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CONVERTING BROWN OFFICES TO GREEN APARTMENTS

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ABSTRACT

The conversion of brown office buildings to green apartments can contribute towards a solution to three pressing issues: oversupply of office in a hybrid-and-remote-work world, shortage of housing, and excessive greenhouse gas emissions. We propose a set of criteria to identify commercial office properties that are are physically suitable for conversion, yielding about 11% of all office buildings across the U.S. We present a pro-forma real estate model that identifies parameters under which these conversions are financially viable. We highlight several policy levers available to federal, state, and local governments that could accelerate the conversion, and that may be necessary should policymakers desire the creation of affordable housing. We highlight the role that the Inflation Reduction Act could play.

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1 Introduction

The COVID-19 pandemic has caused significant shifts in real estate markets, including increased urban-to-suburban migration (Gupta, Mittal, Peeters, and Van Nieuwerburgh, 2022), residential rent and housing affordability issues, as well as reduced value of urban office and retail real estate due to the mass adoption of remote and hybrid work (Gupta, Mittal, and Van Nieuwerburgh, 2023). These shifts threaten the fiscal health of cities as property taxes on these assets are major contributors to local government budgets, and risk triggering an urban doom loop in which public good provision declines, taxpayers leave, and property values fall further (Van Nieuwerburgh, 2023). Additionally, the crisis of climate change has led to upcoming regulations to reduce greenhouse gas (GHG) emissions of buildings, which along with other factors, poses challenges to commercial real estate values, and in particular to older, lower-quality office buildings.

Housing Affordability Crisis There is a severe housing crisis in the US, with the average renter spending at least 30% of income on rent.[1] High-density cities face an even more severe rent-burden problem due to limited space for new residential construction, high land and construction costs, and difficult permitting processes. The housing affordability problem has become worse over time. Between March 2015 and April 2023, rental growth was 43% whereas per capita personal income growth was only 34%. Hence, the share of income going to rents grew from 32.7% to 35.8% over the past eight years.[2]

Office Revenues and Oversupply The demand for commercial office space is expected to remain weak due to the mass adoption of remote work, leading to record high vacancy rates and decreased office rent growth, and sparking concerns that office buildings have become "stranded assets." Gupta et al. (2023) find 18% declines in office cash flows nationwide between the end of 2019 and the end of 2022, and directly link declines in office demand to tenants' work from home policies. Observed office values from the public markets indicate that remote work is perceived

[1] See Moody's 4th Quarter Housing Affordability Update: https://cre.moodysanalytics.com/insights/market-insights/q4-2022-housing-affordability-update/.

[2] Since per capita personal income growth is an average for the entire population and since renters tend to have lower average incomes than owners, the share of income paid on rent by renters is higher than the shares computed here. Hence, these numbers understate the extent of housing affordability. Rent data for the U.S. are from Zillow's Rental Index and income is from the Bureau of Economic Analysis NIPA Table 2.6.

by investors as highly persistent. Declines in office demand are much larger for lower-quality, class-B and class-C office space.

Climate Crisis The real estate sector is a major target for emissions reduction policies as buildings account for 29% of all U.S. GHG emissions (Leung, 2018).[3] Regulations such as New York City's Local Law 97 impose fines on building owners for exceeding emission limits, which affects cash flows. Older, poorly-amenitized properties are most affected, facing both weak office demand as well as non-compliance with emissions limits.[4]

Urban Doom Loop When left unaddressed, these challenges will lead to persistently high levels of office vacancy and an erosion of property values. Underutilization of office due to remote work creates negative externalities in commercial neighborhoods. Less foot traffic contributes to more crime and public disorder. It spills over into lower retail sales, which in turn trigger lower retail property values and lower retail property tax revenues, but also lower sales tax and income tax revenues. Reductions in public transit fare box revenues represent other downstream consequences of lower office demand and commuter traffic.

Lower tax revenues combined with a budget-balance requirement force cities to plug the fiscal hole by taxing residents and businesses more or by cutting government spending. Budgets for local education, transportation, sanitation, and public safety will decline as a result, risking more urban decay and crime. Faced with higher taxes or lower public goods provision, some residents will leave the city in search for locations with better amenities-to-tax ratio. The high-skilled are more prone to leave due to stronger job prospects and higher taxation. They currently pay a

[3] In 2021, total gross U.S. greenhouse gas emissions were 6,340.2 million metric tons of carbon dioxide equivalent according to the Evironmental Protection Agency's annual Inventory on U.S. Greenhouse Gas Emissions and Sinks (EPA, 2023). The EPA puts the real estate sector's share of emissions at 30.3% in 2021. The residential real estate sector accounts for 15.0% (5.8% of direct emissions and 9.3% of electricity-related emissions), while the commercial real estate sector accounts for 15.3% (6.9% direct and 8.4% electricity-related) of emissions (Table 2-14). These numbers do not include emissions from the construction of new buildings. The production of steel, concrete, and cement is emission-intensive. According to the Global Status Report for Buildings and Construction, produced under the auspices of the United Nations, global CO_2 emissions from buildings operations reached an all-time high of around 10 giga ton CO_2 in 2021, 2% higher than the previous peak in 2019 (United Nations Environment Programme, 2022). This amounts to 27% of global operational-related CO_2 emissions and 37% of global energy and process-related emissions, where the latter number includes the construction of buildings. To be aligned with reaching net zero carbon emissions by 2050, emissions would need to fall by over 98% from 2020 levels, even as the global real estate floor area grows from 250 billion m^2 in 2020 to 450 billion m^2 in 2050.

[4] Urban Green Council (2019) found that retrofitting all 50,000 buildings covered by the law would cost $24.3 billion through 2030 .

disproportionate share of local income tax revenue. Increased out-migration lowers demand for local real estate and local services, further lowering property, sales, and income tax revenues. This prompts further cuts in government services, further lowering the quality of live or increasing the cost of doing businesses. This population exodus can trigger an urban doom loop.

When faced with lower cash flows, existing office owners will struggle to afford the greenhouse gas emission fines and lack the resources to invest in retrofits to improve the energy efficiency of their buildings. The climate challenge will go unaddressed.

Keeping half-empty offices around also prevents the creation of new housing. The city faces a fundamental misallocation of space: too much office, too little housing.

Incentivizing Conversions of Brown Office Buildings We explore policies that could stimulate the conversion of brown class B/C offices to green apartments, designed to address these challenges. Such conversions could preserve asset value while creating residential housing supply and addressing climate change. The rehabilitation of existing buildings produces 50–75% fewer carbon emissions than new construction. This concept of adaptive reuse is not new; it's a vital mechanism by which cities adapt to shifting economic realities (Benmelech, Garmaise, and Moskowitz, 2005; Loewenstein, Riddiough, and Willen, 2021; Gillette, 2023).

The three key aims of our paper are to (i) identify office buildings suitable for conversion, (ii) develop a financial model that illustrates the economics of conversion, and (iii) describe possible local budgetary, zoning, and building code changes as well as federal subsidy programs to facilitate conversion. We highlight that federal climate funding resources are potentially available for such conversions under the Inflation Reduction Act (IRA).

The two key takeaways from our analysis are that, first, there is a non-trivial fraction of office assets that is physically suitable for conversion. We find that about 15% of office buildings in the commercial districts of the 105 largest cities in the U.S. are physically suitable for conversion. Removing properties that still have a substantial share of long-term tenants in place reduces this fraction to 13%, and removing relatively clean buildings leaves us with 11% of properties.

Second, conversions from office to market-rate residential are financially feasible if offices change hands at their new fair market values. Since the latter values are substantially depressed from pre-pandemic valuations, inducing existing building owners to sell at such reduced prices is likely to be a challenge. Due to the negative externalities associated with suboptimal use, there is a rationale for policy intervention to encourage such conversions.

Conversions that only generate market-rate apartment units may not align with the goals of policymakers, who may have indicated a preference for creating affordable housing. We propose a variety of alternatives to policymakers who are interested in promoting affordable housing through tax abatement and subsidized financing programs, and quantify the trade-off between generating more affordable housing units and providing additional subsidies.

We highlight the availability of federal climate funding resources under the Inflation Reduction Act (IRA) that could support such conversions. We identify several provisions in the IRA that permit the use of funds to aid the green transition of the built environment (section 4.2.2). The most prominent IRA program is the $27 billion EPA's Greenhouse Gas Reduction Fund, which needs to be spent by September 2024. Using the GHGR fund to subsidize the green investment component of a brown office-to-green apartment conversion is not only compatible with the IRA's mission to reduce GHG emissions but, when the conversion creates affordable housing units, also with its emphasis on climate justice. Providing healthy and affordable living options for households across the income spectrum would thus seem to fit squarely within the Act's aims. Without the help from the IRA, apartment conversions risk being either green or affordable, but not both.

We illustrate the power of a green conversion subsidy in a concrete example of a brown office building conversion in New York City (section 3.5.5). A subsidy of $40 per gross square foot for the green component of the investment succeeds in closing most of the funding gap that arises from the inclusion of an affordable housing component in the project.

The rest of this paper is organized as follows. Section 2 describes and applies an algorithm to identify office buildings that are physically suitable for conversion. Section 3 details the model that quantifies the financial returns for a generic office-to-apartment conversion. We provide a detailed numerical example for a class-B office building in New York City and apply our model to the largest 20 office markets in the United States, using region-specific parameters. Section 4 discusses policy options. Section 5 concludes.

2 Identifying Plausible Conversion Candidates

A key hurdle in successfully implementing office conversions is the physical viability of conversion. While some historic office buildings have relatively narrow floor plates suitable for conversion into apartments, many modern office buildings have the wrong physical attributes for apartment living. In particular, many massive full-block glass-and-steel office buildings feature floor plates that are simply too deep for conventional apartments. They would therefore need at least one core drilled in the middle to create enough windows, need major plumbing changes to accommodate many apartment units on each floor, may not have windows that open, and otherwise present physical obstacles to conversion. To begin to address these challenges, we identify buildings that are plausible candidates for office conversion based on both their physical characteristics as well as the leases in place. Buildings with high occupancy and many existing tenants are unlikely to be viable candidates for conversion. Since our focus is on converting brown office to green apartment buildings, we begin by studying New York City (NYC) where we observe GHG emissions at the building level and are so able to layer in environmental considerations. In a second step, we scale up the analysis to the entire United States.

2.1 New York City

We use building-level energy use data from the Energy and Water Data Disclosure for Local Law 84, and convert energy use to CO_2 equivalents. Emissions include both direct (on-site fossil fuel) and indirect (electricity use) emissions. Appendix A1 contains the details.

We then compare emissions to the emission limits under Local Law 97. Passed as a part of the Climate Mobilization Act by the New York City Council in 2019, this local regulation aims to reduce emissions by 40% in 2030 and 80% by 2050, and imposes steeply increasing carbon taxes to implement these goals. We find that 16% of large office buildings (i.e., above the 25,000 sf threshold) are over the limits set for 2024 and 72% of large office buildings are over the limits set for 2030. The emissions dataset contains 1,867 office properties in NYC (column "Full" in Table 1). It shows that 70.5% of properties in this sample were built before WWII and 92.7% of properties were built before 1990. The former group account for 44.8% of aggregate GHG emission fines that will need to be paid under the status quo after 2030, the latter group for 89.4% of total fines.

