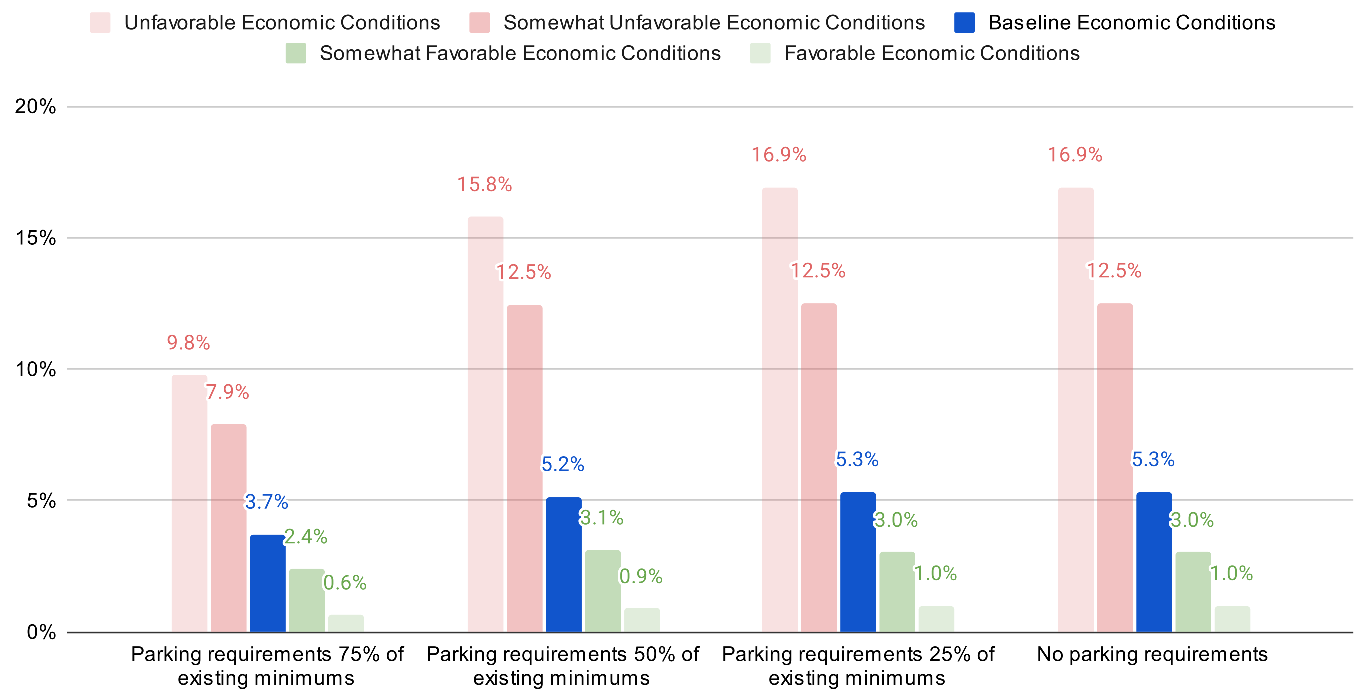
Parking Demand Assumption 3: Developers include at least 0.5 spaces per unit within 0.5 miles of a light rail station and at least 1.0 spaces per unit elsewhere.

In this last assumption, rather than assume a standard 0.86 units of developer-provided parking uniformly across the city, we instead assume that developer-provided parking is likely to be reduced in transit-adjacent areas compared to locations that are far from transit. This is a more nuanced and dynamic approach to approximating developer-provided parking.

EFFECTS ARE SIMILAR WHEN WE ASSUME DEVELOPERS PROVIDE LESS PARKING NEAR TRANSIT

Percent increase in expected dwelling units per year from status quo simulation - transit-dependent optional parking provided



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In Parking Demand Assumption 3, under the somewhat unfavorable economic conditions, eliminating city parking requirements but assuming developers will provide parking at 0.5 spaces per unit near light rail and 1.0 spaces per unit away from light rail, expected unit counts rise by over **460 marginal new units per year from a status-quo baseline of 3,682 expected units per year, a 12.5% increase.** While this is not necessarily a flood of new units, it is a non-trivial and substantive impact given that it results from a change in only one policy.

4 DISCUSSION AND IMPLICATIONS

Taken together, these simulation results show that eliminating parking minimums is likely an effective strategy to modestly increase housing production in Denver, especially in challenging development environments. In addition, based on conversations with Denver developers, the additional housing that ultimately gets built as a result of this reform is more likely to be middle-market or affordable than high-end or luxury, and more likely to be located near transit or in walkable neighborhoods rather than in highly car-dependent locations. Based on Denver's prior experience, most developers will continue to provide parking for their buildings to ensure they can attract tenants and meet investor and lender requirements.

Reducing parking minimums creates more options for developers and renters

Reducing parking minimums can lower costs and provide more design options for builders, especially for projects that might not otherwise be financially feasible. For developers, reducing parking minimums can allow them to shed costly above- or below-ground parking structures, making a wider variety of site plans and building layouts possible. This frees both physical space and financial capital that can instead go towards additional units or amenities for residents, or towards helping make the project financially viable at lower rent levels. In underwriting terms, the reduction in total development cost improves the project's debt service coverage ratio and yield on cost, meaning projects that once missed lender or investor thresholds can now secure financing.

