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Article

Green Affordable Housing: Implications of Costs and Benefits for Municipal Incentives

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Abstract: In the year 2017, about 89 percent of the total energy consumed in the US was produced using non-renewable energy sources, and about 43 percent of tenant households were cost-burdened. Local governments are in a unique position to facilitate green affordable housing that could reduce cost burdens, environmental degradation, and environmental injustice. Nonetheless, limited studies have made progress on costs and benefits of green affordable housing to guide decision-making, particularly in small communities. This study investigates density bonus options for green affordable housing by analyzing construction costs, sale prices, and spillover effects for green certifications and affordable housing units. The authors employ construction costs and sale data from 422 Low-Income Housing Tax Credit (LIHTC) projects and 11,418 Multiple Listing Service (MLS) transactions in Virginia. Using hedonic regression analyses controlling for mediating factors, we find that the new construction of market-rate green certified houses is associated with small upfront costs but large and statistically significant price premiums. The construction of market-rate green certified houses has large and statistically significant spillover effects on existing non-certified houses. Existing non-certified affordable housing units show small and statistically insignificant negative price impacts on transactions of surrounding properties. The magnitude of social benefits associated with green building justifies the local provision of voluntary programs for green affordable housing where housing is expensive relative to its basic costs of production to promote sustainable development.

Keywords: density incentive; earthcraft; energystar; green premium; hedonic pricing; LIHTC; rehabilitation

1. Introduction:

In the year 2017, the residential sector in the US consumed 20 percent of all energy production, and 89 percent of the total energy consumed by all sectors was produced using non-renewable energy sources, including petroleum, natural gas, coal (all of them considered fossil fuels) and nuclear power (not a fossil but nonrenewable fuel) (USDOE, 2019). In the same year, according to the American Housing Survey data, about 43.4 percent of tenant households were cost-burdened (i.e., spent more than 30 percent of their income on housing costs) often due to poverty and, in large metro areas, mainly due to rising house prices (Glaeser & Gyourko, 2003). These trends indicate that there is a critical need to simultaneously address housing affordability and environmental sustainability in the residential sector to reduce existing concerns about national economy, energy security, declining world reserves, and climate change.

The sustainable development paradigm has established Environmental Policy Integration (EPI) as a key strategy to increase organizational effectiveness in policy coordination and achieve equal weighting of sectorial and environmental policy (Adelle & Russel, 2013; Jordan & Lenschow, 2010). US states have integrated green building with affordable housing programs to achieve multiple environmental objectives, e.g., improving energy efficiency and water conservation, increasing

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indoor environmental quality, providing safe, healthy, and productive built environment, and promoting sustainable environmental stewardship (Pearce, DuBose, & Bosch, 2007). Simultaneously, empirical measures have shown that green building increases housing affordability through energy efficiency savings that constitute a significant percentage of annual income of extremely low-, very low-, and low-income families (Zhao et al., 2018). In the US, the supply of green affordable housing tends to be initiated by a synthesis of public and private sector actions facilitated by mandates and incentives that address risks and return on investment concerns of investors, owners, and financiers. Despite an overall increase in the market penetration of green buildings since the early 2000s, the diffusion of buildings with high environmental performance has been slow, relegated to a slower new construction market as well, and the need for more affordable housing persists in areas where housing is expensive relative to its basic costs of production (Fuerst, Kontokosta, & McAllister, 2014). Currently, green buildings represent less than one percent of the total building stock and tend to be in larger cities with higher socioeconomic capacity, and there is a concern about the economic viability of green affordable housing particularly in smaller urban areas with existing stock (Chegut, Eichholtz, & Kok, 2019; McCabe, 2011).

To make cost and benefit analyses of different policies and programs and to estimate the amount of incentives required to offset the upfront cost of green affordable housing in the residential sector, local governments need substantial empirical evidence on viability in the local housing market (Fuerst et al., 2014; Hu, 2019). Previous research has primarily focused on the capitalization of nationally recognized labels (e.g., EnergyStar and LEED) into commercial property prices in larger cities; thus, leaving little information on private and public benefits in the residential sector. The lack of systematic analyses and evidence on construction costs and price impacts of green affordable housing could lead to irrational underinvestment based on the widespread perception of green buildings as expensive to build and affordable housing as the cause of lowered property values (Kahn & Kok, 2014).

This study investigates potential benefits and policy implications of the integration of green building and affordable housing by analyzing construction costs, sale prices, and spillover effects of affordable and market-rate houses built to local green building standards. The next section describes recent empirical evidence on costs and benefits of green building and affordable housing and presents a concise microeconomic background on the application of cost and price premiums in the development of local tax and subsidy systems. Then, the authors employ construction cost data from Low Income Housing Tax Credit (LIHTC) projects in Virginia to analyze the impact of an increase in the level of EarthCraft Virginia (hereafter termed EarthCraft VA and called Viridiant as of 2018) certification – a regional green building rating system – on the total construction cost of affordable housing projects between 2011-19. The current analysis focuses only on EarthCraft VA certified developments since nearly 100% of approved LIHTC projects have pursued EarthCraft VA certification, and LIHTC project data and detailed technical information on the design and construction of EarthCraft VA certified projects are publicly available. The authors use sale data from Multiple Listing Service (MLS) transactions, the primary source of real estate market information in the US, to provide evidence on the magnitude and statistical significance of sale price premiums associated with market-rate EarthCraft VA certified single-family houses in Montgomery County, VA. In addition, we use MLS data to monetize spillover effects of certified market-rate houses and non-certified affordable houses in the county. We use the obtained results to analyze the feasibility of a voluntary density incentive program that offsets upfront construction costs of green affordable housing.

Based on regression analysis, the authors concludes that (1) EarthCraft VA certified affordable housing developments are associated with small and statistically insignificant upfront costs but large and statistically significant price premiums; (2) existing non-certified houses benefit from positive and statistically significant spillover effects resulting from proximity to recently constructed market-rate certified houses; (3) existing non-certified affordable housing units have negligible and statistically insignificant negative spillover effects. Our data suggest that the adoption rate of green buildings has not progressed since 2014 despite the presence of significant social benefits. In the

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presence of regulatory barriers to mandatory green affordable housing programs, voluntary density incentive policies and programs could help facilitate the integration of green building with affordable housing to promote environmental sustainability, environmental justice, and economic development where housing is expensive relative to its basic costs of production.

2. Literature Review:

2.1. Costs and benefits of green building and affordable housing

The US Green Building Council (USGBC) defines green building as a comprehensive approach to planning, design, construction, operations, and, ultimately, end-of-life recycling or renewal of structures with several central considerations, including energy use, water use, indoor environmental quality, material section and the building's effects on its site (USGBC, 2019a). There are several green building rating programs that encourage the development of green buildings and energy-efficient products and appliances in the US from which LEED and EnergyStar are often cited as the two most prominent. USGBC, a private membership-based non-profit organization, developed LEED in 1999, and the Environmental Protection Agency and the Department of Energy jointly developed EnergyStar in 1992, extended it to buildings in 1995, and initiated the EnergyStar labeling program for buildings in 1999 (USGBC, 2019a). In a parallel effort and at the regional level, Greater Atlanta Home Builders Association and Southface established EarthCraft jointly in 1999, which was extended to Virginia in 2006 as EarthCraft VA and named Viridiant since 2018 while the certification standards are similar to or higher than EarthCraft (EarthCraft, 2019). To become certified, an EarthCraft project must meet or exceed local International Energy Conservation Code (IECC) requirements for energy code for energy and water efficiency and meet certain required standards and optional points in a series of categories determining Certified, Gold, or Platinum levels of certification (i.e., the expected levels of environmental performance). An analysis of LEED and Energy Star-certified properties suggests several trends over the first decade after the programs' inception: increases in the rate of adoption, improvements in certification standards, decreases in the share of buildings certified at the lowest level, growth of the share of private – versus public – developers (Fuerst, 2009). Previous research has compared costs and benefits of green buildings to those of conventional buildings (e.g., in terms of energy and water efficiency, indoor environmental quality, health and productivity) using a variety of indicators, but construction costs and price premiums are among the most concrete indicators to reflect total costs and total benefits for the purpose of policy and planning (Zuo & Zhao, 2014).