We merge the emissions data with CompStak, a data set that contains detailed property and leasing characteristics for office buildings. The intersection with the GHG emission data set contains 1,037 properties. This sample has similar age and emissions distributions (column "CompStak" in Table 1).

Table 1: Descriptive statistics for office buildings subject to LL97

	Count		2024 Fine ($mi)		2030 Fine ($mi)	
Year Built	Full	CompStak	Full	CompStak	Full	CompStak
Pre-War	1,317	763	21.70	16.38	61.38	46.28
1945–1959	129	65	1.75	1.25	15.19	9.34
1960–1979	189	101	5.40	2.20	37.57	30.16
1980–1989	96	64	2.60	1.64	8.34	6.56
1990–1999	33	16	0.41	0.07	2.58	2.02
2000–2009	63	11	3	0.04	7.97	1.27
2010–2019	38	17	0.96	2.52	3.92	7.05
2020+	2	0	0	0	0.06	0
Total	1,867	1,037	35.81	24.09	137.01	102.68

To arrive at a sample of plausible office conversion candidates, we winnow our sample in a series of seven steps.

First, we impose a location requirement and only keep buildings located in midtown and downtown Manhattan.The rationale is to focus on the locations where the negative externalities from office vacancy are the strongest, as well as to focus on locations with strong transportation amenities. Because the transportation network was originally built to move workers into the central office district, residents in converted buildings will enjoy the benefit of network centrality in accessing other areas of the city: a desired and valued residential amenity (Gupta, Van Nieuwerburgh, and Kontokosta, 2022).

Second, we only keep buildings built before 1990.[5] Many historic buildings tend to be cheaper, have smaller floor plates, and are more charming, all of which increases their conversion appeal.

Third, we subset on Class A-, B and C buildings as reflecting the properties facing greatest financial distress and so possible scope for conversion activity. Class A+ buildings are excluded since they have benefited from a flight-to-quality among the remaining office tenants.

[5] This is consistent with the recommendation by the NYC Office Adaptive Reuse Study to facilitate conversions by buildings in this age range https://www.nyc.gov/assets/planning/download/pdf/plans-studies/office-reuse-task-force/office-adaptive-reuse-study.pdf.

Fourth, we drop buildings smaller than 25,000 sf which may lack scale economies for conversion. Such projects may be attractive for smaller conversions, but the latter are unlikely to attract institutional capital. The administrative cost-benefit analysis of approving or subsidizing small projects may be unfavorable as well.

Fifth, we drop buildings with deep floor plates. Specifically, we remove buildings with a distance from the window to the core that is more than 60 feet.[6] Many modern office buildings have physical attributes that are unfavorable for apartment conversion. In particular, many massive full-block glass-and-steel office buildings feature deep floor plates that make it difficult to bring enough light and air into the interior of the structure. They would therefore require at least one core drilled in the middle or side of the structure to create enough light, which greatly adds to the cost of conversion. They typically also have inadequate plumbing to accommodate many bathrooms on each floor, may not have windows that open, feature too many elevators, and otherwise present physical obstacles to conversion.

These criteria ensure that we focus on properties in the urban core, that have sufficient scale, reasonable floor plate depth, and are older and lower-quality than average. Such buildings are both browner and cheaper, making them better candidates for conversion to green apartments. At this stage, we have 625 NYC buildings left in the candidate set.

Given weakness in demand, many office buildings are experiencing nontrivial vacancy. However, a building that still has substantial occupancy is difficult to convert since the presence of existing tenants complicates a conversion project and buying out existing tenants may ruin the economics of the conversion.[7] Therefore, in the sixth step, we narrow our sample of candidates further by selecting buildings with no (or few) major long-term leases left as described in Appendix A2.[8] We are left with 409 plausible conversion candidates.

Approximately 76% of the conversion target list exceed the 2030 GHG limit. Selecting those properties leaves us with 311 "brown office" to green apartment conversion candidates, or 30% of

[6] In the NYC data, we observe building width and depth from the PLUTO data set. This allows us to calculate the distance from the core of the building to the window as the width/2 or the depth/2. We define distance to the core as the minimum of these two numbers.

[7] We are aware of instances where residual office tenants were willing to pay to be released from their lease, and this payment contributed partial funding for the conversion. It is unclear how widespread such instances are. What is clear is that there is a hold-out problem whereby the last remaining tenant in a building slated for conversion has substantial bargaining power.

[8] We caveat this analysis by noting that CompStak does not cover the universe of leases. For NYC, the data set has a coverage rate of 73.5% according to Gupta et al. (2023).

the initial 1,037 properties (14.5% of the initial square footage). This sample accounts for a total of $17.5 million in GHG emission fines under the 2030 limit (15.1% of total emissions and 17% of total fines for the initial sample).

2.2 Scaling Up Conversion Nationally

Having selected conversion candidates for NYC, we can scale up the exercise to the entire U.S. We apply the same selection criteria we used for NYC to all 105 office markets covered by the CompStak data set. That is, we identify older, lower-quality office buildings of sufficient scale and with small enough floorplates located in downtown areas.

Table 2 shows how, starting with the CompStak universe of office buildings, each step of the algorithm whittles down the number of conversion candidates.[9] This results in 3,118 conversion candidates, of which 592 properties are located in New York City.

We do not have data on GHG emissions for buildings outside NYC. However, we can impute a GHG emission level for each building based on that building's characteristics. We estimate the relationship between emissions and building characteristics in the NYC sample of conversion candidates, and use the estimated regression coefficients, reported in Appendix Table A3, for this imputation. We select the properties with imputed emissions in excess of the imputed emissions limit according to the 2030–2034 NYC parameters.

The selection algorithm leaves us with a final, national sample of 2,644 properties whose physical attributes, remaining office tenants, and greenhouse gas emissions make them ripe for conversion to green apartments. These properties represent 11% of all office properties located in high-density commercial districts (2,644 out of 23,903). They total 214 million square feet.

The takeaway from this analysis is that a nationwide conversion strategy is viable because of the large number of plausible conversion candidates across the country. The potential exists for the reallocation of substantial space from office to apartment use.

We plot the total number of suitable conversion buildings, by decade of construction, in Figure 1. Most of the conversion candidates in NYC are pre-WW-II buildings (red bars), while the rest of

[9] To implement the location requirement, we select office properties located in ZIP codes with at least 1,000 residents per square mile. Since this algorithm does not condition on the presence of GHG emission data and considers other dense neighborhoods besides midtown and downtown, the set of buildings for NYC is larger as well. We apply the national algorithm to NYC in the second column.

Table 2: Conversion Candidate Sample Summary

Step		NYC	National Candidate Algorithm NYC only	excl. NYC
	Initial Sample	1,037	1,550	28,387
1	Location	832	1,505	22,398
2	Year Built	802	1,387	15,369
3	Class	800	1,373	15,078
4	Size	796	1,238	11,093
5	Distance to Core	625	779	2,820
6	Outstanding Leases	409	592	2,526
7	Emissions	311	586	2,058
Total Emissions (tons of CO_2)		193,936	269,978	565,479
Apartments Produced		38,734	52,947	118,522

Notes: Starting from the first row (Full Count), the table applies successive filters to select conversion candidates. Each row show the remaining number of properties after the filter in that row has been applied. The first column labeled NYC is based on the intersection of the GHG emission and Compstak data sets for NYC. In this column, the location filter selects properties in downtown and midtown Manhattan. The Distance to Core filter for this column uses the depth and width of the building as inputs. The second and third columns start from the Compstak data sets. The location filter in these columns selects properties in ZIP codes with residential density greater than 1,000 people per square mile. Distance to Core in these last two colums is computed as the square root of the average floor size divided by 2, and properties where this number is greater than 60 feet (corresponding to greater than 14,400 square feet average floor plate) are filtered out.

the country also features many post-WW-II candidates (blue bars).

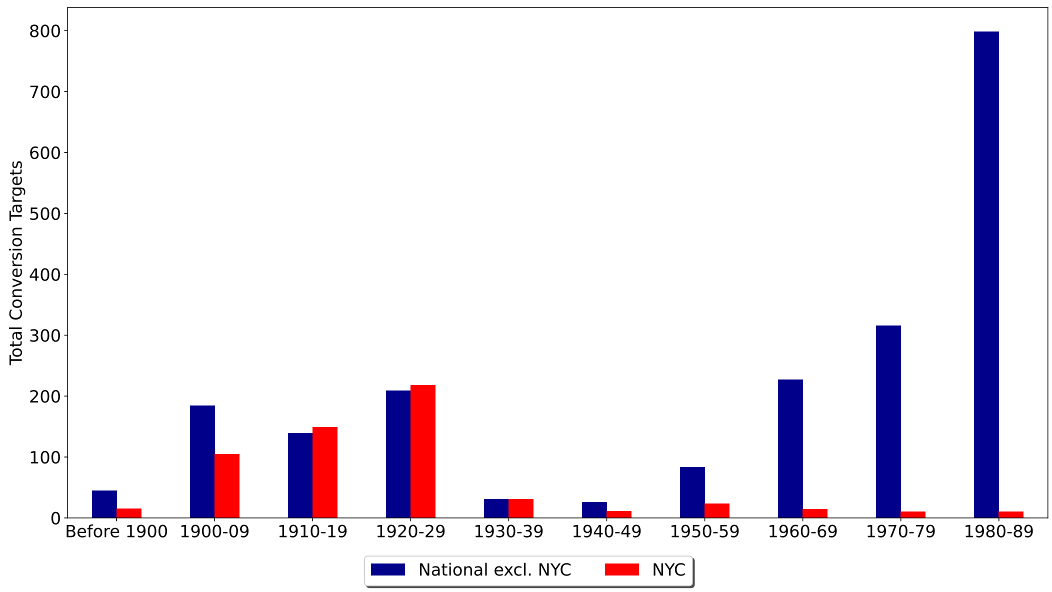
Figure 2 shows the location of the 2,644 conversion candidates. Table 3 provides a breakdown of our conversion candidates for the top 20 MSAs.

Within NYC, conversion candidates (selected by applying the national algorithm to New York City) are concentrated in the financial district (downtown) and midtown, as shown in Figure 3.

How Many Apartment Units Can Be Created from Office Conversions? At 875 sf per apartment unit, and after incorporating a 30% loss factor, these conversions can create 171,470 additional housing units. Scaling up for incomplete data coverage, results in 400,000 additional apartment units.[10] For comparison, about 260,000 apartment units were created in the United States in a typical year between 2001 and 2022.