This flexibility provides a vital buffer when real estate cycles turn and financing becomes more expensive, a benefit that most directly benefits middle-market and affordable developments that cannot rely on high-end luxury rents to ensure projects pencil. As cap rates rise and rent growth cools, reducing the cost of structured parking can save millions in development costs at a point in the cycle where even modest cost reductions can keep projects from stalling. Allowing developers the flexibility to control their own construction costs can help prevent middle-market housing production from freezing during cyclical downturns.

Parking will still be provided where needed

Even without municipal parking minimums, developers are incentivized to provide parking where needed. Undersupplying parking can create as much of a risk to the success of a project as overparking can. While providing excessive parking is financially and spatially costly during development, undersupplying parking can push potential tenants to look elsewhere for housing instead, ultimately reducing the rents the project can

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command. To balance these risks, many lenders and investors have their own minimum parking requirements standards or else require a site-specific parking demand study before they will put their money in a project. The result is a market-calibrated parking balance that more accurately reflects actual renter preferences and can vary widely by location and target market.

Reducing administrative costs can reduce housing costs

Municipal parking mandates impose hidden but significant administrative costs on both the city and on housing developers. Denver's recent Modernizing Parking Minimums report estimated that city staff spend 654 hours annually administering parking regulations - time that would be better spent focusing on critical health and safety reviews. This does not include the administrative and staff time spent by developers working to revise drawings and redesign site plans in order to meet these mandates. In addition to the costs associated with delay, every plan redesign and resubmittal results in additional architectural, legal, and consultant fees for developers while diverting city staff hours that could be focused on structural, fire, or accessibility reviews. These additional development costs are typically passed along to consumers in the form of higher rents, affecting housing affordability. Removing parking minimums will let initial plan reviews move faster, reduce revisions, and refocus government capacity on more critical issues, while reducing the added development costs that ultimately flow through to rents.

Collateral benefits of eliminating surplus parking requirements

This analysis focuses primarily on the impact of reducing mandated parking minimums on multi-family housing projects. However, removing or reducing parking minimums results in several collateral benefits that extend beyond the production of additional units.

First, removing mandates and minimums across the board frees up land for other, more economically productive uses, serving additional needs of the community and generating rents and revenue that support civic infrastructure. For example, commercial buildings and big box stores are often surrounded by acres of empty parking spaces required by zoning rules and mandated parking. These vacant spaces impose significant costs to the developer and landlord in construction and maintenance expenses while generating no economic benefit to the landowner or to the community. Worse, consumers pay for the benefit of those empty spaces at the register because the costs of those parking spaces are passed along through the pricing of goods and

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services. Allowing builders to determine the right number of spaces to serve the development's purpose can free up excess lands for more housing and more economically productive uses.

Likewise, reducing parking requirements can increase the flexibility to utilize small in-fill sites for missing – and much-needed – forms of housing, like duplexes or triplexes, and to allow for the adaptive reuse of historic buildings that may have been built before the city required on-site parking. On small lots or in the case of historic properties, building on-site parking spaces may simply not be possible due to site constraints. In these instances, rigid parking minimums can prevent the adaptation of these properties for housing or other uses and limit the production of small starter homes or middle-density housing types.

Finally, eliminating a requirement for surplus parking spaces allows more compact, efficient forms of development (or less sprawl), which results in many collateral benefits. For example, compact development reduces the per capita cost of building and maintaining sidewalks, energy and water infrastructure, and other services. It also can result in better urbanism, with more walkable, pedestrian-friendly, and connected neighborhoods at a level of density capable of supporting desired amenities like bike paths, parks, retail establishments, and other community assets. When located near transit, compact and transit-oriented development that prioritizes people over parking leads to more transit ridership, which in turn, maximizes the utility of significant public investment in public transportation, reduces environmental impacts and gridlock, and supports healthy, thriving communities.

CONCLUSION

The combined results of the seventy five model Scenarios supports the conclusion that Denver's current minimum parking requirements materially reduce housing production. When we eliminated those requirements and ran the simulation model, assuming developers continue to provide parking to approximately the same extent they have historically when freed from parking mandates, the model showed a notable increase in multifamily production regardless of economic conditions. Across the two realistic sets of assumptions for developer-provided parking and the five economies tested for each, the predicted increase in housing production above the status quo policy environment averaged nearly 8%, representing nearly 450 additional homes per year - a modest but real and important contribution towards addressing Denver's housing shortage. Critically, the expected increase was most significant in challenging financing environments like that of today, when pro-forma margins are weak and every cost reduction matters. In other words, removing minimum parking requirements is best understood not as a silver bullet to end the housing crisis but rather as a simple reform to help smooth out typical boom-bust multifamily development cycles by modestly increasing the amount of homes that are feasible to build during development downturns.

These production gains are the result of two primary mechanisms. First, the direct cost savings of tens of thousands of dollars per unit from not building structured parking improves the financial metrics that investors and lenders analyze before putting their money in a project. Second, eliminating parking minimums rewards design creativity: architects can repurpose physical space from parking spots to homes, allowing more homes to be built on a given lot and allowing tenants to only pay for parking that they actually use rather than having it priced into their monthly rent. The result is lower per-unit costs without public subsidy, healthier project underwriting in downturns, better administrative efficiency for CPD, and a modest contribution to Denver's climate and mobility goals by removing the cross-subsidy that incentivizes car ownership.