During the last decade, a growing body of empirical research has tracked the economic performance of green buildings based on reported construction costs, rents, sale prices, and occupancy rates. So far, there is little evidence on the magnitude of upfront green construction cost premiums in the residential sector in the US, and available studies in the commercial sector provide no conclusive answers. Two recent reviews covering a variety of geographies, building types, and rating systems, Dwaikat & Ali (2016) and Zhang, Wu, & Liu (2018) reported that the majority of incremental costs for all levels of certification fall within the range of -0.4 – 21 percent and -0.4 – 11 percent, respectively. Large-sample statistical studies of new construction, however, have reported narrower ranges. For instance, Matthiessen & Morris (2004) and Matthiessen & Morris (2007) did not find a statistically significant upfront cost premium from an analysis of the actual cost of green against conventional buildings. Based on anecdotal evidence from homebuilders, EarthCraft reports an upfront cost premium of 0.5 – 3 percent, which is consistent with a hypothesis by Fischer & Lyon (2014) suggesting that entry-level certification standards and costs are often kept loose and low to attract stakeholders with low willingness to pay for environmental labels (Earth Craft, 2019). In addition to impacts of confounding variables that could explain the variability of results (e.g., stage of involvement with the program, choice of the program and magnitude of its requirements, builders' level of experience, building characteristics, the choice of research methodology) some variability is

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attributed to the nature of green building programs (e.g., availability of optional easy or hard credits, interactions of project-specific issues and program credits) (GSA, 2004).

Although empirical cost estimates are often based on industry reports, more comparable systematic studies have emerged on estimated rents and sale price premiums of green certification on office properties in the US based on commercial real estate databases (Eichholtz, Kok, & Quigley, 2010, 2013; Fuerst & McAllister, 2011a, 2011b; Robinson & McAllister, 2015; Wiley, Benefield, & Johnson, 2010). According to these studies, average sale price premiums for EnergyStar and for LEED-certified buildings could fall between 5.1 – 31 percent and 11.7 – 28.4 percent, respectively. In some cases, results are not statistically significant, and contrasting results have been found about incremental premiums associated with different levels of certification. In the residential sector, there is comparatively less research available on both construction costs and price premiums. In an study of three US metro areas between 2005 – 2011, Walls, Gerarden, Palmer, & Bak, (2017), found 2 percent and 4 – 9 percent sale price premiums associated with single-family units with EnergyStar and local green building certifications, respectively. Kahn & Kok (2014) found EnergyStar certified single-family dwellings in California transacted at an average premium of 4.7 percent between 2005 – 12, with higher but insignificant premiums for GreenPointRated and LEED certifications. Stephenson (2012) estimated a sale price premium of 8.3 percent for EarthCraft certified houses in Atlanta. Using American Community Survey 2007 data, Koirala, Bohara, & Berrens, (2014) estimated that energy efficiency codes IECC 2003-06 resulted in an increase of 23.25 percent in house rents. Based on contingent valuation analysis, Robinson, Simons, Lee, & Kern (2016) estimated that the aggregate stated willingness to pay for green features was 9.3 percent. A general conclusion from the past analyses is that green buildings can have small upfront cost premiums, but price premiums often offset the cost of certification.

The US Department of Housing and Urban Development (HUD) broadly defines affordable housing as "housing for which the occupant(s) is/are paying no more than 30 percent of his or her income for gross housing costs, including *utilities*" (Ezennia & Hoskara, 2019; HUD, 2019). While helpful, the definition combines all the potential reasons for lack of affordability (e.g., housing prices, housing quality, household income, household choices, public policies); thus, making affordability difficult to understand (Quigley & Raphael, 2004). A voluntary inclusionary housing program – used interchangeably with an affordable housing program – places a rent or price control on a percentage of new development to keep its units affordable to very low-, low-, or moderate-income households for a pre-determined period of time, and in return, offers economic or zoning benefits to builders to offset the imposed costs (Powell & Stringham, 2005). Many program-specific studies on costs and benefits of affordable housing have explored diverse effects of housing conditions (e.g., affordability, stability, quality, location) on program participants (e.g., residential mobility, residents' satisfaction, health outcomes, labor market outcomes, educational outcomes, criminal offending, parenting behavior, etc.) and stakeholders (e.g., origin communities, host communities, taxpayers, and government agencies) but the most common method has been quantifying the value impact of locating near affordable housing properties (Baum-Snow & Marion, 2009; Johnson, Ladd, & Ludwig, 2002; Mueller & Tighe, 2007). A general conclusion from existing value impact analyses is that conventional affordable housing properties can have negative but small spillover effects, which should be addressed by planning and policy instruments (Nguyen, 2005). However, there is also evidence that the construction of well-maintained affordable housing properties can appreciate property values in neighborhoods containing abandoned or physically deteriorating housing units (Santiago, Galster, & Tatian, 2001).

Since the inception of green building rating systems in the early 2000s, state and local governments have provided incentives to promote the integration of green building with affordable housing (Yeganeh & McCoy, 2019). Many researchers have seen the integration of environmental principles into traditionally single-purpose policy sectors, such as affordable housing, as a goal of governance to reduce policy conflicts and inefficiencies (Kivimaa & Mickwitz, 2006; Runhaar, Driessen, & Uittenbroek, 2014). As affordable housing advocates increasingly demand the inclusion of affordable housing beyond central cities, the integration could make affordable housing

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developments more acceptable for host neighborhoods in suburbs and more cost-effective for low-income occupants on a life-cycle basis; thus, helping to achieve multiple policy goals (Bradshaw, Connelly, Cook, Goldstein, & Pauly, 2005; Foy, 2012; Mueller & Tighe, 2007). Nonetheless, costs and benefits of green affordable housing have rarely been investigated, despite the fact that low-income households are often exposed to low quality housing conditions; thus, bear disproportionate costs of energy, transport, healthcare, safety, etc. (Chegut, Eichholtz, & Holtermans, 2016; Zhao et al., 2018). Except for a few recent studies in the EU, available evidence on green building cost premiums is from the gray literature on the commercial sector; thus, leaving little information for public and private entities considering green building certifications in the housing sector (Chegut et al., 2019; Zhang et al., 2018).

2.2. Incentivizing the supply of green affordable housing

Focused on quantifying relationships between local characteristics and the market penetration of green buildings, a number of previous studies have recognized the importance of economic, political, environmental, and social composition of urban areas to the market penetration of green building (Yeganeh, McCoy, Reichard, Schenk, & Hankey, 2019). For instance, Eichholtz, Kok, & Quigley (2016) concluded that some industry types (e.g., financial services industry) are more likely than others to choose to locate in green buildings; thus, cities with a high concentration of those industries are more likely to have a higher number of green buildings per capita. Fuerst et al., (2014) concluded that large, growing, and wealthy cities with highly educated workforce are more likely to have a higher adoption of green buildings. Financial benefits of green buildings and features (e.g., solar panels, green roofs, etc.) increase where more energy savings can be achieved due to the scarcity of water reserves (i.e., higher water costs) or frequency of heating or cooling degree days (Kahn & Kok, 2014; Simons, Choi, & Simons, 2009). Such economic, political, environmental, and social drivers could help explain reasons behind the slow market penetration of green buildings despite documented tangible benefits. Therefore, municipal policy measures – whether regulatory policies or incentives – should be seen as a small fraction of all drivers of green building (Choi, 2010; Simcoe & Toffel, 2014).