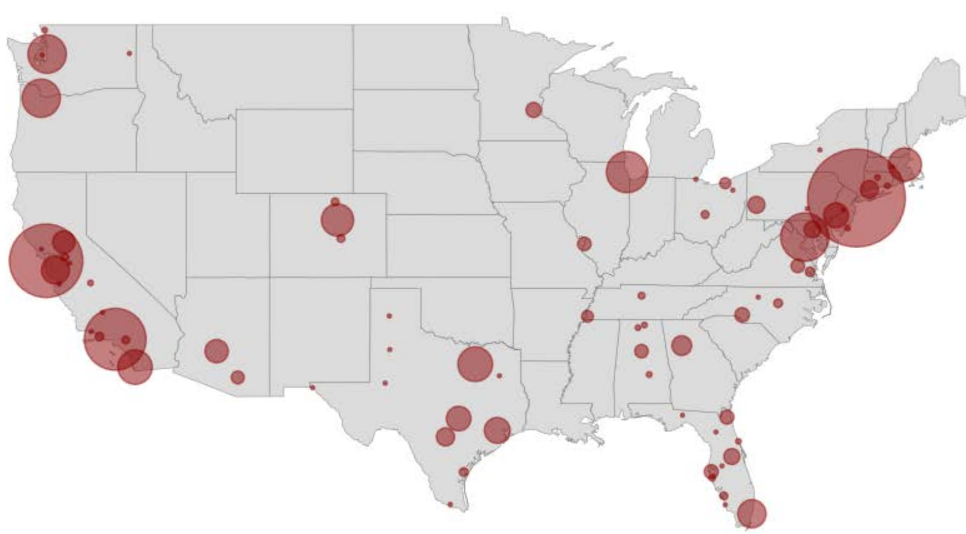
[10] By comparing with Cushman & Wakefield data on total market size, Gupta et al. (2023) calculate that Compstak covers 73.6% of office floor area in NYC and 36.0% in the other 104 office markets. Applying these coverage ratios to the number of apartments in the last row in Table 2 results in 71,958 apartments in NYC and 329,136 apartments outside NYC from conversion for a total of 401,094.

Figure 1: Conversion Targets by Decade of Construction



Notes: The figure plots total properties suitable for conversions, after applying all of the filters in Table 1, across decade of construction for the national sample excluding New York City, as well as for New York City.

Figure 2: National Candidates



Notes: Plotted points correspond to the number of conversion suitable buildings per MSA.

How Much GHG Emission Can be Removed by Conversion? The final conversion candidate sample accounts for 835,457 tons of predicted CO_2 emissions. Scaling up for incomplete data cov-

Table 3: Conversion Candidates by MSA

CBSA	Candidate Count	Total Gross SF (M)
New York-Northern New Jersey-Long Island	634	68.4
San Francisco-Oakland-Fremont	358	21.2
Los Angeles-Long Beach-Santa Ana	254	16.2
Washington-Arlington-Alexandria	155	11.6
Chicago-Naperville-Joliet	113	14.0
Seattle-Tacoma-Bellevue	98	6.6
Portland-Vancouver-Beaverton	97	5.8
Dallas-Fort Worth-Arlington	80	8.4
San Diego-Carlsbad-San Marcos	79	3.9
Boston-Cambridge-Quincy	73	4.2
Denver-Aurora	69	5.9
Miami-Fort Lauderdale-Pompano Beach	53	4.9
San Jose-Sunnyvale-Santa Clara	52	2.5
Houston-Sugar Land-Baytown	44	4.2
Philadelphia-Camden-Wilmington	41	3.8
Austin-Round Rock	40	2.1
Phoenix-Mesa-Scottsdale	36	2.2
Sacramento-Arden-Arcade-Roseville	33	1.3
Atlanta-Sandy Springs-Marietta	26	2.8
San Antonio	22	1.9

erage results in 1,937,255 tons of CO_2 emissions.[11] These emissions could be reduced significantly by conversion to energy-efficient green apartments. If we assume that brown office conversions result in apartment buildings that are 25% under the 2030 NYC emission cap, the total GHG emission reduction is 1,550,191 tons or 80.0% percent.[12] In summary, office to apartment conversions can make a meaningful dent in GHG emissions.

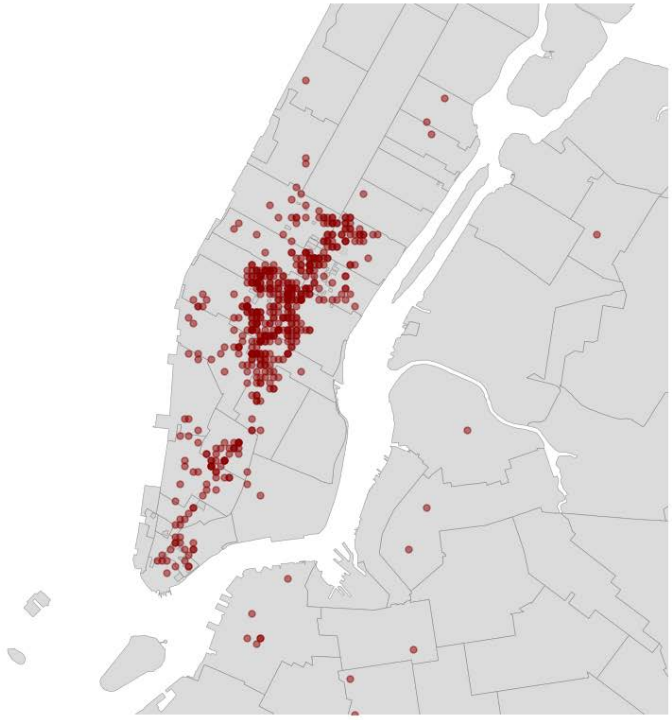
3 The Economics of Office Building Conversion

We begin with a simple model to demonstrate the financial viability of transforming traditional "brown" office buildings into eco-friendly apartments. This analysis assumes that such transformation is structurally viable without requiring major re-engineering and that all necessary regulatory approvals have been granted. We discussed the issue of physical suitability in section 2 and

[11] We use the same coverage ratios for NYC and the rest of the country as in the previous footnote. Direct and indirect CO_2 emissions from all commercial buildings in the U.S. were 751.6 million tons in 2021 according to the EPA.

[12] A GHG level of 25% under the 2030 emission cap makes an apartment building top-10% in terms of its GHG emissions.

Figure 3: Geographic Distribution of NYC Candidates



Notes: The figure plots conversion candidates in New York City that were identified using the estimated coefficients on property characteristics.

cover the issue of zoning and building code policy in section 4.

3.1 Conceptual Framework for Building Valuation

The model is composed of two primary elements. Initially, it calculates the current value of maintaining the property as a class-B "brown" office building. This calculation is based on the discounted value of net cash flows over the forthcoming decade and the remaining value at the point of sale after ten years. We make plausible assumptions about revenues and costs for a representative class B office building in NYC and discount these cash flows using a typical discount rate to obtain the "fair market value" of the office. We perform this office valuation both from a pre-pandemic vantage point and in the current environment. This current value is significantly lower than pre-pandemic office valuation levels, reflecting the extent to which office values have been impaired by remote work, higher interest rates, and climate regulation. We assume that this depressed current value is the the acquisition price of the property slated for conversion to apartments.

The second element is the value derived from converting the brown office into a green apartment building. Initially, we consider a market-rate rental project built without subsidies. Again, we make plausible assumptions about the cost and timeline for construction to achieve the conversion to multifamily use, likely financing expenses (higher due to the rising interest rate environment), and likely future net income as an apartment rental property.

The green aspect of the conversion enters our calculation in several ways. First, because the green apartment building is built to modern energy efficiency standards, it does not incur any GHG emission fines. Second, we are assuming low vacancy rates given strong projected demand for urban living in green building. Third, we assume a rent premium due to the value tenants place in living in a green building. Fourth, green status lowers operational expenses due to energy cost reductions. Fifth, green status lowers both construction and permanent financing costs, given lenders' stated intent to enhance the sustainability features of their loan portfolio. Sixth, we assume a risk discount (i.e., a lower beta) compared to a regular apartment building due to the building's green status, which results in a boost to the building's valuation.

Our model sells the apartment ten years after acquisition, aligning with the ten-year holding period used in the office valuation.

3.2 Valuing Brown Buildings Pre-Pandemic

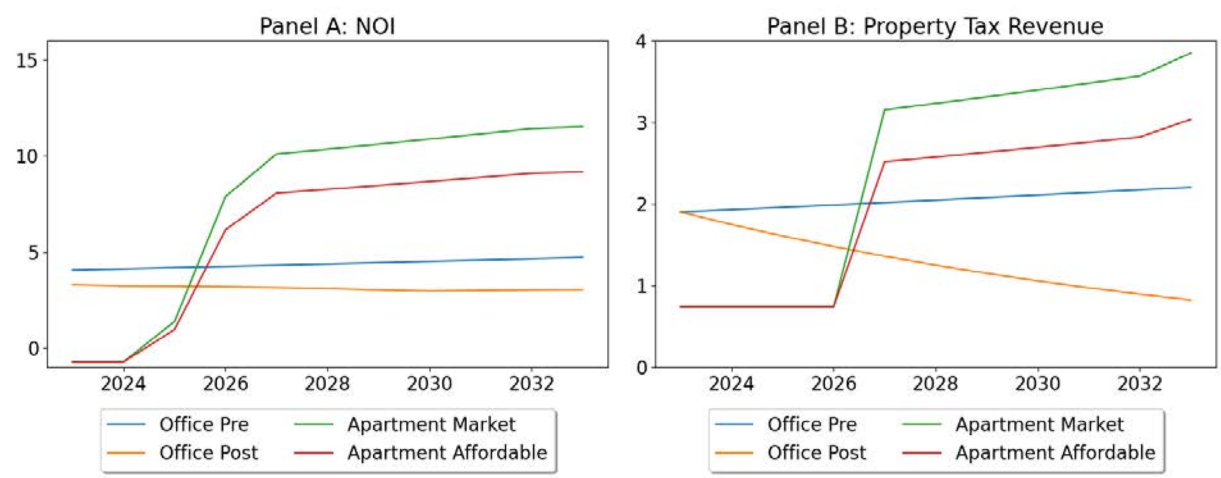
We envision a generic 250,000 gross square feet (sf) class-B office property. For concreteness' sake, we apply our model to New York City. However, our model is generic. It applies equally to all cities in the United States, as long as input parameters are properly adjusted.

Before the pandemic, such an office would be worth about $400/sf, or $100 million in NYC. This valuation can be justified using our pro-forma model under the following assumptions on cash flows, which are realistic for the few years just before the pandemic. We assume a net effective rent (NER) of $49.44/sf per year, representing about 70% of the pre-pandemic average Manhattan office rent, reflecting that Class B properties command below-average rents. Second, we assume the building faces a 12% constant vacancy rate, around the pre-pandemic office vacancy rate in Manhattan. And third, we assume a 5.5% discount rate which is the sum of the 10-year Treasury rate of 2%, a good assumption for the average 10-year yield over the 10-year period 2013–2022, plus a risk premium of 3.5%.

The first column of Table 4 summarizes the key model parameters. This $100 million building generates $54.9 million in total current and future property tax revenues for the city in present value terms.[13]

Figure 4 graphs two key model outputs: annual net operating income (NOI) in the left panel, and annual property tax revenue in the right panel, plotted over the course of the 10-year holding period from 2023–2033. The blue lines represent the output for the pre-pandemic office.

Figure 4: Model Results Over Time



Notes: The figure shows outputs from the model over time for the four cases examined (offices before the pandemic, offices after the pandemic, market-rate apartments, and apartments with an affordable component). The left panel plots the property's net operating income or NOI (Panel A) and the right panel plots property tax revenues in millions of dollars (Panel B).

[13] All present values of government tax revenues are computed using the Treasury yield curve as the discount rate.