Equally valuable is what this analysis taught us about the Denver Housing Policy Simulator. First, scenario modeling is essential. By testing the policy change under a range of economic conditions and Parking Demand Assumptions, the Simulator illuminated nuances in the effects of this policy change that a single-scenario analysis would have missed. Second, accurate assumptions are critical. Discussions with builders, developers, and lenders who spend every day working to get multifamily housing projects built were key to refining the construction cost and financing assumptions underlying the model.

CONCLUSION

This analysis also illuminated other potential use cases for the simulator model. In addition to parking, the model is well equipped to analyze the effects of 'missing middle' policy reforms, accelerated permitting timelines, and even revised inclusionary zoning requirements, all under a variety of economic conditions and model assumptions. In other words, this Simulator can help researchers and policymakers model the comparative effects of a wide variety of proposed policy changes in order to identify which policies are likely to be the most effective at addressing a given policy goal. Perhaps the most powerful feature of this tool is the opportunity it creates to ground Denver's housing policy in data rather than anecdotes and keep the city at the forefront of evidence-based housing policy reforms.

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Appendix A: Simulator Methodology in Detail

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1. Overview of the Terner Housing Policy Simulator: The Terner Housing Policy Simulator (THPS) enables policymakers and researchers to simulate the impact of various policy scenarios on the financial feasibility of housing development. The Simulator models a comprehensive suite of feasible multifamily developments on a site, the financial viability of each potential development, and the likelihood of development for the most profitable option. Users can then toggle between policy options and compare their potential impact on future development. The Simulator uses a built-in pro forma to calculate the profitability of rental projects, from a duplex to a 1,000-unit building, which conform to site regulations and user input assumptions across potentially hundreds of thousands of parcels. After determining which building type is legally allowable, physically possible, and financially profitable, the Simulator identifies the optimally profitable structure. The Simulator then cross-references historical building data from the

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given jurisdiction and assigns a probability weight to the parcel, which indicates how likely it is that this project would be built.

1.1 Breakdown of Terner Housing Policy Simulator: The following files and programs are used to create the Simulator:

- Parcel file: This file contains the parcels of a city or county with coordinates and geometry attributes. This is sourced from local or county governments. Terner Labs staff assign property values using assessor data and other methods sourced from Landvision™ or directly from county assessor offices. Terner Labs staff disqualify undevelopable portions of parcels such as parcel slopes (see Note 4), public easements, rivers, parks, airports, graveyards, and roadways based on geographic data from OpenStreetMaps™. Condo parcels stacked on top of each other are flattened into one, condo-identified parcel. Irregularly drawn parcels adjacent to each other with the same owners or accessor parcel number are combined into one parcel.
- Assumptions layer: Controls the economic, construction, and financial assumptions used in our pro forma calculations. Assumptions can vary by zone, neighborhood, city, county, or state, or remain consistent across all simulators.
- Zoning layer: A shapefile containing zoning geometries and associated construction rules within the zoning code which will be spatially joined to the parcel file. This is sourced from local or county governments.
- Generic pro forma: The core of the Simulator, for which all parcels will undergo analysis to determine the feasibility of developing housing. For each parcel, up to 60 hypothetical projects will be evaluated through the pro forma's 10 modules to determine the profitability and feasibility of each project. The modules are explained in section 2 below, and the Simulator will evaluate each project through them in the respective order described.
- MapCraft™ web application: MapCraft is the online interface between users and the aforementioned files and pro forma and where the Simulator is hosted. On the MapCraft interface, users will be able to run a simulator and visualize the expected number of dwelling units built and other outputs for each parcel on a digital map. Users can toggle different economic, zoning and other policy scenarios on the side pane and re-run the pro forma simulations using these inputs.

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Parcel files, zoning files, and fee information are sourced from city or county websites or provided by planning department staff. Economic assumptions are sourced from federal data sources or building industry reports. Some local development and economic assumptions were provided as direct feedback from multifamily developers working in those jurisdictions, or were derived from actual project budgets/pro formas shared with Terner Labs.

2. THPS Proforma Modules

The pro forma consists of several modules that estimate the construction parameters, costs, and revenues of a project at each stage of its development, from conception to disposition (the re-sale of a property once development is completed).

To start, each pro forma contains configuration files. These files will make up the input toggles and outputs that users see on Mapcraft for a given simulation run. This is required for the Simulator to work. Refer to Mapcraft Toggle Inputs for all variables and their descriptions.

Configuration Setup:

- User inputs: The 80 fields users will input (or default to) consisting of construction constraints, economic climates and laws. Each jurisdiction is studied by Terner Labs when determining default assumptions. Typical sources for the default data include Federal Reserve reports on vacancy rates and inflation; HUD data on area median income for below-market-rate dwellings; state-specific construction costs for low- and high-rise buildings from MetroSight™ (an economic consultant specializing in housing development economics); and timelines for obtaining entitlements from local government sources.
- Parcel inputs: Statistics on each parcel concerning size, zoning constraints and proximity to transit or special districts. These are provided by Terner Labs and can be modified upon request.
- Parcel outputs: The results and intermediary calculations of the simulation that pertain to individual parcels such as optimal dwelling counts, likelihood of development, net revenue after construction, assume parking spaces added, total fees, or construction type. Data includes area-wide averages and summations such as expected dwelling units or median likelihood of development.

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2.1. Building Envelope Module

The building envelope determines how many units can be built on a parcel based on the zoning regulations and physical restrictions of the parcel. The Simulator begins by creating 60 hypothetical apartment projects by density. The lowest density project is a duplex (2 units) and the highest is a large building of 1,000 units. The Simulator assumes that each unit in a project is a 2-bedroom unit, sized between 900 - 1,100 square feet depending on the jurisdiction (refer to “Dwelling Unit Specifications” for more). In between these are 58 different density levels. The Simulator does not yet determine a single allowed number of units for a site; rather, it evaluates whether each of the 60 potential building sizes falls within the constraints of the parcel and its zoning requirements.