Besides findings on effective real-world performance and economic viability of green buildings, states and local governments have increasingly developed policies and programs that require or encourage public-private partnerships to internalize life-cycle externalities associated with conventional buildings (e.g., construction waste, water run-off, energy inefficiency) (DSIRE, 2019; IEA, 2019; Olubunmi, Xia, & Skitmore, 2016; USGBC, 2019b). These policy instruments include a blend of energy price increases (e.g., by introducing an ecological tax), mandatory energy-efficiency standards, and incentives for new construction and rehabilitation projects (Alberini & Filippini, 2011). Mandatory green building standards often apply to publicly owned or funded projects, and voluntary economic instruments (e.g., loans, tax-based incentives, soft-cost assistance, technical assistance, information provision) and zoning instruments (e.g., height and/or density incentives, parking incentives, flexible lot sizes) influence the incorporation of green standards in both public and private sectors (Circo, 2007). Assuming other drivers of green building are to some extent present, the goal of an incentive is to help local builders to supply an efficient quantity of green affordable housing when the free market fails to provide a socially optimum level of such benefits for the society. Previous research considers a variety of factors that could lead to underinvestment in green building, including but not limited to split incentives, information asymmetries, risk aversion, skill shortages, and analytical failures (Deng & Wu, 2014; Fuerst et al., 2014; Matisoff, Noonan, & Flowers, 2016).

The rationale for inclusionary housing programs (i.e., incentivizing private developers to incorporate affordable housing into market-driven developments) is the historic shortage of housing units for low-income households (Sirmans & Macpherson, 2003). Underinvestment in affordable housing has been historically exacerbated by local opposition from host neighborhood to equitable affordable housing siting. For instance, in a survey of 74 not-for-profit and for-profit developers, Scally & Tighe (2015) found that 70 percent of developers experienced local opposition to affordable housing developments, leading to construction delays, delays in leasing or selling units, denied building permits, reduction in the number of units, changes in project location, or cancellation of the entire development. Figure 1 illustrates the effect of introducing a per square foot incentive, where an upward shift in the demand curve, the marginal private benefit (MPB), is needed to increase the free market supply quantity (Q_1) toward a socially optimum level (Q_2) where the marginal private cost of production (MPC) – which is equal to marginal social cost of production (MSC) assuming no negative externalities compared to conventional buildings – is equal to marginal social benefit of consumption (MSB).

While aiming for socially efficient green affordable housing, incentives are often linked to other urban planning goals to further address market failures in environmental sustainability and economic development. For instance, urban planners strategically use density incentive programs to direct development to areas with locational and temporal priorities and common challenges. In addition, green building programs could provide opportunities to fund or realize long-term community benefits (e.g., open space preservation, historic preservation, pedestrian and bicycle connectivity, compliance with urban design guidelines) in new construction projects. These programs could work towards a more efficient use of existing infrastructure (e.g., higher transit ridership, reduction in road construction) and penalize goods with negative externalities (e.g., congestion, pollution) (Matisoff et al., 2016).

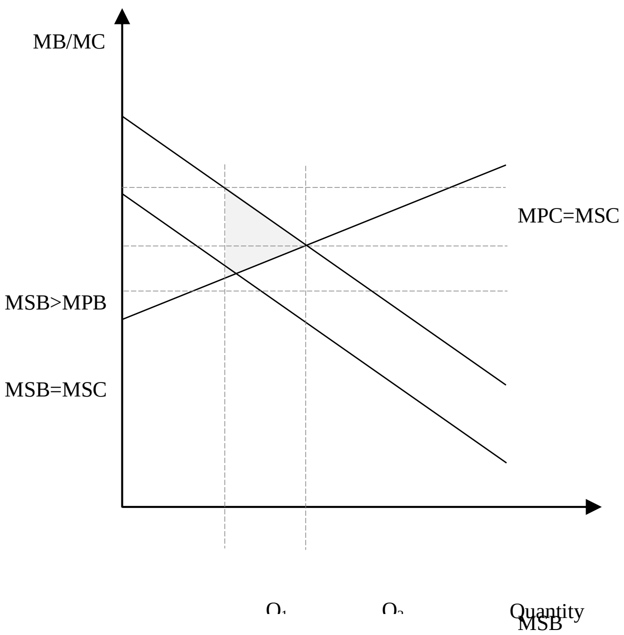

Figure 1 Marginal benefit (MB) and marginal cost (MC) for individuals and the society

Incentives, however, have limited power in inducing general growth and increasing affordability by reducing housing prices in markets with a low price elasticity of supply or demand. In fact, any changes in supply (e.g., associated with regulations, approval delays, growth management) or demand (e.g., associated with changes in income, demographics, mortgage mechanisms) might not be feasible without major regulatory reforms (Eicher, 2008; Ganong & Shoag, 2017; Malpezzi & Vandell, 2002). Figure 2 illustrates such inefficient markets. On the left graph, S_1, D_1, Q_1, and P_0 are supply curve (marginal cost), demand curve (marginal benefit), supply quantity, and equilibrium price in the existing housing market, respectively. The introduction of a per-square-

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foot subsidy would create a new equilibrium in which Q_2, P_P, and P_c are the new supply quantity, the unit price for firms, and the unit price for costumers, respectively. The right graph represents a market with a low-price elasticity of supply, in which introducing the same amount of subsidy ($P_P - P_c = P'_P - P'_c$) would have a little impact on supply quantity (Q'_2). Similar mechanisms are in place in introducing new residential energy efficiency policies that depend on the price elasticity of demand for energy (Alberini & Filippini, 2011).