Table 4: Key Model Parameters

	Office Pre-Pandemic	Office Post-Pandemic	Apartment Market	Apartment Affordable
	Building Characteristics			
Rentable Space	212,500/sf	212,500/sf	175,000/sf	175,000/sf
	Rent and Vacancy			
Monthly Rent	$4.12/sf	$3.50/sf	$8/sf	$6.84/sf
Annual Rent Growth	1.5%	1%	2.5%	2.3%
Vacancy	12%	17%	5%	4.5%
Annual Vacancy Growth	-	1%	-	-
	Operational Expenses			
Credit Loss	1.5%	3%	-	-
Operating Expenses (% Gross Rent)	30%	30%	27%	27%
	Financing Conditions			
Exit Discount Rate	5.5%	8.41%	7.41%	7.21%
Exit Cap Rate	4%	7.41%	4.91%	4.91%
	Property Taxes			
Property Tax Rate of Market Value	1.9%	1.9%	1.4%	1.4%
Property Tax Collected (NPV)	$54.9 mi	$21.7 mi	$104.6 mi	$81.3 mi
	Environmental Attributes			
GHG Taxes 2024–29	-	$0.32 /sf	-	-
GHG Taxes 2030–	-	$0.72 /sf	-	-
	Conversion Details			
Months to Design	-	-	30	30
Months to Lease Up	-	-	18	18
Hard and Soft Costs	-	-	$80 mi	$80 mi
Green Improvements	-	-	$10 mi	$10 mi
	Bottom Line			
NOI 2033	$4.7 mi	$3 mi	$11.5 mi	$9.2 mi
Valuation 2022	$100 mi	$38.9 mi	-	-
NPV 2022	-	-	$4.1 mi	-$8.6 mi
IRR 2022	-	-	16.8%	12.1%

3.3 Triple Headwinds for Office Buildings

Over the past couple of years, the environment for Class-B offices has changed radically with the arrival of triple headwinds: higher interest rates, the emergence and persistence of remote work, and greenhouse gas emission regulation. We make three modifications to our model to highlight the valuation impacts of these three forces. The parameters and key results are shown in the second column of Table 4 and in the orange lines in Figure 4.

Rise in Interest Rates First, we consider the impact of changes in interest rates. We increase the 10-year interest rate from 2% to the observed 10-year Treasury yield as of March 29, 2023, equal to 3.48%. We use the complete 10-year rate forward curve until the close of 2032 for discounting future cash flows. The rise in interest rates alone shrinks the property's value from $100 million to $63.1 million.

This significant decrease in value is largely attributed to the spike in the exit cap rate from 4% to 6.41%, given the forward rate for 2032 is 4.41% or 241 basis points above the previously assumed 2% rate. This large jump in the exit cap rate diminishes the exit value from $117.7 to $73.4 million, even though cash flows remain stable. The rest of the effect comes from applying a higher discount rate to all cash flows when calculating the present value.

It's important to underline the 36.9% plunge in value for a property that is otherwise in good health. The magnitude of the value drop illustrates the power of convexity. Interest rate (cap rate) increases, when coming off a low base rate of interest (a low cap rate), can dramatically lower property values.

Rise in Remote Work Next, we introduce several assumptions to model the cash flow problems emerging from the work-from-home (WFH) shift. Substantial research has grown to document the rise in remote work since the pandemic, with survey evidence highlighting the apparent persistence of remote work (Aksoy, Barrero, Bloom, Davis, Dolls, and Zarate, 2022). These shifts have large implications for both the cash flows and risk inherent in traditional office buildings, as firms respond to these trends by adjusting their office demand (Gupta et al., 2023; Rosenthal, Strange, and Urrego, 2022; Duranton and Handbury, 2023).

We incorporate these adjustments in our model by accounting for class-B office becoming a riskier asset, either due to greater risk in cash flows in the WFH environment or because, in addition, investors may have grown more risk averse. To capture this, we increase the unlevered office risk premium from 3.5% to 4%. The value of the building drops from $63.1 to $58.6 mi due to this increase in risk.

We additionally account for the immediate challenges of remote work on a reduction in rents by 15% to $42.03/sf annually. This decrease corresponds to the observed fall in active lease revenue in the NYC data (measured using the CompStak data). This decrease is phased in over time by presuming that a fixed fraction of leases expires each period and only applying the decrease to newly signed leases. This reduction in office rents reduces the property value to $48 million.

We then decrease rent growth from 1.5% to 1% per year for similar reasons, lowering the value of the building further to $44.1 million.

Next, we elevate the vacancy rate in the property from 12% to 17% to reflect the increase in class-B Manhattan office, consistent with the evolution of the NYC vacancy rate between the end of 2019 and the end of 2022. This lowers the value to $38 million.

Furthermore, we increase the vacancy rate by 1% point each year so that it grows from 17% in 2023 to 27% by 2033, and remains constant at 27% after 2033. This reflects further declines in occupancy as pre-pandemic leases continue to roll off and class-B tenants have better outside options in higher-quality buildings. This lowers the value to $29.8 mi.

Finally, we increase the credit loss from 1.5% to 3% to reflect rising tenant non-payment, resulting in an office value of $28.4 mi.

The above calculations were made under the assumption that the property tax remained unchanged from its pre-pandemic value (specifically at 1.9% of the pre-pandemic market value and growing at 1.5% per annum). This assumption implies that by 2032, the effective tax rate escalates to 9%. However, it is rather unlikely that such a massive depreciation in value, as detailed above, would happen without a substantial reassessment of the tax over the course of the 10-year holding period. The city authorities would likely adjust the assessed value downward automatically as the Net Operating Income (NOI) on similar properties dropped. The NOI is a key measure of operational profits for real estate, and serve as a base for both property taxation as well as valuation. Alternatively, the landlord could contest the tax bill, presenting a compelling argument for a downward revision.

In light of this reality, we incorporate an 8.05% annual reduction in the tax bill. This gradual reduction restores the effective tax rate to its pre-pandemic value of 1.9% of the actual market value by 2032. The reduction in tax leads to a significant increase in the NOI in 2033 and, in turn, a substantial increase in the exit valuation. The responses in property taxes hedge to an extent the shock from remote work. The result is an office value of $40.5 million.

Greenhouse Gas Tax Considerations Lastly, we take into account the environmental impact on the office's valuation. We factor in the greenhouse gas emission fines stipulated by Local Law 97, set at $0.32 per square foot from 2024 until 2029, and at $0.72 per square foot from 2030 onward for New York City. These penalties are calculated based on the published fines for class-B office buildings in 2024 and 2030. They total to $80,000 per annum from 2024 to 2029 and $180,000 annually thereafter. In this scenario, the enactment of Local Law 97 reduces the office building's value to $38.9 million, or by an additional 4.1%.

Implications for Property Valuation To sum up, a property that had a pre-pandemic valuation of $100 million is presently valued at $38.9 million after taking into account the triple forces of rising interest rates, the emergence of remote work, and environmental taxes. This constitutes a 61% loss in value. Interestingly, this figure aligns closely with the forecasts for class B office spaces in the model provided by Gupta et al. (2023).

This office was most likely financed with debt pre-pandemic. A 65% LTV ratio was common before the pandemic, amounting to an initial principal balance of $65 mi. Commercial mortgages have little principal amortization so that there would likely still be $60 million in debt outstanding against this property at the time of the valuation (beginning of 2023). The new $38.9 million valuation would mean that the initial $40 million investment in equity in the office is wiped out, and that the debt is sitting on a loss of $21.1 million or a loss of 35%.

This loss of equity value, in combination with the cash flow shocks which impair the ability to make debt repayments, would likely trigger financial distress, resulting in the owner defaulting on the mortgage. Through a foreclosure sale, a short sale, or a deed-in-lieu of foreclosure, the asset would end up in the hands of a new buyer.

3.4 Conversion to Green Market-Rate Apartments

The financial distress of conventional office buildings sets the stage for the valuation of an alternative: green market-rate apartment buildings. The parameters for this valuation are shown in the third column of Table 4.

Modeling the Conversion Process

The first phase involves the actual conversion. We anticipate a timeline of 30 months for the completion of the transformation, inclusive of the permitting phase. This process is expedited in comparison to a ground-up development, which could take well over five years in NYC. The redevelopment phase is followed by a 18 month period required to lease up the new apartment building.

We assume that the net rentable square footage of the revamped apartment building is 175,000, which is 70% of the total 250,000 gross square footage. This accommodates a larger loss factor for apartments (30%) than for office spaces (15%) to account for the loss of interior space due to deep floorplates or potentially for the necessity to construct an inner courtyard (light well). At an average of 875 square feet per unit, the conversion allows for the creation of 200 apartment units within the property.

We assume it costs $38.9 million to acquire the old office building at its revised fair market value, $80 million for the hard and soft construction costs of conversion (excluding the cost of debt), and $10 million for supplementary green enhancements not already incorporated as part of a standard conversion.

The conversion cost of $80 million equates to $400,000 per apartment unit ($457.14 per sf for the average 875 sf apartment, or $320 per square foot for a building with 250,000 gross square feet before factoring in the loss factor). A 2023 Urban Land Institute report discusses 21 recent conversion case studies with a median hard and soft conversion cost of $255,000.[14] Half of the case studies have a cost between $210,000 and $300,000. Our number is higher because our calculations are for a high-cost market. These costs, however, can vary significantly depending on the unique attributes of the property (requirement for a light well, ventilation improvements, luxury finishes,

[14] See: https://knowledge.uli.org/en/reports/research-reports/2023/behind-the-facade-the-feasibility-of-converting-commercial-real-estate-to-multifamily.

etc.) as well its location (with implications for labor costs, regulations, etc.). We return later to robustness of our estimates with respect to this crucial parameter.

The additional $40 per square foot is a plausible estimate for supplementary development costs required to enhance the building's energy efficiency, given that major construction is already underway.

During the development phase and prior to the completion of lease-up, we assume that the property continues to be taxed as an office. The tax is calculated as the effective rate of 1.9% multiplied by the asset's market value, which we establish as the acquisition value of $38.9 million. This results in a property tax bill of $738,466 for the initial 4 years.

Sources of Funding for Conversion Activity

The funding for this project comes from both debt and developer equity. We assume that the developer obtains 65% of the total $128.9 million in acquisition and development costs from a construction loan, and covers the rest with equity (contributed over the course of the construction phase). This construction loan is drawn in stages: a first tranche at the end of 2022 to buy the office building, a second in 2023 for 50% of the conversion costs, a third in 2024 for 30% of the conversion costs, and the final tranche in 2025 for the last 20% of the conversion costs. The construction loan has a variable rate priced at SOFR plus 4.5% (8.75% all in cost in the first year).

By the end of 2026, the lease-up period concludes and the asset is stabilized. The developer then secures a permanent, fixed-rate mortgage with a 30-year amortization period. The interest rate on the loan is set to the 10-year Treasury forward rate as of lease-up plus a 1.75% spread (all in rate equal to 5.44%). To set the loan-to-value ratio, the lender values the collateral using the 2026 cap rate, calculated from the 2026 discount rate and the rent growth rate. Considering a 2027 NOI of $10.1 million, the building's end-of-2026 value is $241.2 million.