The land use policy, which determines the building envelope, is drawn from the jurisdiction’s generalized summary of zoning regulations, including:

- Maximum and/or minimum floor area ratio (FAR)
- Maximum dwelling units per lot
- Maximum and/or minimum dwelling units per acre (DUA)
- Maximum height of buildings (both feet and number of stories)
- Maximum lot coverage of the building footprint
- Averages of the setbacks on the front, back, and sides of parcels
- Maximum and/or minimum parking requirements per dwelling

The building envelope will determine the maximum unit count and building size a project can construct on a parcel and disqualify building scenarios that exceed the limit.

To determine the maximum number of dwelling units that can be built on a parcel, the building envelope calculates up to four different theoretical maximum dwelling unit limits, depending on what aspects of a zoning code are applicable for the parcel.

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A development's maximum density is determined by the four zoning conditions:

- A direct limit on maximum dwelling units per lot
- Maximum dwelling units per acre and the parcel's acreage
- Maximum density by floor area ratio and allowable building footprint
- Maximum height and lot coverage limits

If zoning does not specify one of these conditions, then it will be ignored, and the other conditions will be used to calculate maximum theoretical density. When maximum lot coverage is not regulated through zoning requirements, the envelope assumes that the building footprint is a square, and maximum lot coverage is obtained by reducing twice the site's average directional setback from each side of the square. This calculation generates the buildable area. The number of assumed surface parking spaces included on a given project directly impacts the maximum building footprint that the building envelope calculates (more details on parking are included in the construction section below). If lot coverage is specified, then the same formula is applied on a square of the specified size. Once this is finished, the lowest of the four maximum number of dwelling units is chosen.

2.2. Construction Module

The construction module estimates construction costs for the 60 different housing project types described above. With the maximum density derived from the building envelope, the Construction function creates a building to fit each project scenario's maximum density. Project scenarios that exceed zoning requirements in the Building Envelope module, or are physically impossible within parcel constraints, are identified as unfeasible and will not be further analyzed.

In real estate development, buildings are often referred to as low-rise, mid-rise, and high-rise (specifics are provided under "Building Structure Costs"), and the Simulator will determine which type of building best accommodates a project's maximum density. For each building type, the simulation assumes a fixed marginal cost per square foot and a maximum density any building type can achieve (refer to Note 1 for the justification for the marginal cost being fixed).

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Parking costs are estimated as a cost-per-square-foot value for surface parking, underground parking, and above-ground parking, and multiplied by the minimum number of spaces or stories required by local and state parking regulations. Parking is classified as being either “all-surface”, “all-aboveground,” or “all-underground” and multiple parking typologies are not mixed within a given project. Based on the assumed number of spaces required and/or included in a project, the parking structure that allows for the least costly building type is prioritized, even if the parking structure itself is more expensive. For example, if a mid-rise project is possible with above-ground parking, but fitting the same number of units using cheaper surface parking would require the building to be a high-rise, the Construction module will pick the mid-rise because the overall project will likely be cheaper. Otherwise, if a project is mid-rise under either parking typology option, the pro forma will opt for the cheaper surface parking rather than aboveground.

The maximum amounts of surface and aboveground parking were obtained as follows:

- Maximum surface parking: The minimal floor plate (refer to glossary) needed to accommodate the set number of dwellings, given average dwelling square footage and the maximum number of floors subtracted from the maximum buildable lot area (lot size times the derived maximum lot coverage). The difference is divided by the gross square footage of a surface parking spot.
- Maximum above-ground parking: The square footage (as opposed to floor plate) needed for accommodating the set number of dwellings, given average dwelling square footage, subtracted from the maximum buildable square footage (lot size times the derived maximum lot coverage times max height in floors). The difference is divided by the gross square footage of the non-surface parking spot.
- Underground Parking is only utilized if above-ground and surface parking is not feasible.

The module also calculates the estimated entitlement cost of each project scenario, based on the size of the building and subjective political assumptions. These include:

- Entitlement duration: default assumptions vary by jurisdiction and building typology. Many of the default assumptions are provided by city staff based on prior studies. Users can change these assumptions in the interface using input toggles (refer to Note 2 for more about these assumptions).

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- Entitlement cost: This is assumed to vary by building size as well. For 2-4 unit buildings the entitlement process is assumed to add 1% to the total construction cost (which excludes the cost of land). For 5-49 unit buildings, it is assumed to add 3% to that cost, and 5% for 50+ unit buildings.
- Entitlement density compromise: This is the most subjective input in the Simulator. The entitlement process is assumed to have the effect of reducing a development's density above the joint effect of explicit land use policies on the building envelope. At times, developers during the entitlement process will reduce the density of their projects to satisfy community boards and win approval. Users can set what percentage of density a proposed project would likely be shrunk down by during the community engagement process. The default setting is to not reduce unit count below the entitled amount; however, the user can toggle different density compromise amounts by whether a building is low-, mid- or high-rise.

For each scenario, the construction function returns a parking structure type, a building type (low-, mid-, or high-rise), the height of the building, and its associated construction costs, entitlement costs and building time in months. The Simulator defaults to assuming that construction will take 14 months for low-rise buildings, 18 months for mid-rise, and 24 months for high-rise, unless these assumptions are changed by the user.