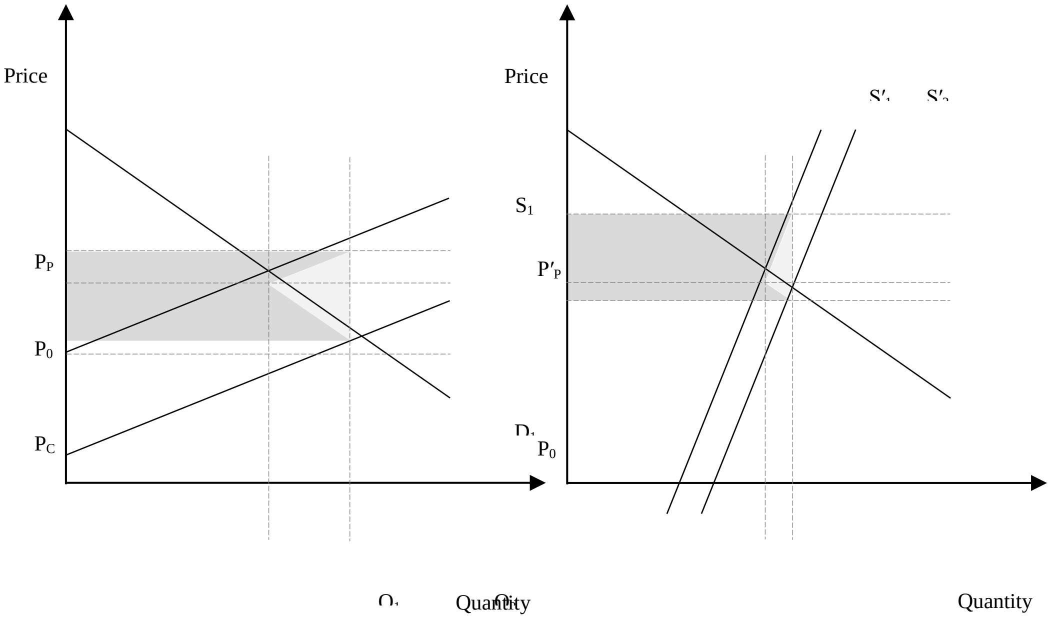

Figure 2 price elasticity (left) and inelasticity (right) of supply

Integration of environmental principles in an affordable housing program requires innovative policymakers to monetize and evaluate all the private and public costs and benefits of the program based on local demographic and housing market data. The extant literature suggests that certified offices and houses have higher rents and/or prices that can come from energy efficiency, water efficiency, improved air quality, and occupant productivity. Nonetheless, evaluation of public benefits (i.e., positive externalities, such as eco-system protection and waste and carbon dioxide emission reduction) associated with green building against environmental damages caused by conventional buildings has been documented with insufficient attention and consensus in the literature (Chegut, Eichholtz, & Kok, 2014; Zhang et al., 2018). Simulation-based life-cycle analyses have provided valuable insight into environmental impacts of green buildings (Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014), but little, if any, research has been performed to date to analyze spillover effects of green buildings, e.g., in terms of the impact of presence or density of green buildings on prices of nearby non-green buildings. Such analyses would have provided more details on price dynamics and social benefits of green buildings and consequences for local sustainability and climate change policy (Yeganeh, McCoy, & Schenk, 2019). The need for monetary analyses is reinforced by the fact that construction cost data, performance data (e.g., energy use, water use) and outcome data (e.g., on health, pollution, congestion) are generally confidential, limited, or simply unavailable, and engineering simulation studies could be hard to compare or have restricted generalizability due to heterogeneities involved in the operation stage. Monetizing all the impacts of green affordable housing could reduce uncertainties associated with forecasts and allow policy analysts to obtain systematic and context-driven conclusions about social benefits of such programs based on cost benefit analysis (Fuguitt & Wilcox, 1999; Kats & Alevantis, 2003).

The current analysis aims to address the lack of attention in the existing literature to the residential sector in smaller urban areas through a cost analysis of EarthCraft VA certified LIHTC developments, a price analysis of market-rate EarthCraft VA certified single-family houses, and an

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analysis of spillover effects associated with market-rate certified houses and affordable non-certified houses in Montgomery County, VA. As previous research (Choi, 2010; Kontokosta, 2011; Sanderford, McCoy, & Keefe, 2018; Sauer & Siddiqi, 2009; Simons et al., 2009) has documented large associations between the presence of density incentives and a higher production of green residential buildings in a state or county we apply our findings on costs and prices to the design of a county-wide voluntary density incentive program to explore how much additional floor area could compensate local builders for investment in the construction of green affordable housing units in for-sale and for-rent scenarios.

3.Methodology:

3.1. Study context and data

This study employs separate datasets and regression analyses for construction costs and transaction prices of green affordable housing. We extracted LIHTC construction cost data from all publicly available applications on the Virginia Housing Development Authority website. The cost premium sample included 422 new construction and rehabilitation residential projects across VA with Gold and Platinum levels of EarthCraft certification. To estimate price premiums and spillover effects of EarthCraft VA certified houses, the authors employed all MLS transaction data for housing units in Montgomery County, VA, between 2000-2019. We removed units built before 1800 and units with above 100 acre lots as outliers. The price premium sample included 38 EarthCraft certified houses built between 2008-2019 with an average transaction price of $444,549.6 (SD 130,701.8) and 45 affordable rental apartment complexes. The affordable properties included Section-8 rental housing assistance apartments, apartments that accepted housing vouchers, and income-restricted complexes. The certified houses and affordable properties were in census blocks in which 1,098 and 2,199 transactions took place during the study period, respectively, and located in different areas within the county; thus, exhibiting no spatial autocorrelation or clustering impacts. Latitude and longitude data were obtained from Texas A&M Geo-Services website to control for zoning characteristics and potential externalities, and data on population, education, and income at the Census-defined block group level were obtained from the US Census Bureau's 2018 ACS 5-year estimates.

We used STATA 14 to perform hedonic regression analyses to assess the total construction cost and transaction price impacts of EarthCraft VA certification and to estimate the spillover effects of EarthCraft VA certified homes and affordable housing properties on non-green houses in Census-defined blocks. The hedonic approach to sale price reflects both supply and demand influences and recognizes the value of a house as an additive function of the utility-bearing characteristics of the structure, the lot, and the neighborhood in which the house is located (Brueckner, 2011). Based on the theory of hedonic prices formulated by Rosen (1974), Equation 1 is one of the earliest and frequently used applications of linear hedonic regression models in housing offered by Grether & Mieszkowski (1974), where v_i is the house value and S_i , L_i , and N_i are vectors of characteristics of the structure, lot, and neighborhood and α, β, and γ are vectors of unknown coefficients.

$$ln\, v_i = S_i\alpha + L_i\beta + N_i\gamma + \bar{\mathcal{E}}_i \qquad \text{Equation 1}$$

To obtain estimates for a voluntary density incentive program for green affordable housing in Montgomery County, VA we assumed that there are 3 percent, 6 percent, and 10 percent increases in construction costs associated with EarthCraft VA Certified, Gold, and Platinum levels of certification, based on a synthesis of the literature, EarthCraft industry reports, and our regression analyses. To estimate the amount of additional floor area required to incentivize green building in the for-sale scenario, we set the estimated total sale profit from new construction under the density incentive zoning ordinance (i.e., market price minus the total cost of financing and production including general contractor's overhead and profit) equal to the estimated total profit from new construction under the existing zoning ordinance and solved for the increased floor area under the density incentive zoning ordinance. Green building area (Q_g) can be estimated using Equation 2, where C and C_g are production and financing costs, and Q and Q_g are the total areas of non-green and green buildings, respectively, and P is the sale price of non-green building. Similarly, the incentivized affordable housing floor area is estimated using Equation 3, where P_m and P_a are sale prices, and Q_m and Q_a are the total areas of market-rate and affordable rate units, respectively. To solve for the necessary increase in density, Q_a is treated as a percentage of Q_m. In this equation, C_e and C_i are production and financing costs of building under existing zoning and under incentive conditions, respectively, and Q_e is the total area under existing zoning conditions. Alternatively, the total loss of income due to the presence of affordable units can be assumed as a per unit area additional cost of construction. In a for-rent affordable housing scenario, the net monthly operating income is equal to the constant monthly construction loan due (*A*), which is found by the amortization calculator formula (Equation 4) using the total cost of construction loan (*P*), monthly interest rate (r), and total number of payments (n). When there is a deficit in the net monthly operating income as the result of rent caps on affordable units (often determined based on 30% of household income) the net present value of the total deficit plus the green premium, if present, is translated into a percentage of the net monthly operating income to determine the density incentive. Table 1 includes descriptive statistics of the sample set and descriptions of primary independent variables used in the current analysis. In addition to these variables, price estimate models accounted for the fixed effects of years of transaction (19 variables), site characteristics (10 variables), and school districts (6 variables) based on the MLS dataset.

$$(P - C) \times Q = (P - C_g) \times Q_g \quad \text{or} \quad Q_g = \frac{(P - C) \times Q}{(P - C_g)} \qquad \text{Equation 2}$$

$$(P_m - C_e) \times Q_e = (P_m \times Q_m + P_a \times Q_a) - C_i \times (Q_m + Q_a) \qquad \text{Equation 3}$$