Note that the 2027 property tax, a fixed percent of the apartment building's market value, is $3.32 million or 1.4% of the new apartment market valuation. The market value, in turn, is affected by the property tax. This circular dependence is resolved by finding a fixed point. For this fixed-point computation, we exclude the property tax abatement for green buildings from the NOI calculation, as the green abatement is temporary.

Apartment Cash Flows

The economic viability of converting to apartments hinges upon the generation of sufficiently high cash flows from these apartments. We base our calculations on the assumption that the newly converted apartment building will charge a standard rent comparable to new, upscale multi-family properties in NYC. This amounts to a rent of $8 per square foot monthly in 2023 (the 90th percentile of Manhattan rents in May 2023 according to a report by Elliman), in addition to with a green rent premium of 3.1%.[15] This implies a monthly rent of $7,217 per unit (of 875 square feet).

We assume that apartment rents (for green assets) grow at 2.5% per year after 2023. We assume that the vacancy rate is 5% for green NYC apartments and constant over time. We assume no credit losses.

These revenues are balanced against operating costs which are expected to be 27% of potential gross rent for standard new apartments (excluding property taxes but including recurring capital expenditures). However, for our green building, we expect 5% lower operating costs due to energy efficiency gains.[16]

Another significant cost change occurs following the conversion of the building into an apartment complex in 2027, when the property tax rate changes from 1.9% (office) to 1.4% (apartments). This is applied to the end-of-2026 property value of $237.2 million, yielding an annual 2027 property tax of $3.32 million, which then grows at the rate of rents (2.5%). Interestingly, this conversion results in the government collecting more property tax in present value terms over time.

The result of these shifts is that the NOI is projected to rise from $10.1 million in 2027 to $11.5 million in 2033. By the end of 2032, the building is sold, its value calculated as the 2033 NOI divided by the 2032 cap rate for a green apartment asset (4.91%). This results in an exit value of $234.7 million before, and $230 million after sales fees and transaction taxes.

After repaying the outstanding mortgage balance of $109 million, the net sales proceeds amount to $121 million at the end of 2032.

[15] The Elliman report can be found at: https://www.elliman.com/resources/siteresources/commonresources/static%20pages/images/corporate-resources/q2_2023/rental-05_2023.pdf. The green rent premium number is based on a study by Cushman & Wakefield: https://www.cushmanwakefield.com/en/united-states/insights/green-is-good-series. Green building premiums have also been documented for office properties (Eichholtz, Kok, and Quigley, 2010).

[16] Given that energy is only one component of operating expenditures, the energy bill reduction is larger than 5%.

The Bottom Line: Does Conversion Make Sense?

Our model shows a before-tax internal rate of return (IRR) for the office to apartment conversion of 16.8% for the developer. This is a levered return or equity return.

Determining whether this is a reasonable equity return, given the associated risks, is challenging due to the investment's complex nature. The conversion entails a blend of a speculative 4-year development, akin to a high-risk "opportunistic" private equity investment, followed by a 6-year stabilized asset investment, akin to a lower-risk "core" (PE) investment.

An approximate way to estimate the levered beta for the stabilized ("core") phase is to multiply the unlevered beta by the assets-to-equity ratio, which is 2.0 in this case (given a loan-to-value ratio of 0.5). With an unlevered beta of 0.6, we derive a levered beta of 1.2. The fair discount rate, consequently, is the 10-year Treasury yield plus a risk premium of 6% (1.2 times 5%). With an average 10-year forward Treasury yield of around 3.9%, the fair cost of equity capital is around 9.9%. Indeed, this is a plausible value for a levered return in a core real estate investment. We use this discount rate to discount the value of the stabilized apartment building's cash flows back to the end of 2026, obtaining the value of the stabilized apartment building at that time.

To discount this 2026 value back to the end of 2022, we use a much higher discount rate to reflect the much higher risk associated with the development and lease-up phase. We use the 10-year Treasury yield plus a risk premium of 12%, twice the value for the stabilized investment.

As is common for the initial development stage, the cash flows to the equity investor are negative (2023–2025). To reflect the commitment associated with these outlays, it is customary to discount them at the risk-free rate (10-year Treasury yield). By discounting them at a low rate, we increase the present value of the outlays, and lower the NPV of the overall conversion project. This builds conservatism into the approach.[17]

The key conclusion of our analysis is that office to apartments conversions can be financially profitable, yielding a project IRR of 16.8% which exceeds the cost of equity capital. Put differently, the conversion results in a positive net present value (NPV) of $4.1 million. While positive, this NPV is small relative to the overall project cost of $128.9 million. The safety margin is small. Still, the central takeaway is that conversions can be financially viable if the developer can purchase the

[17] These assumption on discount rates imply a single discount rate of 15.33%, which, when applied to all cash flows, delivers the same net present value.

office building significantly below pre-pandemic valuation levels (a 61% discount in our example).

Our calculations show that the conversion turns from positive to negative NPV at a purchase price of $43.2 million. This last calculation suggests that apartment conversions might help put a floor under office valuations, at least for properties that are suitable for conversion.

3.5 Office Conversion to Green Apartments with an Affordable Housing Component

A key aspect of the economic viability of the above office-to-apartment conversion was the ability to lease new units at market rates. Is it economically feasible to create affordable units as part of an office to apartment conversion conversion? If not, what government subsidies (which programs and how many dollars) are needed to make such programs pencil out?

Conversions from office to market-rate apartment rentals were typical in the Financial District of New York City, in which historic office buildings began being converted into luxury apartment units starting from the 1980s. The area, previously thinly populated, saw large numbers of new apartment units both from converted offices and new apartment buildings on reclaimed land in Battery Park. It remains one of the highest-income areas in NYC today. Concerns about growing income disparities in the area began to influence policymakers, who introduced property tax abatements—in the form of the 421-g program—to both encourage conversion activity with an affordable housing component. A rationale for such programs may be ensure that low-income residents have improved access to opportunity. The presence of local residents at varying degrees of income may facilitate cross-class social connections (Chetty, Jackson, Kuchler, Stroebel, Hendren, Fluegge, Gong, Gonzalez, Grondin, Jacob, et al., 2022), and avoid the entrenched patterns of income segregation observed elsewhere in cities. The 421-g program accompanied looser zoning restrictions in the area to facilitate conversions and implemented a 14 year abatement of property taxes, during which time converted units were subject to rent stabilization.[18]

[18]The Citizens Budget Commission estimates that the 421-g program was used for conversions totalling 13 million square feet of office space in Lower Manhattan between 1995 and 2006. 12,865 residential units were created at a cost of $92,000 per unit. See: https://cbcny.org/research/potential-office-residential-conversions. Ellen and Kazis (2022) and Willis (2023) also advocate for affordable housing being a component of office-to-residential conversions to avoid the prospect of gentrification, and also provide a visualization of proposed conversion properties in New York City at https://furmancenter.org/thestoop/entry/implications-and-geography-of-office-to-housing-conversions.

3.5.1 Defining Affordability

We define an affordable rental housing unit as one where a tenant whose income is at 80% of Area Median Income does not spend more than 30% of household income on rent. AMI for a family of three is $96,080 in NYC. An affordable rent is therefore $1,922 per month per unit (of 875 sf) or $2.20/sf. This compares to the market rent of $7,217/unit or $8/sf.

The model considers several ways in which affordable units differ from market-rate units. First, we assume that the affordable units do not earn the green building rent premium we assumed for market-rate units. Second, we assume that the rent on an affordable unit grows at a slower pace as the rent on a market-rate unit, consistent with rent-stabilization practices. We set this rent growth rate to 1.5% per year, compared to 2.5% for market-rate units. Third, we assume that the vacancy rate for affordable units is only 2.5%, compared to 5% for market-rate units, to reflect the fact that there is excess demand (a long waiting list) to get into a new apartment building at below-market rents. Fourth, we assume that affordable units have lower risk given rent-stabilization and low vacancy. We assume an unlevered beta that is 0.2 lower (for the affordable units only). Fifth, the property tax bill reflects the lower market value of the property. Sixth, we assume that the affordability mandate lasts for a finite period of time (25 years), after which the property reverts to a market-rate property.

3.5.2 Scenario Without Subsidies

If the office to apartment conversion mandates 20% affordable units, the developer must set aside 40 of the 200 apartments for below-market tenants. This is a version of mandatory inclusionary housing. Without subsidies, the IRR of the investment falls from 16.8% to 12.1%, and the NPV drops from $4.1 million to -$8.6 million. The cost in terms of foregone developer profit per affordable unit provided is $318,345.

Given that the NPV is negative, the developer would not pursue the conversion. Increasing the percentage of affordable units or lowering the income threshold for affordability would make the conversion even less attractive. This shows that even modest affordability requirements can ruin the economics of the deal.

The affordability requirement lowers the NPV of tax collections by $23.3 million (in NPV terms) *relative to the market-rate development*, or $581,742 per affordable unit.

The combined cost to produce the 40 affordable units to the government (in lost tax revenue) and the developer (in lost profit) is $36 million or $900,087 per affordable unit.

There is, however, another way to look at these tax implications. *Relative to the status quo*, which is a poorly performing class-B office building that brings in only $21.7 mi in NPV of tax revenues, the tax revenues from the apartment property with affordability mandate are nearly $60 million higher. The apartment building with 20% affordable units captures 72% of the increase in tax revenues of a 100% market-rate apartment building.

Since the NPV from conversion for the developer is negative, preventing the conversion from taking place, a natural suggestion is to use some of the increase in tax revenues (obtained by moving away from the staus quo) to subsidize the conversion. We consider this next.

3.5.3 Policy 1: Property Tax Abatement

In order to increase the NPV of the affordable development, the government can provide a property tax abatement during the affordability period (here, 25 years). Property tax abatements are a common policy tool used by local governments to create more affordable housing.

For our building, the tax payment needs to be reduced by 40.5% between 2027 and 2051 in order to increase the NPV to the developer from –$8.6 million to $0. This tax abatement brings up the developer's IRR to 14.8%, the minimum required to do the conversion under the affordability mandate.

This property tax abatement costs the government $40 million in lost tax revenue in present value, relative to a 100% market-rate rental building. In other words, each affordable unit costs the government $1 million in forgone tax revenue and society $1.1 million when including the (now much smaller) developer's profit reduction.

Tax revenues remain nearly $43 million higher relative to the status quo of keeping the property as a defunct office building. Seen from this perspective, an office-to-apartment conversion with 20% affordable units that receives enough subsidy tho make the conversion financially feasible remains beneficial to the taxpayer. The subsidy is an investment in affordable housing in the city center, financed with some of the incremental tax revenue.

NYC introduced a new tax incentive for renovations of large office buildings in June 2023, called the MCORE program. It provides for 16 years of full property tax abatements followed by four years of phase-out.[19] While not aimed at office-to-apartment conversions, a similar program could provide an effective stimulus for such conversions.

3.5.4 Policy 2: Debt Subsidy

Another commonly implemented housing policy involves lowering the cost of debt for affordable housing projects. There are multiple such programs at both local and federal government levels.

In our model, we simplify this treatment by assuming that a certain percentage of both construction and permanent loans can be obtained at below-market interest rates. We assume the subsidized portion of the construction (mortgage) loan enjoys a 200 (100) basis point funding advantage. Concretely, for our building with 20% affordable units, we assume that 50% of the loan amounts benefit from the subsidy. This debt subsidy reduces the effective interest rates on the construction loan from 8.75% to 7.75% and on the mortgage from 5.44% to 4.94%.