Building Structure Costs:

Each building type (low-rise, mid-rise, and high-rise) assumes a fixed marginal cost per square foot, and parking structures (above-ground, below-ground, and surface-level) assume a fixed cost per parking stall. These costs vary by jurisdiction and are sourced from county economic reports (data is mostly limited to 2023 but is inflation-adjusted for the current year). Users also have the option to choose different construction timeframes for each building and parking type.

Building Assumptions are outlined below. Refer to the glossary for more information about construction types:

- **Low Rise**: Construction Type VB for 2-4 units; Type VA if greater than 4. The building height is 1 to 4 stories. The building material is wood frame. The maximum density is 30 dwelling units per acre.
- **Mid Rise:** Construction Type IB. The building height is 5 to 12 stories. The building has a concrete podium with a

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wood frame structure on top. The maximum density is 100 dwelling units per acre.

- **High Rise:** Construction Type IA. The building height is 13 stories and beyond. The building has a steel frame. The maximum density is 400 dwelling units per acre.
- **Above-ground Parking:** 400 square feet per stall.
- **Surface-Level Parking:** 330 square feet per stall.
- **Below-ground Parking:** 400 square feet per stall.

2.3 Fee calculator Module

The Fee calculator is a collection of local fee schedules compiled and written by Terner Labs staff to automatically calculate anticipated fee amounts per parcel and per building type for each jurisdiction. Fee districts that spread beyond city limits such as utility, water and school districts are also included.

Certain local fees were incorporated differently depending on the way in which they are apportioned, e.g. as a lump sum fee, or in proportion to the number of dwellings, the square footage, or the construction cost. Fees were collected from city, county, and special district fee schedules and categorized as environmental fees, impact fees (e.g. schools), building services fees (e.g. utilities), or planning department fees. Generally, Terner Labs staff cross-referenced these fees with the fees for actual development projects paid out (if city or county staff provided this information). Certain fees are “flat fees” and apply to all projects citywide. Each project is provided with a summation of fees across these four categories. Users can experiment by setting these fees or voiding them using toggles.

For fees where unit specifications are relevant, the assumed dwelling unit specifications are as follows.

Dwelling Unit Specifications:

- 1,000 square feet (this can be changed by the user)
- 3 people in a dwelling

- 1 bathroom
- Valuation per square foot is sourced from the given jurisdiction or the International Code Council's Building Valuation Table

2.4 Operating Revenue Module

The operating revenue module determines the average net operating income per unit. Net income is rental income minus the income lost to vacancies (based on the vacancy rate) and operating expenses. Operating expenses are a percentage of a building's overall revenue.

Income is calculated by multiplying the number of market-rate units by the average rent price for newly constructed rental units of a similar density in the area, sourced from CoStar™. The Terner Labs staff use data from CoStar to set market-rate rents to those of comparable new buildings.

Below market-rate (BMR) units' rents and the discount on them relative to market-rate, are calculated from the county or HUD income limit and are also added to the building's total income.

Operating expenses for a multifamily building include property management, staffing, janitorial services, utilities, insurance, property taxes, insurance, maintenance, repairs and turnover, and replacement reserve. The simulator assumes a 30% cost when adjusting gross operating income to net operating income. This figure was obtained from an analysis completed by MapCraft. The vacancy rate is used in adjusting from gross to net operating income. The vacancy rate is sourced from CoStar data on new rentals in local submarkets.

2.5. Financial Outcomes Module

2.5.1 Property Values and Imputation Methodology

A key component in the simulator's financial metrics is the assumed cost of acquiring the land. This is also the only way in which the existing use of the parcel is taken into account. There is no readily available source of information on every parcel's current value. To predict the cost of buying property, we used a series of statistical modeling techniques

based on county assessment data, outlined below:

1. Acquire property value assessments from the County Assessor
2. Join property information with Census total population and neighborhood indicators.
3. Use spatial data from OpenStreetMaps™ to disqualify parcels located on streets, railways, rivers, parks, cemeteries, etc., and isolate developable areas, if any
4. Use a clustering analysis to group lots that resemble parcels of similar size, zoning and other attributes
5. Acquire recent property sales, remove outliers in the data, and use a Cubist tree machine learning model to train this data
6. Identify parcels that have missing assessor data
7. Predict the current year property values of lots whose tax assessment data we have based on Cubist tree training data and fill missing assessments with the mean of comparable lots from the cluster groups
8. Conduct a second round of outlier value detection of parcels' land values per square foot and correct these outliers using a group mean imputation

2.5.2 Financial Metrics Methodology

The Financial Outcomes Module calculates three financial outcomes for all scenarios of housing projects not yet disqualified:

1. Residual land value to property value ratio (RLVPV): A static measure that divides the residual value of the development and land by the cost of acquiring the property.
2. Net present value (NPV): Dynamically considers the timing of income to estimate the net value of a property post-development compared to its present value.

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3. Net present value per dollar of equity (NPV/E): Divides the NPV by the total equity of a project to determine investor return exclusively.

These metrics were chosen to account for the timing of cash flow, a demonstration of how multiple financial measures could be combined, and the lighter computational burden of NPV versus its sibling measure, the Internal Rate of Return (IRR).

The NPV and RLVPV additionally depend on the assumed cap rate at disposition, the typical loan-to-cost ratio that dictates the necessary investor equity, investors' preferred returns, and the duration of construction, as well as the cost of acquiring the land for development. NPV is the same as RLVPV with the addition of investors' preferred rate of return.