$$A = P\frac{r(1 + r)^n}{(1 + r)^n - 1} \qquad \text{Equation 4}$$

Table 1 Description of variables in regression analyses

Variable	Definition	Mean	Std. Dev.	Min	Max

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	LIHTC Residential Construction Cost Model				
(n = 422)					
Ln_Cost	Natural logarithm of air-conditioned residential space construction cost	15.62	0.751	13.778	17.418
Cost	Total air-conditioned residential space construction cost in USD	7,950,613	6,157,603	962,950	40,000,000
Gold Level	If building has Gold Level EarthCraft certification (1) or not (0)	0.393	0.489	0	1
Platinum Level	If building has Platinum Level EarthCraft certification (1) or not (0)	0.586	0.493	0	1
Rehabilitation	If project is rehabilitation of an existing structure (1) or not (0)	0.463	0.499	0	1
Age	Age of existing structure(s) in years				
Buildings	Number of buildings in a project				
Residential Area	Total air-conditioned residential space area in SF	64685.16	37673.86	9018.6	208294
Stories	Number of building stories	2.914	1.423	1	12
Latitude	Geographical latitude of project city in decimal units	37.555	0.734	36.59	39.77
Longitude	Geographical longitude of project city in decimal units	-77.843	1.486	-86.16	-75.82
Year	Project year	2014.76	2.615	2011	2019
	Single-Family House Price Model				
(n = 11,418)					
Ln_Price	Natural logarithm of the total house price	12.251	0.507	9.159	13.815
Price	Total house price in USD	236,660.2	121,379.2	9,500	999,500
EarthCraft	If building is EarthCraft certified (1) or not (0)	0.003	0.058	0	1
EnergyStar	If building is EnergyStar certified (1) or not (0)	0.001	0.036	0	1
Area	Total finished interior space area in SF	2084.33	864.34	100	9528
Full Baths	Total number of full bathrooms	2.181	0.731	0	8
Half Baths	Total number of half bathrooms	0.482	0.546	0	6
Townhouse	If building is a townhouse (1) or not (0)	0.126	0.332	0	1
Year Built	Year of construction	1985.656	23.682	1800	2019
Acreage	Total lot area in acres	1.392	4.634	0.01	100
Latitude	Geographical latitude of lot in decimal units	37.177	0.06	36.994	37.348
Longitude	Geographical longitude of lot in decimal units	-80.415	0.05	-80.611	-80.19
Public Transport	If public transport is within walkable distance (1) or not (0)	0.086	0.281	0	1
Recreation	If recreational facility is within walkable distance (1) or not (0)	0.049	0.216	0	1
School	If elementary school is within walkable distance (1) or not (0)	0.076	0.265	0	1
Christiansburg	If building is in Christiansburg (1) or not (0)	0.392	0.488	0	1
Montgomery	If building is in Montgomery (1) or not (0)	0.33	0.47	0	1
Year	Transaction year fixed effects	2010.964	5.288	2000	2019
	Single-Family House Price Models with SES variables				
Education	Percentage 25+ years old adults with bachelor's degree or higher in BG	50.324	22.589	5.982	100
Income	Median household income in BG in 2017 in 1000 USD	70.810	26.436	6.860	141.250
Population	Total population living in BG in 100 persons in 2017	19.276	6.342	5.290	33.510
	Proximity to Green Building and Affordable Housing Model (n = 11,372)				
Affordable Housing	If affordable housing is present (1) or not (0) in the block	0.193	0.395	0	1
Green Building	If green building is present (1) or not (0) in the block	0.097	0.295	0	1

As opposed to single-family and multi-family developments, planned residential developments (PRDs) often achieve multiple incentives (e.g., flexible unit sizes, increased FARs, and decreased minimum lot sizes, and multiple community features) and should be studied on a case-by-case basis (see Dowall, 1985). Third-party consultants should examine the accuracy of pro-forma statements of PRD builders, and the minimum profitable production costs and land costs can be obtained from RSMeans and linear regression of land price on land characteristics (see, e.g., Glaeser & Gyourko, 2018). Then, detailed sale price estimates can be obtained from MLS data using hedonic regression (or other advanced multivariate analytical tools such as neural network software) that accounts for the variety of unit characteristics. Once the difference between the estimated total costs and sale

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prices are determined, planners could negotiate with the builder on the project's expected benefits for the society based on the magnitude of the estimated profit.

4. Results

The LIHTC properties data suggest that the level of 'greenness' of LIHTC buildings has become increasingly important as compared to simply having obtained the 'barely green' (i.e., EarthCraft VA Certified) certification. Table 2 presents results from the regression analysis of the total construction cost of LIHTC residential projects with Gold and Platinum levels of EarthCraft certification. To interpret the percentage change in construction cost in these semi-log models – where the dependent variable has been log-transformed but the predictors have not – we exponentiate the coefficient of the independent variable, subtract one from the result, and multiply it by one-hundred to interpret coefficients in percentages (the result is shown in the Impact column). Model-1 (All) includes both new construction and rehabilitation projects and indicates a significant cost impact of a change in the level of certification. Nonetheless, Model-2 (Rehab) and Model-3 (New) distinguish new construction and rehabilitation project data, respectively, suggesting that a change of certification level does increase the average cost of new construction (04.60%, p = 0.368) but the increase is statistically insignificant. Model-2 suggests that the change has a considerable impact on the total cost of rehabilitation, and the impact is statistically significant (12.60%, p = 0.033). The 95 percent confidence intervals for new construction and rehabilitation impacts are -5.20 – 15.4 percent and 1.01 – 25.48 percent, respectively.

Table 3 presents results from the regression analysis of single-family houses with and without EarthCraft VA certification. Based on Model-1 (Hedonic), which includes hedonic characteristics of houses, lots, and neighborhoods, EarthCraft VA certified homes are, on average, associated with 11.62 percent sale price premium compared to otherwise identical buildings, and the premium is statistically significant (percentages are shown in the Impact column). Houses with EnergyStar appliances are, on average, associated with 5.07 percent sale price premium compared to houses without those features, but the premium is statistically insignificant. Model-2 and Model-3 control for the socioeconomic (SES) variables of education, income, and population at the Census-defined block group level, the smallest geographical level for which these data are available. Although these SES variables show small coefficients, the inclusion of these statistically significant variables increases the estimated average sale price premium for EarthCraft VA certified homes from 11.62 percent to 13.63 percent and 14.94 percent. The models also suggest that houses located within walking distances to public transport on MLS records are negatively affected by some undesirable locational characteristics (e.g., air pollution, congestion, noise) and, on average, are 2.51 percent less expensive. Nonetheless, houses located within walking distance to elementary schools are transacted with an average of 4.98 percent sale price premium compared to similar houses not located within walking distance to the district elementary school.

Table 2 OLS regression analyses of residential construction cost

	Model-1			Model-2				Model-3			
	All			Rehab				New			
	Coef.	Std. Err.	P>|t|	Coef.	Std. Err.	P>|t|	Impact (%)	Coef.	Std. Err.	P>|t|	Impact (%)
Platinum Level	0.0849	0.0398	0.034**	0.1187	0.0551	0.033**	12.60	0.0450	0.0499	0.368	04.60
Rehabilitation	-0.4941	0.0356	0.000***								
Age				0.0041	0.0012	0.001***	0.41				
Buildings	0.0106	0.0030	0.001***					0.0094	0.0036	0.010**	00.94
Residential Area	1.07E-05	4.95E-07	0.000***	1.4200E-05	6.6900E-07	0.000***	00.01	8.42e-06	4.71e-07	0.000***	00.01
Stories	0.1252	0.0128	0.000***	0.1007	0.0202	0.000***	10.59	0.0977	0.0133	0.000***	10.26
Latitude	0.1128	0.0208	0.000***	0.0252	0.0344	0.464	02.55	0.1908	0.0249	0.000***	21.02
Longitude	0.0199	0.0106	0.062	0.0232	0.0138	0.094	02.35	0.0505	0.0171	0.003***	05.18

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Year	0.0571	0.0079	0.000***	0.0690	0.0111	0.000***	07.14	0.0466	0.0099	0.000***	04.77
Constant	-102.9944	15.9513	0.000***	-124.1019	22.5913	0.000***		-82.1426	19.8885	0.000***	
Obs	422			191				230			
Prob > F	0.000			0.000				0.000			
R-squared	0.857			0.800				0.790			
Adj R-squared	0.854			0.792				0.783			
Root MSE	0.292			0.296				0.240			

Notes:

1. The dependent variable is the natural log of the total cost

2. The reference level of EarthCraft certification for which the dummy variable is zero is EarthCraft Gold

3. *** and ** denote p<0.01and p<0.05, respectively

Table 3 OLS regression analyses of single-family house prices

	Model-1				Model-2			Model-3		
	Hedonic				Hedonic & education			Hedonic & income		
	Coef.	Std. Err.	P>|t|	Impact (%)	Coef.	Std. Err.	Impact (%)	Coef.	Std. Err.	Impact (%)
EarthCraft	0.1099	0.0411	0.008***	11.62	0.1277***	0.0406	13.63	0.1392***	0.0419	14.94
EnergyStar	0.0495	0.0643	0.442	05.07	0.0644	0.0635	06.65	0.0406	0.0644	04.14
Area	0.0003	0.0000	0.000***	00.03	0.0003***	0.0000	00.03	0.0003***	0.0000	0.03
Full Baths	0.0555	0.0052	0.000***	05.71	0.0513***	0.0051	05.27	0.0561***	0.0052	05.77
Half Baths	0.0689	0.0051	0.000***	07.13	0.0682***	0.0051	07.06	0.0720***	0.0052	07.46
Townhouse	-0.1544	0.0080	0.000***	-14.31	-0.1631***	0.0080	-15.05	-0.1530***	0.0083	-14.19
Year Built	0.0043	0.0001	0.000***	00.43	0.0043***	0.0001	00.43	0.0043***	0.0001	00.43
Acreage	0.0102	0.0006	0.000***	01.02	0.0101***	0.0006	01.02	0.0101***	0.0006	01.02
Latitude	0.1363	0.1056	0.197	14.61	-0.1872	0.1079	-17.07	0.0749	0.1080	07.77
Longitude	-0.4163	0.0795	0.000***	-34.05	-0.2121***	0.0796	-19.11	-0.4739***	0.0802	-37.75
Public Transport	-0.0254	0.0095	0.007***	-02.51	-0.0177	0.0094	-01.75	-0.0115	0.0101	-01.14
Recreation	0.0168	0.0113	0.136	01.69	0.0090	0.0111	00.90	0.0158	0.0115	01.59
School	0.0486	0.0094	0.000***	04.98	0.0296***	0.0094	03.01	0.0467***	0.0096	04.78
Christiansburg	-0.0405	0.0125	0.001***	-03.97	-0.0179	0.0126	-01.78	-0.0452***	0.0127	-04.42
Montgomery	-0.0572	0.0095	0.000***	-05.56	-0.0139	0.0099	-01.38	-0.0569***	0.0098	-05.54
Education					0.0031***	0.0002	00.31			
Income								0.0010***	0.0001	00.10
Population					-0.0010**	0.0004	-00.10	-0.0013***	0.0005	-00.13
Year FE	Yes				Yes			Yes		
Site FE	Yes				Yes			Yes		
District FE	Yes				Yes			Yes		
Obs	11,418				11,395			11,167		
Adj R-squared	0.762				0.767			0.764		
Root MSE	0.247				0.244			0.248		

Notes:

1. The dependent variable is the natural log of the total price

2. *** and ** denote p<0.01and p<0.05, respectively

3. FE refers to fixed effects of transaction year, site characteristics, and school districts

Table 4 OLS regression analyses of spillover effects of certified houses and non-certified affordable houses

	Model-1				Model-2			Model-3		
	Coef.	Std. Err.	P>|t|	Impact (%)	Coef.	Std. Err.	Impact (%)	Coef.	Std. Err.	Impact (%)

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Green building present	0.0580	0.0082	0.000	05.97	0.0461***	0.0082	4.72	0.0683***	0.008	07.07
Affordable housing present	-0.0050	0.0061	0.405	-00.50	0.0050	0.0060	0.50	-0.0005	0.006	-00.05
Area	0.0003	0.0000	0.000	00.03	0.0003***	0.0000	0.03	0.0003***	0.000	00.03
Full Baths	0.0573	0.0052	0.000	05.90	0.0537***	0.0051	05.52	0.0582***	0.005	06.00
Half Baths	0.0700	0.0051	0.000	07.25	0.0691***	0.0051	07.16	0.0738***	0.005	07.66
Townhouse	-0.1479	0.0081	0.000	-13.75	-0.1568***	0.0080	-14.51	-0.1463***	0.008	-13.61
Year Built	0.0043	0.0001	0.000	00.43	0.0042***	0.0001	00.43	0.0042***	0.000	00.43
Acreage	0.0102	0.0006	0.000	01.02	0.0101***	0.0006	01.02	0.0101***	0.001	01.02
Latitude	0.1640	0.1057	0.121	17.82	-0.1698	0.1080	-15.62	0.1107	0.108	11.71
Longitude	-0.4033	0.0795	0.000	-33.19	-0.2151***	0.0796	-19.35	-0.4607***	0.080	-36.91
Public Transport	-0.0290	0.0095	0.002	-02.86	-0.0210**	0.0094	-02.07	-0.0142	0.010	-01.41
Recreation	0.0165	0.0113	0.145	01.66	0.0091	0.0112	00.91	0.0151	0.012	01.52
School	0.0507	0.0094	0.000	05.20	0.0315***	0.0094	03.20	0.0481***	0.010	04.93
Christiansburg	-0.0394	0.0125	0.002	-03.86	-0.0158	0.0126	-01.57	-0.0428***	0.013	-04.19
Montgomery	-0.0519	0.0096	0.000	-05.06	-0.0087	0.0100	-00.87	-0.0496***	0.010	-04.84
Education					0.0030***	0.0002	00.30			
Income								0.0011***	0.000	00.11
Population					-0.0010***	0.0004	-00.10	-0.0015***	0.000	-00.15
Year FE	Yes				Yes			Yes		
Site FE	Yes				Yes			Yes		
District FE	Yes				Yes			Yes		
Obs	11,372				11,372			11,130		
Adj R-squared	0.761				0.766			0.764		
Root MSE	0.247				0.244			0.247		

Notes:

1. The dependent variable is the natural log of the total price
2. *** and ** denote p<0.01and p<0.05, respectively
3. FE refers to fixed effects of transaction year, site characteristics, and school districts

Table 4 presents results from the regression analysis of spillover effects of certified market-rate and non-certified affordable housing units on other houses within the Census-defined block. Based on Model-1, which includes hedonic characteristics of houses, lots, and neighborhoods, the presence of certified units in a block is, on average, associated with 5.97 percent sale price premium for non-certified houses within the block (the 95 percent confidence interval is 4.28 – 7.69 percent) and the spillover effect is statistically significant at 99 percent. The presence of non-certified affordable housing units is associated with an average of -0.50 percent sale price premium for non-certified houses within the block (the 95 percent confidence interval is -1.68 – 0.69 percent) but the spillover effect is statistically insignificant. Model-2 and Model-3 control for the socioeconomic variables of education, income, and population at the block group level, and show slight changes but statistically significant spillover effects.

Table 5 presents a longitudinal analysis of spillover effects based on the timeframe of transactions. First EarthCraft VA certified houses in Montgomery County, VA were built in 2008. Therefore, no significant spillover effect is observed in Model-1 (2004-07) and Model-2 (2008-11). Model-3 and Model-4 suggest that statistically significant positive impacts of certified single-family housing units have increased over time. During the study period, the presence of affordable housing units is associated with negligible statistically insignificant spillover effects.