The subsidized debt policy increases the NPV to -$5.1 million and the IRR to 13.1%, showing the utility of debt subsidies.

Adding enough property tax abatements to get the developer's NPV up to zero requires a 23.6% tax abatement. This compares to a 40.5% tax abatement without debt subsidies. This tax abatement results in a total cost per affordable unit of $928,866.5 compared to $1.1 million without the subsidized debt. This does not count the (opportunity) cost of the debt subsidy itself.

3.5.5 Policy 3: IRA Grant

Our conversion project required $10 million (or $40 per gross square foot) in additional investment for green features. As a first policy, we consider federal grants in the same amount for such green investments. This policy would increase the project's IRR to 14.5% and NPV to -$309,965 an increase of 2.4% in the IRR and $8.3 million in the NPV compared to the baseline case without subsidies. This policy is almost enough to bring NPV into positive territory so that only a minor property tax abatement is necessary to restore the developer to zero-NPV (a 1.46% reduction in the

[19] The program also provides for a reimbursement of state and local sales tax on construction materials. It applies to office buildings larger than 250,000 square feet.

property tax bill). The property tax expenditure to the local government, relative to a market-rate building, becomes $596,841 per affordable apartment unit. Of course, the IRA grant adds $250,000 in federal tax expenditures per affordable unit.

3.6 Sensitivity Analysis

The model's results rely on various assumptions, so it's crucial to understand how changes in key parameters might affect the outcomes. By returning to the baseline model parameters and modifying one variable at a time while keeping others constant, we can observe the sensitivity of the results. Table 5 provides a summary of these findings. The model's conclusions are most sensitive to conversion cost estimates, apartment rent levels, acquisition price of the asset, the building's suitability for conversion, and the affordable housing mandate. This underscores the importance of doing the analysis case by case.

Table 5: Sensitivity Analysis

Conversion cost ($1000/unit)	200	300	**400**	500
NPV (in millions of $)	37.27	20.70	4.14	-12.42
IRR (in % per year)	31.04	23.04	16.79	11.85
Apartment rent ($/sf/month)	6	7	**8**	9
NPV (in millions of $)	-24.74	-10.30	4.14	18.59
IRR (in % per year)	7.04	11.98	16.79	21.49
Acquisition cost ($/gross sf)	100	**155**	200	300
Relative to Office Value (%)	-75%	**-61%**	-50%	-25%
NPV (in millions of $)	17.30	4.14	-6.42	-30.13
IRR (in % per year)	22.23	16.79	13.38	7.61
Loss factor (%)	0	15	**30**	45
NPV (in millions of $)	53.66	28.90	4.14	-20.61
IRR (in % per year)	32.46	24.78	16.79	8.47
Share affordable units (%)	**0**	10	20	30
NPV (in millions of $)	4.14	0.20	-4.35	-9.52
IRR (in % per year)	16.79	15.15	13.44	11.68
PDV of tax revenue (in millions of $)	104.58	88.06	73.06	59.52

3.6.1 How Sensitive Are Results to Construction Costs?

A first key parameter is the hard and soft conversion cost. We vary it from $200,000/unit, among the lowest estimates in the literature, to $500,000/unit, a higher estimate that may reflect higher costs of labor, supply chain disruptions, or (unforeseen) structural issues with the conversion. For every $100,000/unit in extra conversion costs, the NPV goes down by about $17 mi, or $82,806/unit ($95/net rentable sf).

3.6.2 How Sensitive Are Results to Apartment Rents?

The conversion's profitability is highly dependent on the rental market's robustness. In the baseline model, we assumed a monthly rent of $8/sf for a new market-rate apartment. After accounting for a 3.1% green rent premium, this equals $7,217 monthly rent per unit. However, if the base rent drops to $7/sf (or $6,315 monthly post-green premium), the NPV becomes negative. If it drops further to $6/sf ($5,413 monthly), the NPV is significantly negative.

There may be a trade-off between creating high-end apartments with high rent and high conversion cost, and creating somewhat cheaper apartments at lower cost. For instance, at a rent of $6/sf, a much lower conversion cost of $225,594/unit (as opposed to the baseline $400,000/unit) is required to maintain the baseline NPV.

A similar trade-off may arise across markets. Markets like NYC or San Francisco may have high conversion costs and high apartment rents, while other markets like Minneapolis or St. Louis have much lower apartment rents but also lower conversion costs. We return to this discussion below.

3.6.3 How Sensitive Are Results to the Acquisition Cost?

In the baseline model, the office building is purchased at a significant discount from its original valuation (-61%). But at that price, the previous owner may be underwater on her mortgage and unwilling to sell. Similarly, in a distress debt situation in which the owner has handed the keys of the office to the lender, the existing lender may not be willing or able to take such a large loss.

For instance, at a -50% discount ($200/sf instead of $155/sf), the NPV decreases to -$6.42 million. Conversely, at an even larger -75% discount, the NPV increases to $17.30 million.

3.6.4 How Sensitive Are Results to the Loss Factor? The Power of the Density Bonus.

The suitability of a building for conversion, represented by the loss factor, also significantly influences profitability. The NPV can decrease by \$24.8 million if the loss factor is 45% (about 30 apartment units fewer) or increase by the same amount if the loss factor is only 15%.

Zoning policy can confer a "density bonus" for the creation of affordable housing units. A density bonus is equivalent to a lower loss factor in our model. A 10% loss factor corresponds to 257 apartment units, a 28.6% density bonus compared to 200 units in the benchmark model. The NPV of \$53.66 million is large and positive. This illustrates the power of the density bonus. Moreover, this policy has no direct fiscal cost.

3.6.5 How Sensitive Are Results to the Scope of the Affordability Mandate?

The affordable housing mandate, which involves varying the share of affordable housing units and adjusting the property tax abatement and share of subsidized construction and permanent debt accordingly, impacts NPV, IRR, and the PDV of tax revenues. Specifically, for a share of affordable units of x%, we reduce property taxes by x% and provide subsidized construction and permanent financing for a portion of x% of the respective loans.

The NPV and IRR decrease with the share of affordable units increases even as the tax expenditure increases. This suggests that proportional debt subsidies and tax abatements cannot entirely compensate for the reduced rents from the affordable units.

3.7 The Geography of Conversions

Table 3 provided the geographic distribution of office buildings that were physically suitable for conversion to apartments. We now ask whether these conversions are also financially feasible.

This is a challenging question which ideally requires a building-by-building analysis. Such analysis is beyond the scope of this paper. We take a first pass at this question by using a limited set of regional information. Specifically, we account for differences in (i) pre-pandemic office values for class-B office, (ii) declines in office values over the 12/2019-12/2022 period, (iii) apartment rents, and (iv) costs of construction across metropolitan areas. These numbers are listed in the first four columns of Table 6. Besides the office purchase price, the conversion cost, and the apartment rent, all other model parameters are held fixed at their benchmark values (and hence do not vary regionally). Since we use the same inputs for each building in a given CBSA, this exercise predicts that either all or none of the buildings are financially feasible conversions. The last column of the table therefore reports either the total number of buildings that are physically suitable for conversion for those CBSAs for which the typical conversion is also financially feasible or zero for those CBSAs where the typical class-B office conversion is not financially feasible. The conversion assumes a 100% market-rate apartment rental building.

Table 6: Market Rate Conversion Feasibility

CBSA	(i) Initial Price	(ii) New Price	(iii) Apt Rent	(iv) Conv. Cost	Positive NPV Conversions
New York-Northern New Jersey-Long Island	400	172	8.00	360	634
San Francisco-Oakland-Fremont	343	88	7.60	353	358
Los Angeles-Long Beach-Santa Ana	192	74	5.17	304	0
Washington-Arlington-Alexandria	229	86	4.49	260	155
Chicago-Naperville-Joliet	81	32	3.29	325	0
Seattle-Tacoma-Bellevue	181	76	5.14	291	0
Portland-Vancouver-Beaverton	113	47	3.73	286	0
Dallas-Fort Worth-Arlington	88	37	2.71	234	0
San Diego-Carlsbad-San Marcos	141	59	4.80	298	0
Boston-Cambridge-Quincy	143	63	5.96	311	73
Denver-Aurora	90	36	4.38	249	69
Miami-Fort Lauderdale-Pompano Beach	130	57	3.85	232	0
San Jose-Sunnyvale-Santa Clara	233	98	7.16	340	52
Houston-Sugar Land-Baytown	79	29	2.41	236	0
Philadelphia-Camden-Wilmington	77	31	2.90	315	0
Austin-Round Rock	145	63	3.23	236	0
Phoenix-Mesa-Scottsdale	94	40	3.07	237	0
Sacramento-Arden-Arcade-Roseville	86	36	3.56	286	0
Atlanta-Sandy Springs-Marietta	83	37	2.82	243	0
San Antonio	84	38	2.16	228	0

Notes: For (i), we use data for 2019.Q4 from Real Capital Analytics on the hedonically-adjusted average office value per square foot in each CBSA. We compute the ratio of each CBSA's office value relative to the New York CBSA. We anchor the pre-pandemic New York CBSA office value for class-B at $400/sf, and apply the office value ratio to this number for the other markets. For (ii), we use the percent decline in office values between the end of 2019 and the end of 2022 from Gupta et al. (2023). Since this price decline is for all office and not just class-B, but we know from from Gupta et al. (2023) that percentage price declines are much larger for class-B office, we compute the percentage price change for class B office in CBSA i as: $\Delta p_i^B = 1 - (1 - \Delta p_i^{All})(1 - c)$. We set $c = 0.34$. For (iii), we use data on the hedonically-adjusted average apartment value per unit and the hedonically-adjusted average apartment cap rate for 2019.Q4 and compute the Net Operating Income as the product of these two numbers. We then divide the NOI by 0.7 to obtain the apartment rent. This assumes that operating expenses are 30% of rent revenues. We compute the ratio of apartment rent in each CBSA to that in New York. We set the apartment rent in New York to $8/sf for luxury rentals, and apply the ratio to this amount for the other cities. For (iv), we use the 2021 composite construction cost index data from RSmeans. The index captures hard and soft construction costs for commercial buildings. We express the index relative to New York and anchor the conversion cost to the New York value of $360. The latter consists of the $320 conversion cost per gross square foot plus the $40 per gross square foot for the energy-efficiency upgrades. This information is available for 13 of the 19 top-20 CBSAs for which we have office and apartment price data. For the remaining 6, we apply the construction cost index of a similar and/or geographically nearby city.

Table 6 suggests that the typical conversion is financially feasible in New York, San Francisco, San Jose, Boston, Washington D.C., and Denver. These are markets where apartment rents are high enough to overcome the purchase cost of the office building and the cost of conversion. While informative, we reiterate that these are just averages that likely hide substantial variation within CBSAs.

The principles of office-to-apartment conversions apply equally to suburban and urban locations. Much of the suburban office stock in the U.S. is functionally obsolete and ripe for conversion, much like the class-B urban office. Naturally, the parameters that enter our financial model must be adapted to the specific office asset and market under consideration. Office values are lower in suburban than in urban areas and conversion costs may be lower as well. however, apartment rents may be lower as well and taxes may differ.