2.5.3 Economic Assumptions

The following assumptions are subject to change by users but most financial assumptions are sourced from CoStar or from macroeconomic reports from Federal Reserve Economic Data (FRED) and include the following:

- **Interest rate:** Construction loans are assumed to persist through the sale of the development at the end of the stable period following absorption. The interest on loans is assumed to be 7% in 2025 based on FRED data.
- **Loan to construction cost (LTC) ratio:** The LTC ratio determines the equity and debt mix is assumed to be 65%.
- **Multifamily cap rate:** The cap rate used to infer the proceeds from selling the development from its net operating income. The capitalization rate varies slightly by area and is sourced from CoStar.
- **Investors' preferred rate of return:** Investors' preferred rate of return, which is essential in determining the residual land value, is assumed to be 10%. This figure is obtained from MapCraft.
- **Absorption** is assumed to progress at a pace of 30 units per month, and the stable period following absorption was assumed to take 18 months. These figures were sourced from consultation with select developers.

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These assumptions can be adjusted by users and default values may vary slightly by jurisdiction.

2.5. Optimal Building

With income flow and residual value determined, the optimal building phase will select the most profitable development scenario out of the 60 project scenarios analyzed that have proven technically and legally feasible. The building type for each parcel determined to be financially optimal is the result that users will see in the Simulator. Subsequent statistical aggregations regarding overall housing development statistics for a region will also be based on the optimal dwelling unit count for each parcel.

Each development project scenario is assigned a single score based on a combination of the residual land value to property value ratio (RLVPV), net present value (NPV), and net present value per equity dollar (NPV/E) from the prior module. This score reflects how consistently profitable a given scenario is. To calculate the score, a Cobb-Douglas utility function is used, which favors scenarios and building types that perform moderately well across most or all financial metrics, rather than those that excel in a few areas but perform poorly in others (refer to Note 3 for details)

After scoring, the building project that is most likely to be profitable and feasible in a variety of financial scenarios (the “optimal dwelling unit”) is identified.

2.6 Probability Module

With the most optimal project determined, the probability of this project being built is weighed against the historical outcomes of similarly-scored projects using the Terner Simulator Probability Model. The probability model is calculated outside of the pro forma framework, and its resulting coefficients are applied within the Probability Module of the Simulator’s pro forma. The Probability Model uses the historical relationship between the development of financial feasibility metrics and observed multi-family residential development to estimate the likely number of residential units resulting from a given simulation.

The Simulator is grounded in the idea that developers tend to make rational, profit-maximizing choices about where and when to build new residential buildings in a city. While parcels with higher development feasibility metrics

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are expected to be more likely to develop, there are a variety of reasons that profitable parcels may not actually see development during a given time period. For example, the existing parcel owner may have highly specific and unobservable financial considerations. Another use not considered in the Simulator's pro forma may be more profitable (e.g. a hotel or office building). In a given year, there is a limited set of existing real estate developers that have access to a limited amount of capital. Even in a constrained market, only a limited number of new residents are able to occupy any new construction, and overbuilding will drive down prices in the short term, making simultaneous construction on all feasible sites not actually feasible.

The probability model is built by constructing "historical Simulators" in jurisdictions with current-year Simulators. These historical Simulators are meant to capture conditions about 5 to 15 years before the current year (see Note 5). Each historical Simulator uses historic zoning, land values, economic assumptions and rents to estimate past financial metrics derived from the Simulator's pro forma framework, and observe the relationship between those metrics and actual observations of development that has already occurred by the current year. The historical parcel file includes an additional field indicating whether development occurred on the parcel between the historical year and the current year, along with the year it was built and the number of units added. This data is primarily sourced from CoStar and county assessments.

The parcel-level multi-family conversion rate is computed by dividing the number of parcels developed during the observation period by the total number of parcels that legally allow multi-family development. This number is then annualized to allow for comparison between jurisdictions with different historic period lengths and between segments of the observed time period to better understand the range of development rates. The conversion rate provides a simple indicator of how likely parcel conversion was during the historic period and offers potential insight into the likely rate of conversion today.

A statistical model is then used to ground this historic rate of conversion in the macroeconomic and land use policy environment of the historic period, so that an improved conversion rate is available for various current-day scenarios where either or both of these factors may have changed. Specifically, a logistical regression model is used to model the relationship between the development metrics output from the historic Simulator and the observed development

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dataset. This model aims to capture the behavior of the pool of potential real estate developers present during the historic period. The unit of analysis is each parcel that legally allows multi-family residential development. An observed development event represents the case where a developer made the choice to build a new muti-family building. We expect the probability that a parcel is developed to increase monotonically as the financial metrics increase. We also expect other factors (both observable and non-observable) to make the relationship between the financial metrics and observed development less consistent.

Once estimated and, if needed, calibrated, the logistical regression model is used to predict the number of units likely to be built with a different set of pro forma model inputs. This generally involves changes to the macroeconomic or policy inputs that impact the development feasibility metric. The model's prediction assumes that similar levels for this metric will lead to similar probabilities of parcel conversion, and uses this relationship to predict the probability of parcel conversion with the modified inputs. These probabilities are then multiplied by the pro forma's optimal dwelling unit output for each parcel to calculate the number of annual expected units for a given scenario.