Table 5 Longitudinal analyses of spillover effects of certified houses and non-certified affordable houses

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	Model-1 (2004-07)		Model-2 (2008-11)		Model-3 (2012-15)		Model-4 (2016-19)	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Green building present	0.0276	0.0151	0.0337	0.0214	0.055***	0.017	0.087***	0.016
Affordable housing present	-0.0153	0.0106	-0.0115	0.0149	0.007	0.013	-0.002	0.012
Area	0.0003***	0.0000	0.0003***	0.0000	0.000***	0.000	0.000***	0.000
Full Baths	0.0566***	0.0093	0.0682***	0.0132	0.048***	0.012	0.065***	0.010
Half Baths	0.0746***	0.0090	0.0761***	0.0129	0.065***	0.012	0.066***	0.010
Townhouse	-0.1168***	0.0148	-0.1330***	0.0190	-0.165***	0.016	-0.181***	0.015
Year Built	0.0035***	0.0002	0.0041***	0.0003	0.005***	0.000	0.004***	0.000
Acreage	0.0108***	0.0012	0.0203***	0.0020	0.011***	0.001	0.010***	0.001
Latitude	0.1910	0.1821	0.4076	0.3012	0.553**	0.281	-0.670***	0.240
Longitude	-0.7142***	0.1361	-0.3859	0.2171	-0.121	0.206	-0.145	0.179
Christiansburg	-0.0112	0.0235	-0.0581	0.0334	-0.079***	0.028	-0.017	0.024
Montgomery	-0.0401**	0.0169	-0.0471	0.0246	-0.099***	0.021	-0.048***	0.018
Year FE	Yes		Yes		Yes		Yes	
Site FE	Yes		Yes		Yes		Yes	
District FE	Yes		Yes		Yes		Yes	
Obs	2,972		1,887		2,497		3,094	
Adj R-squared	0.782		0.754		0.752		0.744	
Root MSE	0.214		0.252		0.253		0.264	

Notes:

1. The dependent variable is the natural log of the total price
2. *** and ** denote p<0.01and p<0.05, respectively
3. FE refers to fixed effects of transaction year, site characteristics, and school districts

Table 6 presents the results of our density incentive estimates for single-family and multi-family housing of various sizes in for-sale and for-rent scenarios, respectively, where costs and prices are shown in per square foot of residential area. In the for-sale scenario, builders recover cost premiums at sale times, whereas, in the for-rent scenario, cost premiums are recovered in the long run. In the for-rent scenario, the amount of the incentive, i.e., the additional floor area in percentage, to compensate builders is proportional to and slightly higher than the green building certification cost premium expressed in percentage. Table 7 presents an example of a 100,000 sqft low-rise multifamily building, in which about 25 percent of the total market-based rent is lost due to the presence of affordable housing units dedicated to local workforce with different levels of income relative to the area median income. In this case, an increase in the residential area to 124,813 sqft could recover the loss in rent, and further increases to 128,669 sqft, 132,651 sqft, and 138,180 sqft are enough to recover the total construction cost of different levels of EarthCraft VA certification during the operation of the building. The calculations are based on a 15-year construction loan with 5 percent interest rate.

Table 6 Estimates of incentives for green single-family and multi-family housing

	Area (sqft)	Price/Rent	Cost of Construction				Incentive Floor Area		
	Non-Green	Non-Green	Non-Green	Certified	Gold	Platinum	Certified	Gold	Platinum
Single-Family (For sale)	1,200	$199	$135	$139	$143	$149	6.85%	14.71%	27.18%
	1,400	$180	$128	$132	$136	$141	8.06%	17.54%	33.09%
	1,600	$176	$123	$127	$131	$136	7.62%	16.50%	30.89%
	1,800	$165	$118	$122	$126	$130	8.27%	18.04%	34.18%
	2,000	$157	$113	$117	$120	$125	8.45%	18.45%	35.06%
	2,200	$151	$110	$113	$116	$121	8.74%	19.16%	36.61%
Multi-Family Low-rise (For sale)	50,000	$204	$106	$109	$112	$117	3.44%	7.25%	13.03%
	60,000	$204	$96	$99	$102	$106	2.82%	5.90%	10.49%
	70,000	$204	$89	$92	$95	$99	2.47%	5.15%	9.12%
	80,000	$204	$85	$88	$91	$94	2.26%	4.71%	8.30%

	90,000	$204	$82	$85	$88	$91	2.14%	4.43%	7.80%
	100,000	$204	$81	$83	$86	$89	2.06%	4.27%	7.51%
Multi-Family	50,000	$0.96	$106	$109	$112	$117	3.09%	6.28%	10.71%
Low-rise	60,000	$0.84	$96	$99	$102	$106	3.09%	6.28%	10.71%
(For rent)	70,000	$0.76	$89	$92	$95	$99	3.09%	6.28%	10.71%
	80,000	$0.71	$85	$88	$91	$94	3.09%	6.28%	10.71%
	90,000	$0.67	$82	$85	$88	$91	3.09%	6.28%	10.71%
	100,000	$0.65	$81	$83	$86	$89	3.09%	6.28%	10.71%

Table 7 Estimates of incentives for green affordable multi-family housing in a for-rent low-rise scenario

Units	Area Median Income	Count	Area (sqft)	Market Rent/Unit	Affordable Rent/Unit	Market Income	Loss of Income
0-Bedroom	30%	10	500	$750	$276	$7,500	$4,744
500 sqft	50%	10	500	$750	$458	$7,500	$2,916
One person max	80%	10	500	$750	$733	$7,500	$169
	100%	5	500	$750	-	$3,750	$0
	120%	5	500	$750	-	$3,750	$0
	Market	4	500	$750	-	$3,000	$0
1-Bedroom	30%	10	750	$960	$368	$9,600	$5,925
750 sqft	50%	10	750	$960	$611	$9,600	$3,488
One and half person max	80%	10	750	$960	-	$9,600	$0
	100%	5	750	$960	-	$4,800	$0
	120%	5	750	$960	-	$4,800	$0
	Market	4	750	$960	-	$3,840	$0
2-Bedroom	30%	10	1,000	$1,230	$471	$12,300	$7,588
1000 sqft	50%	10	1,000	$1,230	$655	$12,300	$5,750
Three persons max	80%	10	1,000	$1,230	$1,048	$12,300	$1,825
	100%	5	1,000	$1,230	-	$6,150	$0
	120%	5	1,000	$1,230	-	$6,150	$0
	Market	5	1,000	$1,230	-	$6,150	$0
Total			100,000			$130,590	$32,403
Loss of Income/Market Income Ratio							24.81%
Area after incentive (add the Ratio)							124,813
Area after EarthCraft Certified (add 3.09%)							128,669
Area after EarthCraft Gold (add 6.28%)							132,651
Area after EarthCraft Platinum (add 10.71%)							138,180

5. Discussion

5.1. Key findings and comparison to previous work

Based on an analysis of 422 LIHTC projects applied for income tax credits between 2011-19 across VA, our findings suggest that an increase in the level of EarthCraft certification from Gold to Platinum increases the cost of rehabilitation and new construction by 12.60 percent and 4.60 percent, on average, while controlling specifically for statistically significant attributes of residential area, number of stories, age of existing buildings, coordinates, and the year of construction. The result on the cost premium in new construction is supported by Chegut et al. (2019) as small increases in the level of green building certification in new construction are statistically insignificant. Compared to new construction projects, rehabilitation projects might be more cost-effective in terms of rate-of-return, but rehabilitation project options and specifications might require additional scope and/or restrict the menu of credit-earning solutions that would be available in new construction. Another complicating factor is that within green building programs, there are separate certifications for rehabilitation of existing buildings, whereas, almost all research to date has focused on new

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construction cost premiums. Whether new construction or rehabilitation, buildings certified as green within each category are likely to take longer to complete than conventional buildings; thus, requiring less experienced builders to wait longer to obtain revenues. Allocating more incentives to rehabilitation projects could be reasonable where there is a tendency for lowering undesirable economic, environmental, and social impacts of developments (e.g., reduced cost and time of construction, reduced waste generation and resource consumption, increased reuse of existing materials); thus, increasing social benefits (Alba-Rodríguez, Martínez-Rocamora, González-Vallejo, Ferreira-Sánchez, & Marrero, 2017; Power, 2008).