The main consideration that sets urban areas apart from suburban ones is the presence of significant amenities, first and foremost access to public transit, but also agglomeration benefits that arise from thick labor markets. This consideration, as well as the more mundane issue of small office samples in suburban areas, explains our focus on urban office conversions.

4 Policy Levers for Conversion Activity

The surge of remote work has introduced a unique challenge for policymakers. Yet, it also provides them with a unique opportunity to promote a once-in-a-generation investment in the urban environments of the future.

4.1 At the Local Level

State and local governments control many of the policy levers that impact the feasibility of office to apartment conversions. Many cities are already reevaluating their zoning rules to make office conversions more feasible and economically viable. For instance, New York City's "City of Yes" zoning amendments, introduced in June 2022, aim at zero carbon, economic opportunity, and housing opportunity.[20]

[20] We summarize recent policy developments in NYC, Washington DC, Boston, Chicago, San Francisco in a companion document available at https://www.dropbox.com/scl/fi/z7uoej8pzu22e0b6718bd/Policy-Summary_final.xlsx?rlkey=h4ir622l18squt5jcsmcpr4zy&dl=0.

4.1.1 Zoning and Building Code Changes

Local government could take a number of steps to facilitate conversions. For example, they could provide regulatory relief for office conversions by making changes to the Zoning Resolution, Multiple Dwelling Law, Housing and Maintenance Code, and Building code. In addition, the permitting process could be streamlined to further expedite the conversion timeline.

Zoning regulates the use and bulk (physical dimensions) of buildings. Parts of the central business district may need to be rezoned to allow for residential use. Such rezoning could be enabled as-of-right, meaning that owners are able to convert buildings without being required to file for discretionary permits, saving time, costs, and reducing uncertainty that could adversely impact the economics of conversion. Even when zoned for residential use, a converted building needs to comply with bulk regulations (i.e., restrictions on building height, setback lines, and the percentage of open areas). When those are more permissive for office than residential use, bulk regulations may stand in the way of an office conversion. More flexible standards would allow more office buildings in commercial districts to be be converted in their entirety for residential use.[21] If governments wish to go even further, they could provide additional density bonuses for conversion targets in order to accommodate additional residential units, especially when the building height is below neighboring properties. Such bonuses could be justified on the grounds that apartments feature larger loss factors than offices, and so increasing height can offset space losses associated with the conversion.[22]

Other zoning changes could eliminate parking requirements and allow for more additional types of residential housing such as supportive housing and student dormitories. Conversion into alternate in-demand commercial uses (for instance, medical office, educational institutions, daycare centers, retail and hospitality) may also be feasible in some cases, and can provide additional amenities valued by local residents.

Local municipalities may also wish to revisit certain building code features, such as the requirement that bedrooms have windows. Some cities (such as New York City) mandate this require-

[21]For example, the NYC Multiple Dwelling Law caps the residential floor-area ratio (FAR) at 12, except for buildings built before 1968. This prevents the full conversion of larger office buildings built after 1970. The NYC Adaptive Reuse Study proposes expanding the range of buildings eligible for the most flexible conversion regulations to those built before 1990. This change would provide 120 million sf of Manhattan office an easier path to conversion.

[22]Such density bonuses can also be structured in tandem with increased affordable housing requirements, as is common in inclusionary zoning programs.

ment, but others (Philadelphia and Washington D.C., and some student dorms) do not. A window mandate is particularly onerous for office conversions of post-WW-II buildings, for which wide floor plates necessitate that bedrooms be placed along the perimeter of buildings, leaving substantial dead space in the center. Alternate uses in such cases may involve hollowing out a portion of the core of buildings, which may prove expensive (and lower the load factor), or using such space for common functions paired with micro units along the perimeter.

4.1.2 Direct Subsidies

Given the decline in property values and property tax revenues from urban offices and retail, cities may have limited resources for office conversion subsidies. However, our calculations show that local governments will eventually see increased property tax revenues from office conversions. The initial drop in tax revenue during the conversion phase is more than compensated by the increase in tax revenues once the apartment property is stabilized. From the local government's perspective, an office conversion is an investment in future tax revenue. If this incremental tax stream were to be isolated, it could serve as the collateral for a municipal bond issuance. The proceeds from such bond issuance could pay for conversion subsidies and be used to offset the initial tax revenue shortfall.

Policymakers may desire the creation of affordable housing units. As discussed in the previous section, imposing a mandatory inclusionary housing requirement on office conversions can easily turn the project from positive to negative NPV. Property tax abatements and subsidized debt finance are two crucial policy levers to make office conversions financially viable. Our calculations showed a substantial tax expenditure for each affordable housing unit. However, relative to the status quo of a declining tax revenue stream from a poorly performing office, the tax revenues from a mixed-use apartment property are much higher.

4.2 At the Federal Level

Since local governments may have limited resources to subsidize office conversions, it is reasonable to ask whether the Federal government could chip in.

4.2.1 LIHTC and Debt Subsidies

The federal government runs several project-level programs that subsidize for the creation and financing of affordable housing properties. The $9 billion Low Income Housing Tax Credit program administered by the department of Housing and Urban Development (and distributed via the states) provides funds for the construction of new (the 9% program) and the rehabbing of existing (the 4% program) affordable housing properties in low-income areas. It is unclear whether existing office assets would qualify at all, and under which of the two programs. It is also unclear how many of the nation's commercial districts would qualify as low-income areas. But if and where they qualify, the LIHTC could be an avenue to create apartment buildings with deeper levels of affordability than otherwise feasible.

The Federal Home Loan Bank, Fannie Mae, and Freddie Mac all run large affordable housing finance programs under the oversight of the Federal Housing Finance Agency. These same entities have recently taken a renewed interest in climate change. There is an opportunity for the creation of a new office conversion finance program, possibly with special modalities for eco-friendly conversions. There is precedent for incorporating environmental assessments in these lending programs in the form of Fannie Mae and Freddie Mac's Green Bond program, which specifically finance environmentally sustainable single- and multi-family properties.

4.2.2 Inflation Reduction Act

Given the environmental aspects of the conversion considered, the Inflation Reduction Act (IRA) may be a viable source of financial assistance. Passed in August 2022, the IRA dedicates $369 billion over 10 years to promote clean energy, pollution reduction, and environmental justice. It contains a plethora of tax incentives for wind and solar energy, batteries, nuclear power, clean hydrogen production, electric vehicles, heat pumps and much more. Bistline, Mehrotra, and Wolfram (2023) contains a more detailed analysis of other provisions in the IRA and their likely climate and economic impacts.

While the IRA never explicitly mentions green office conversions, our reading suggests that five provisions could be relevant.

One provision (Section 179D, Commercial Buildings Energy-Efficient Tax Deduction) allows owners of commercial buildings (including REITS) who reduce the energy and power cost of interior lighting, HVAC, and hot-water systems by at least 25% a tax deduction of $2.50 to $5 per square foot by demonstrating improvement in energy use relative to existing energy use.[23] We have already applied this green tax abatement in our model of the previous section.

A second provision (Sections 50121 and 50122) earmarks $4.3 billion in direct rebates to homeowners and owners of multifamily properties for energy efficiency upgrades of up to $400,000 ($200,000) when the retrofit achieves modeled energy savings of at least 35% (20%). It also provides $4.5 billion in rebates for electrification projects for low- and moderate-income households. Potentially, office conversions with an affordable component may qualify for both programs.

Third, there is up to $1 bi in grants and $4 bi in loans from HUD for upgrades that improve energy and water efficiency, improve air quality, implement building electrification, climate resilience and other sustainability measures. Eligible entities are nonprofits and other owners of qualified affordable housing, including multifamily projects. This program could lower the cost of debt.

A fourth program (Sec. 48 Renewable Energy Investment Tax Credit, Sec.13102 & 13702) provides a tax credit of up to 30% of cost of solar, geothermal, combined heat and power, storage and other clean technologies.[24] This credit can be further boosted if domestic content requirements are met, if the project is located in "Energy Community" regions intensive in fossil fuel extraction, and if projects are located in low-income areas or are dedicated to affordable housing. Eligible entities are taxpaying property owners (office, retail, etc.) who purchase eligible technologies.

Fifth, and most importantly, the $27 billion Greenhouse Gas Reduction Fund at the Environmental Protection Agency (Sec. 60103) is aimed broadly at cutting greenhouse gas emissions nationwide. The program provides competitive grants in three buckets: (i) $12 billion for projects that reduce or avoid greenhouse gas emissions, (ii) $7 billion to enable low-income and disadvantaged communities to utilize zero-emission technologies, and (iii) $8 billion for climate-related activities in low-income and disadvantaged communities.

[23]The higher amount applies conditional on wage and apprenticeship requirements. Unlike other elements of the IRA bill, which only apply for ten years, this section was made permanent under the Taxpayer Certainty and Disaster Relief Act of 2020.

[24]The credit is dropped to 6% if prevailing wage and apprenticeship requirements are not met. Also note that such tax deductions do not affect our IRR calculation, which is pre-tax. In practice, real estate enjoys generous tax treatment through depreciation and interest rate tax shields, and this program would layer additional after-tax benefits.

The EPA could provide further guidance on whether energy-efficiency, location-efficient adaptive reuse projects qualify as eligible project types for GHGRF funding. The EPA needs to get the money out the door to states, green banks, and other intermediaries by September 2024.

Our reading suggests that market-rate conversion projects that turn brown offices into green apartments ought to qualify for the first $12 bi bucket of grants. If such conversions also contain an affordable component, they could also qualify for the latter two programs ($8 and $7 billion). The right to a green, clean, healthy living arrangement can be viewed as a basic tenet of climate justice, one of the express goals of the IRA.

5 Conclusion

Seismic shifts in the real estate landscape, accelerated by the COVID-19 pandemic, have brought urban real estate to a critical crossroads. The urban exodus, housing affordability issues, and the diminished value of urban offices due to the widespread adoption of remote work have precipitated pressing challenges for the fiscal health of cities. These trends are amplified by additional headwinds surrounding higher interest rates and environmental considerations, adding up to a challenging environment for commercial real estate.

The conversion of underused class A-/B/C office buildings into green apartments addresses these challenges head on. It paves the way for restoring asset values and tax revenues, alleviating housing shortages, and meeting climate goals, while mitigating the negative externalities of vacant offices.

This paper identifies about 10-15% of all office space as targets of conversion targets across American cities. It contributes a model to compute the financial return on conversions. Such transformations are not only environmentally responsible, but can also be financially viable, as long as buildings are able to transact at fair values and apartment rents remain high enough.

Executing on office-to-apartment conversions will require concerted efforts from local and federal policymakers. Modifications to local zoning regulations, building code adjustments, local property tax abatements and debt subsidies, and the activation of federal programs, including the Inflation Reduction Act, all have a role to play. The trade-offs inherent in generating affordable housing units necessitate thoughtful policy design, balancing the benefits of affordable housing creation with fiscal constraints.

While challenges abound, the potential to reimagine urban spaces for an economically and ecologically more sustainable future is immense.

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A Appendix

A1 Measuring Emissions

To calculate annual building emissions for buildings in New York City, we convert energy use to metric tons of carbon dioxide equivalents. Energy use data come from the Energy and Water Data Disclosure for Local Law 84 and cover privately-owned buildings larger than 25,000 ft^2 and City-owned buildings larger than 10,000 ft^2.