The results of the historical simulation are then entered into a logistical training model that estimates the probability of projects with similar RLVLV, NPV, and NPV/E outcomes. The Probability Model returns a series of bivariate slopes, ranges of probabilities, and a model. Each parcel's three financial outcomes are then calculated as a bivariate value against the probability model's coefficients and the average of the three values is chosen as the final probability of development (between 0% and 100% likelihood of development).

3. Notes

Note 1: If the marginal revenue did not vary with building size then these assumptions would imply that developers would always choose to build either at the maximum allowed density or at the upper end of a building type's feasible density. That is still mostly the case, but not necessarily (because rents can vary with building size).

Note 2: These default values are drawn approximately from the findings on entitlement process duration reported in O'Neill et al. The approximation involves choosing round numbers closer to the entitlement duration mean than to the median. The former tends to be higher, indicating a long right tail of drawn-out entitlement cases. The choice of the

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mean over the median can therefore be considered an approximation of developers' risk aversion.

Note 3: Before entering the utility function, financial metrics must be standardized so that they are suitable for an apples-to-apples comparison (the utility function is set up to treat all of the financial outcomes symmetrically). This is achieved by subtracting their mean and dividing by their standard deviation (both mean and standard deviation are taken from among the 60 potential building sizes, weighted by the gaps they represent along the 2 to 1000-unit spectrum).

In some edge cases, this optimization function can yield counterintuitive results. Although these edge cases are typically avoided with more intuitive directional results in city-level simulations, the optimization function represents another reason results should be interpreted in the aggregate rather than at the parcel level. For example, under a status quo policy simulation on one parcel, a 160-dwelling unit building and 230-dwelling unit building both require underground parking. After applying the financial module and the optimal building module, the 230-dwelling unit scenario "wins." Under a policy scenario where zoned parking minimums are removed, however, the 160-dwelling unit building no longer requires underground parking (it can actually fit aboveground), whereas the 230-dwelling unit building still requires underground parking. Despite the 160-dwelling unit building presenting a lower NPV ($11M vs $16M) and NPV per equity dollar (0.4037 vs 0.4088) than the 230-dwelling scenario, due to a higher RLVLV (0.78 vs 0.63), our optimization function for this particular parcel identifies the smaller 160-dwelling unit building as optimal.

Note 4: Data on the average percent gradient of every parcel was obtained from MapCraft. The Simulator currently assumes that construction is impossible on parcels with a slope greater than 30%. Users can also choose to activate construction cost premium above a 20% slope, but that option is not activated by default. Sloped sites generally require greater site preparation work, but cost implications are limited for those sites with slopes less than 10% (see here). For steeper slopes, costs typically can rise. The additional costs of building on steep sites may be in the range of several hundreds of thousands of dollars per acre for multifamily sites, which may be a small fraction of the overall development cost of a large multifamily development. For buildable sites in strong markets with relatively intense entitlements, one could argue that slope-related costs are insignificant. Note that multiple site characteristics (such as a low water table or unstable soils)may also add to development costs. We do not currently have spatial data for these

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factors. Although we do our best to realistically model parcel-level development feasibility, it is impossible to account for all site-specific factors that impact the cost of development.

Note 5: Older versions of the THPS simulator used a percentile premium of fair market rent levels from the census however this is now being phased out. Specific data on Co-Star rents is not available for public viewing per a contractual agreement with Terner Labs, however, comparisons with previously used Fair Market Rent methodology by Terner Labs staff have indicated that Co-Star's data is more accurate in its sampling of market-rate rents.

Appendix B: Baseline input assumptions

Baseline assumptions

Variable	Final
Absorption rate (units per month)	30
Affordable rent share for linkage fee exemption (High Market Area 60% of AMI)	10%
Affordable rent share for linkage fee exemption (Typical Market Area 60% of AMI)	8%
Affordable rent share for linkage fee exemption (High Market Area 70% of AMI)	15%
Affordable rent share for linkage fee exemption (Typical Market Area 70% of AMI)	12%
Affordable rent threshold (60% AMI; 2bd)	1761
Affordable rent threshold (70% AMI; 2bd)	2054
Bonus affordable rent share (High Market Area 60% of AMI)	12%
Bonus affordable rent share (Typical Market Area 60% of AMI)	10%
Bonus affordable rent share (High Market Area 70% of AMI)	18%
Bonus affordable rent share (Typical Market Area 70% of AMI)	15%
Cap rate at time of sale	5%
Entitlement added cost, percent, 2-4 units	1%
Entitlement added cost, percent, 5-49 units	3%
Entitlement added cost, percent, 50+ units	5%
Entitlement timeline, months, 2-4 units	9
Entitlement timeline, months, 5-49 units	18

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Entitlement timeline, months, 50+ units	21
Annual appreciation in rent	3%
Vacancy rate	8
Marginal construction cost per square foot, low-rise (wood)	297
Marginal construction cost per square foot, mid-rise (wrap around or podium plus)	390
Marginal construction cost per square foot, high-rise (steel & concrete)	474
Parking space cost, surface lot	$10,309
Parking space cost, aboveground garage	50,000
Parking space cost per square foot, underground garage	65,000
Average gross square footage of recently built (>=2010) dwelling units in 5+ unit multifamily buildings in the city	940
Months to construct low-rise	14
Months to construct mid-rise	21
Months to construct high-rise	27
Floor height (feet)	15
Stable months required before sale	12
Loan interest, annual	7
Loan to cost ratio	65
Max buildable slope (percent)	30%
Maximum density for low-rise construction (du per acre)	30
Maximum density for mid-rise construction (du per acre)	100
Maximum density for high-rise construction (du per acre)	400
Maximum floors for low-rise construction	4
Maximum floors for mid-rise construction	8
Minimum floors for high-rise construction	9
Operating expenses as share of revenue	30
Parking space gross square footage, surface lot	330
Parking space gross square footage, non-surface	400
Investors' preferred rate of return	10%