Houses certified under the EarthCraft VA program in Montgomery County, VA are associated with significant sale price premiums with the estimated average of 11.62 percent, which translates to a dollar value of $30,404 when considering the average home sale price for the county of $261,660 in 2018. This finding is in general agreement with a previous study that found an increase of 8.30 percent associated with 300 EarthCraft certified houses from a sample of 1,094 homes sold in Atlanta between 2007-10, which could be lesser due to a recession in the housing market (Stephenson, 2012). In addition, Walls et al. (2017) found 8-9 percent premiums associated with housing units with local certification schemes in Austin, after matching and hedonic analyses. Anecdotally, EarthCraft VA reports an upfront cost premium of 0.5-3 percent based on local builders, suggesting that the capitalization of green building features into transaction prices, on average, substantially exceeds upfront cost premiums. In the current study, the impact of EnergyStar certification on housing unit prices is smaller (around 5.07 percent) and statistically insignificant.

The density bonus estimates suggest that to recover 3, 6, and 10 percent incremental cost premiums associated with for-sale single-family houses in Blacksburg, VA, homebuilders need about 5-10, 10-20, and 25-40 percent increases in floor area, respectively. More precise estimates can be achieved based on structural and locational characteristics of individual buildings (Table 6). Nonetheless, housing prices are also confounded by dynamic market-driven factors; thus, making it difficult to forecast housing prices using conventional methods. It is likely that regulatory and technological reforms affect certification costs and willingness to invest in certified buildings. Factors such as builders' capacity and experience in green building, energy literacy of households, availability of professional training programs and financial solutions, and recognition of green buildings in the market are important to the economic viability of green buildings. It is also likely that local opposition to affordable housing causes construction delays, delays in leasing or selling units, etc. Therefore, such thresholds could provide local planners with some levels of flexibility in decision-making. In for-sale low-rise and mid-rise multi-family buildings, the percentage and variability of density incentives decrease. In general, our results indicate that where housing is expensive relative to its basic costs of production (e.g., due to zoning) small increases in building area could help builders recoup their initial investment in green affordable housing while keeping the price per unit area unchanged for home buyers and renters. Planners could strategically allocate density incentives towards meeting other goals set by local comprehensive plans or zoning codes, e.g., promoting socio-economically balanced communities, but need to ensure that other constraints, e.g., water permits, height limits, are not limiting the development (Ryan & Enderle, 2012). The real test of whether the offered density incentive ordinance offsets all the costs of green certification and price/rent limits is if local builders would prefer them over the existing ordinance (Powell & Stringham, 2005). Further incentives might include the use of economic instruments (e.g., tax reduction, financial assistance) or the relaxation of zoning requirements (e.g., lot coverage, parking, public space, allowing for off-site construction of affordable units) (Hickey, 2013).

Non-certified market-rate houses in proximity to EarthCraft VA certified houses demonstrate average sale price premiums of 5.97-7.07 percent, which equate to dollar values of $15,621-$18,499 when considering the average home sale price for the county of $261,660 in 2018. The spillover effect has increased to 9.09 percent in the last few years. The combination of price premium and spillover effect, which represents the marginal social benefit of green building in the county, is much higher than the average cost premium to obtain green building certification and justifies the local government's investment in an integrated green affordable housing program. The program could

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reduce public spending resulting from disproportionate costs of energy, transport, healthcare, safety, etc. on low-income groups. As the clustering of green buildings also could disproportionately impact housing affordability by increasing local property values, the introduction of affordable housing units could also address potential segregation impacts. We find evidence that houses in proximity to schools have higher prices, a finding that is supported by the hedonic price literature on pedestrian- and transit-oriented development (Bartholomew & Ewing, 2011). Nonetheless, we find negative price effects associated with proximity to public transportation, which could be explained by the fact that the public transportation system in the county is primarily designed to service student riders, and more expensive houses tend to be in less congested areas.

Extant research on spillover effects of affordable housing and LIHTC properties has found that the magnitude of effects depends on a variety of factors, including but not limited to type and implementation of housing programs, design and management of properties, characteristics of host neighborhoods, and concentration of affordable housing (Baum-Snow & Marion, 2009; Nguyen, 2005). The literature recognizes several reasons for local opposition to any new – and even expensive – housing units, including concerns about the character and quality of structures, negative externalities, diminishing valued open space, etc., which might contribute to a decline in property values (Galster, Tatian, & Smith, 1999; Pendall, 1999). In Montgomery County, VA, non-certified housing units that co-exist with affordable housing developments in a Census block demonstrate an average sale price premium of -0.50 percent, which is statistically insignificant. The presence of positive spillover effects associated with certified units suggests that the integration of green building with affordable housing – along with dispersal of affordable housing throughout the city, reducing the concentration of poverty in buildings through mixed-income developments, and quality management of affordable properties – could enhance the attractiveness of affordable properties in host neighborhoods and reduce local opposition to government-assisted housing.

5.2. Recommendations for future research

Our results show large and significant cost impacts are associated with small increases in the level of certification in rehabilitation projects. Therefore, future research should further investigate the impact of green building certifications on rehabilitation projects as there is currently no comparable systematic study available in the literature. Existing buildings before new energy code improvements of the late 2000s are our largest current stock. As green building policies are increasingly adopted by local governments, multi-jurisdictional studies with larger sample sizes are needed to draw firm conclusions on the external impacts of both market-rate and affordable green housing units, e.g., on local economic, environmental, and social sustainability (Gilderbloom, Hanka, & Ambrosius, 2009). In this research we examined such effects based on either the presence or absence of such units due to sample size limitations, but it would be more fruitful if the relationship is explored in terms of the proportion of land devoted to and distance from certified units and affordable units over time.

Our sample set represents all MLS transactions in the county during the last twenty years. However, the analysis in this case-study is restricted due to the slow diffusion of green building practices in the local marketplace; thus, not allowing for further statistical analyses, e.g., propensity score weighting and matching to reduce selection bias. Despite constant increases in the frequency of transactions in the local market since 2008 and the capitalization of green certifications into house prices, the number of certified houses has not increased since 2014. Such declines, which might be attributed to the emergence of stricter energy-efficiency codes, improvements in construction standards, cost of housing, or negative sentiments towards green buildings in the real estate industry, is worth further investigation in the future research (Brounen & Kok, 2011).

A common limitation in the study of green building cost premium is the lack of organized construction data. LIHTC projects are subject to the Freedom of Information Act (FOIA), which provides the public with access to federal agency records; thus, providing useful resources for future research on construction costs of multi-family residential buildings. Nonetheless, most LIHTC

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agencies in the region did not start to organize and make construction project data electronically available until the last few years. In fact, Virginia Housing Development Authority (VHDA) had the only organized publicly accessible archive of LIHTC construction data in the region, which itself was limited to recent projects. The availability of more LIHTC data in the future would provide researchers with opportunities for investigating the social impacts of green affordable housing, more detailed assessment of which could help address existing barriers and enhance the market recognition of green and affordable housing (Runde & Thoyre, 2010).

6. Conclusion

This empirical study explored density bonus options for green affordable housing by analyzing construction costs, sale prices, and spillover effects for green certifications and affordable housing units. Our findings indicate that the integration of green and affordable units is economically justified, could have a positive price impact on peer buildings, and reduce the risk of investment in affordable housing by enhancing neighborhood conditions and competition on sustainability metrics. Small voluntary density incentives could help facilitate the integration of green building with affordable housing to promote multiple sustainable development goals where housing is expensive relative to its basic costs of production. Achieving green building compliance through third-party verification programs – rather than government-designed programs – could facilitate sustainable development by reducing the cost of program administration. Since buildings represent about 40 percent of global energy use and 30 percent of global greenhouse gas emissions, the major source of contribution to climate change, there are considerable opportunities for positive large-scale impacts on global sustainability and climate change mitigation by gradual investment in the environmental sustainability of local housing markets and, at the same time, address housing affordability and environmental justice (Edenhofer, 2015).

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