Annual building emissions for building i are given by:

$$e_i = \sum_n m_{i,n} \cdot g_{i,n} \tag{1}$$

where:

- $m_{i,n}$ = the energy consumed for each source or fuel type, n, in kBtu (kWh) for the year reported
- $g_{i,n}$ = the GHG coefficient for the year reported for each energy source or fuel type, n, in tCO_2e per kBtu (kWh)

Table A1 describes the greenhouse gas coefficients assumed by Local Law 97.

Table A1: Greenhouse gas coefficient of energy consumption

Energy Source Use	2024-2029 tCO2e/unit	2030-2034 tCO2e/unit
Electricity - Grid Purchase (kWh)	0.000289	0.000145
Natural Gas (kBtu)	0.000053	0.000053
Fuel Oil #2 (kBtu)	0.000074	0.000074
Fuel Oil #4 (kBtu)	0.000075	0.000075
District Steam (kBtu)	0.000045	0.000043

The total building emissions limit for a building i is given by:

$$\bar{e}_i = \sum_p l_p \cdot s_{i,p} \tag{2}$$

where:

- l_p = the emissions factor of each given occupancy group/property type, p, in tCO_2e per ft^2

- $s_{i,p}$ = the total floor area in ft^2 of each occupancy group/property type, p, in a covered building

Table A2 describes the building emissions intensity limit per occupancy group.

Table A2: Emissions intensity limits

Occupancy group	2024-2029 tCO2e/unit	2030-2034 tCO2e/unit
i. A	0.01074	0.00420
ii. B (excluding those in item iv)	0.00846	0.00453
iii. E and I-4	0.00758	0.00344
iv. I-1	0.01138	0.00598
v. F	0.00574	0.00167
vi. B civic administrative facility for emergency response services, B non-production laboratory, B ambulatory health care facility, H, I-2, and I-3	0.02381	0.01193
vii. M	0.01181	0.00403
viii. R-1	0.00987	0.00526
ix. R-2	0.00675	0.00407
x. S and U	0.00426	0.00110

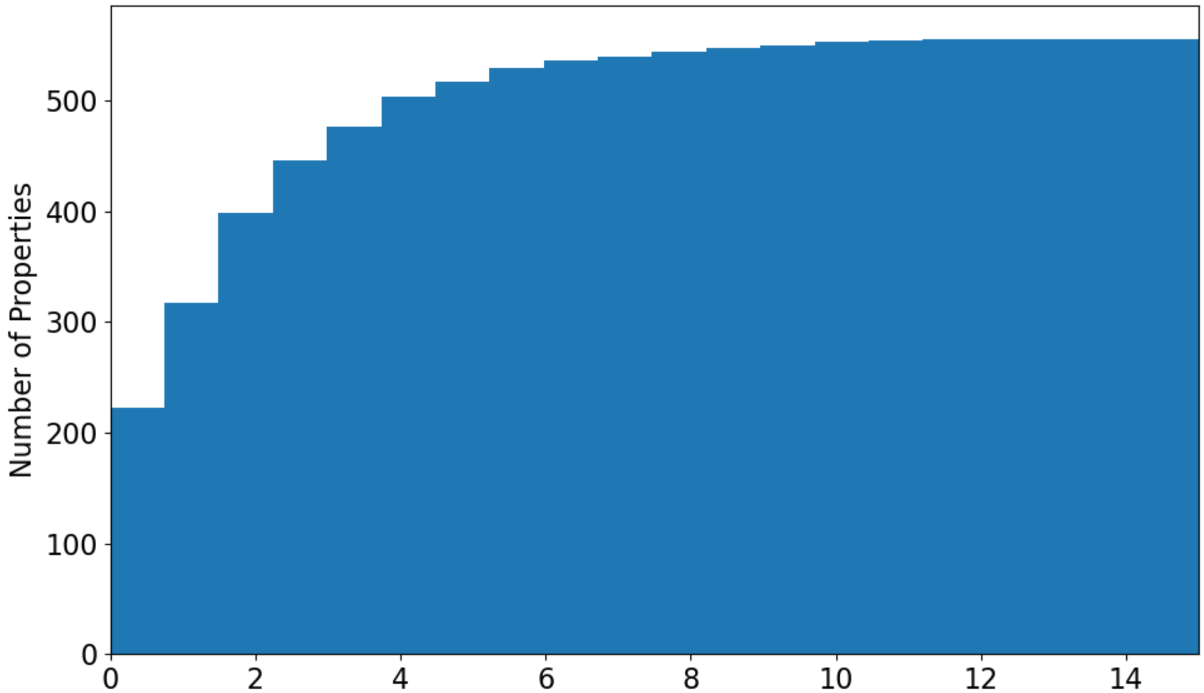
A2 Outstanding Lease Duration

We construct the measure of outstanding lease duration for a building i as follows:

$$D_i = \sum_{j \in i} x_{j,i} t_{j,i}$$

where x_j represents the square footage of an active lease as a share the building size and t_j corresponds to the remaining years on the active lease. Figure A1 plots the cumulative distribution function (CDF) of the remaining lease duration (in years) for NYC office buildings.

Figure A1: Outstanding Lease Duration C.D.F.



A3 Conversion Candidates

We estimate the relationship between emissions and building characteristics described by Equation (3) using the conversion candidates in New York City:

$$\begin{aligned} \ln(e_i) = &\beta^s \ln(\text{Size}_i) + \beta^f \text{Floors}_i + \beta^c \text{Class}_i + \beta^y \text{Year Built}_i + \beta^{fp} \ln(\text{Floor Plate Size}_i) \\ &+ \beta^r \text{Recently Renovated}_i + \beta^e \text{Largest Energy Source}_i + \epsilon_i \end{aligned} \tag{3}$$

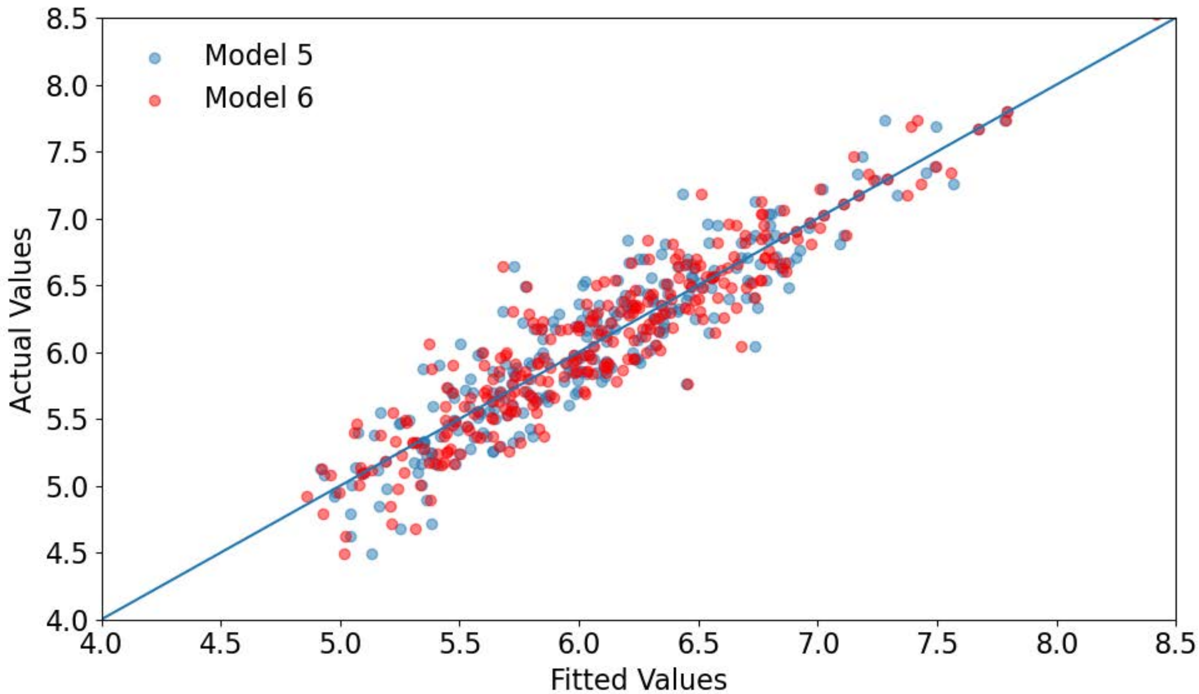
Regression results are presented in Table A3. Figure A2 plots the model fitted values against observed emissions.

Table A3: GHG Emission Imputation

	Dependent variable: Log Emissions					
	Full sample		Compstak		Candidates	
	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	-5.26***	-5.28***	-5.01***	-5.15***	-3.46***	-3.08***
	(0.24)	(0.24)	(0.72)	(0.68)	(0.47)	(0.45)
Log Size	1.10***	1.12***	1.15***	1.15***	0.79***	0.73***
	(0.04)	(0.04)	(0.12)	(0.12)	(0.13)	(0.13)
Log Floor Plate Size	-0.16***	-0.16***	-0.25**	-0.23**	-0.03	-0.01
	(0.04)	(0.04)	(0.11)	(0.11)	(0.13)	(0.13)
Building Floors	-0.00	-0.00	-0.00	-0.00	0.02*	0.02**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Recently Renovated			-0.03	-0.03	-0.15**	-0.12*
			(0.04)	(0.04)	(0.08)	(0.07)
Class A+			0.46**	0.55**		
			(0.23)	(0.27)		
Class A			-0.03	0.02	-0.09	-0.06
			(0.06)	(0.06)	(0.09)	(0.09)
Class C			0.04	-0.00	0.01	-0.03
			(0.06)	(0.05)	(0.04)	(0.04)
Electricity		-0.46***		-0.40***		0.01
		(0.06)		(0.07)		(0.11)
Fuel Oil #2		0.29***		0.23***		0.25***
		(0.05)		(0.06)		(0.05)
Fuel Oil #4		0.27***		0.33***		0.22***
		(0.05)		(0.08)		(0.06)
Natural Gas		0.12***		0.13**		0.20***
		(0.05)		(0.06)		(0.06)
Year Built FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,867	1,867	885	885	283	283
R^2	0.79	0.82	0.79	0.82	0.85	0.86
Adjusted R^2	0.77	0.81	0.77	0.80	0.82	0.83

Notes: The category for Class B buildings is omitted, as well as the category corresponding to steam as the main energy source. Buildings that have undergone a renovation at any time in the last 5 years are classified as recently renovated. *p<0.1; **p<0.05; ***p<0.01

Figure A2: GHG Emission Imputation: Model Fit



A4 Calculating Property Tax Revenue

We calculate tax collections over a 100-year horizon beginning in 2022, where property tax bills are assumed to grow at their respective aforementioned rates. The government's discount rate is calculated as follows:

$$r = \left(\frac{1}{1+i}\right)^t \tag{4}$$

To approximate the interest rate, i, we use the complete 10-year rate forward curve through 2032. We assume interest rates are .02% higher than the previous year for the next 30 years in years 2033-2052, .01% higher in years 2053-2070, and constant at 5% thereafter. The present value of tax revenues are therefore the sum of discounted property taxes.