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Appendix C: Economic Scenarios

Variable	Unfavorable	Somewhat Unfavorable	Baseline	Somewhat Favorable	Favorable
Interest rate	9%	8%	**7%**	6%	5%
Rent appreciation	1%	2%	**3%**	4%	5%
Cap rate	5.5%	5.25%	**5%**	4.75%	4.5%
Vacancy rate	10%	9%	**8%**	7%	6%
Preferred rate of return	12%	11%	**10%**	9%	8%
Building per sq ft construction cost	105%	102.5%	**100%** *$297 lo-rise* *$390 mid-rise* *$474 hi-rise*	97.5%	95%
Parking space construction cost	105%	102.5%	**100%** *$10k surface* *$50k aboveground* *$65k underground*	97.5%	95%

Appendix D: Additional Caveats for Interpreting the Simulator Results

We note three additional caveats for this study: the scope of development types and parcels included in the Simulator; the necessary simplifications for conducting citywide simulations of given policy scenarios; and the potential limitations of Simulator's marginal economic analysis

- **Scope**
  - The Simulator's pro forma is specific to development of multifamily, market-rate rental housing. The Simulator does not model single-family housing production. The Simulator can include production of affordable units within market-rate projects (e.g., through inclusionary zoning), but it does not model the production of affordable housing subsidized through sources like the Low-Income Housing Tax Credit.

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  - The model is limited to the parcels for which the pro forma analysis can be conducted. This precludes, for example, parcels whose observed regulatory restrictions do not currently allow multifamily development, but which could be rezoned. In particular, parcels zoned for single-family homes are not assessed, though ultimately some of these parcels are indeed converted. Also omitted from our analysis are developments that become feasible when the potential for lot assembly is considered, like when two adjacent parcels are acquired and merged into one development. The pro forma also does not currently consider commercial space within a project.

- Necessary Simplification
  - Because the Simulator applies the same generic pro forma across all parcels—an exercise typically done by examining the characteristics of one parcel at a time—it requires simplified generic assumptions that can apply to all parcels (e.g., generic building shapes with consistent unit size). This allows the model to translate the impacts of policies and economic factors into inputs that drive cost/revenue and answer questions typically reserved for an individual project for entire swaths of parcels across a neighborhood or city. However, the generic pro forma will not out-perform a developer's pro forma for a given parcel, consider every possible alternative use for the land, incorporate design variability or parcel changes like unique unit types or lot assembly, or assess development decisions not based on financial performance (e.g., some affordable housing developments).
  - Relatedly, the Simulator assumes that development decisions are made to maximize financial returns in a manner that may not align with people's actual behavior. For example, a 12-unit building may exhibit the best financial returns in the model, yet a developer might instead opt to build a luxury triplex with an outdoor pool instead.
  - When using expected unit counts as the primary unit of measurement, one must be careful in how they interpret a single parcel's estimate. Take, for example, a parcel where the optimal structure type is 200 units and the financials from the structure place the parcel among the highest-likelihood to redevelop. Given the

overall low odds of any development, the expected unit count is reduced to 30. But in practice a developer who does decide to build a 200-unit structure will either build the full 200 on the parcel or not at all. Therefore, the expected unit counts work well to compare rates of increase from the baseline across the entire city and across policies because the calculation smooths out the idiosyncratic factors influencing whether specific parcels are likely to redevelop despite their high financial results (for example, the heirs of an inherited home are enmeshed in the lengthy argument about selling to a developer). But it is also likely to undercount the number of units in a particular parcel or block group.

- Because the predicted probability of development is designed to depend only on the pro forma-based financial outcomes, it may miss the influence of some parcel traits that may influence development in ways that are not captured by the pro forma analysis. For example, the presence or absence of an existing structure on the parcel is considered only through its influence on land value, and neighborhood amenities are not used as an explicit factor beyond their impacts on land costs and rent price estimates derived from existing rental units.
- And finally, the baseline assumptions within the model often reflect our best reasonable assumptions, yet different inputs could significantly affect the outcome. For example, if in practice larger developments faced longer delays in the entitlement process than our baseline model assumes, then our baseline model may be overstating the financial feasibility of larger developments relative to smaller projects.

- Marginal Economic Analysis
    - The Simulator conducts a marginal economic analysis on each parcel rather than including "general equilibrium" effects, meaning it does not capture interactions between housing production across parcels, nor secondary impacts on the construction industry or housing demand. For example, building in some neighborhoods may alleviate demand for housing elsewhere in the metropolitan region, or exacerbate bottlenecks in the construction market, and the Simulator cannot capture this. In other words, if scenarios simulated drive up capacity or probability to the degree significantly more development is financially

advantageous or possible than in recent years, these limitations become more pronounced. For example, large shifts in expected units can result in strained city staff and therefore increasing permit timelines beyond the assumptions modelled, scarcity of certain building trades which could impact construction timelines or hard costs beyond the inputs used, or impacting vacancy rates and rent prices which could alter the financial metric calculations. None of these knock-on effects are able to be captured and therefore large swings in expected units from the recent past should be understood as a potential upper bound.

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