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PECUNIARY EXTERNALITIES AND HEDONIC ASSETS

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To address a lack of attention to the welfare effects of house price returns generated by public policies that enhance environmental quality, We develop a dynamic, discrete-time model for a hedonic housing asset and an associated flow of housing services. We assume the housing asset and rental services are traded in closely linked, competitive asset and rental markets, respectively. The model distinguishes between firms that own the asset and consumers who rent. Assuming an immediate transition to a new steady-state, we consider the effects on the firm and household of an unexpected shock, and we derive present-value welfare change measures for non-marginal and marginal changes in amenities, finding results consistent with the static measures currently available. However, the dynamic model provides additional details about the distribution of benefits over time, highlighting the inherent pecuniary externalities connecting rental and hedonic asset markets. These pecuniary externalities are fundamental to asset values and they transfer much of the economic benefits of amenity improvements from households to landlords. We also develop and consider a model extension specific to owner-occupied housing. We then consider the effects of property taxes and finally we derive a corrective tax and subsidy to offset the increases in rent from the pecuniary externality.

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1. INTRODUCTION

THE VALUATION TOOLS that economists have developed for quantifying ecosystem service benefits provide society with important information about human well-being. Hedonic pricing methods allow economists to quantify diverse ecosystem service values by modeling how people respond to trade-offs associated with observable market activity, typically in labor and housing markets. Information about the benefits that people derive from their homes is a vital component of public discourse and policymaking. In this paper, we revisit the economic theory of the hedonic price method as it is applied to residential real estate. The model we develop retains two important distinctions absent from existing models: between renter and owner as well as between real estate as an asset with a sale price and housing as a service with a rental price. The distinction in the model between home owners and home renters highlights the enormous magnitude of value transfers from renters to owners that are typically obscured by existing applications of the hedonic price method.

A key insight from our work is that conflating the housing rental market with the housing asset market conceals the distribution of benefits between home owners and home renters. The consequence of this conflation is that the economic benefits of public projects are enjoyed to a much greater extent by the asset owners than the asset users than standard analyses typically imply. Kuminoff and Pope (2014) say in their opening paragraph, "Homebuyers implicitly purchase the right to consume a bundle of local public goods when they buy a house." In the context of our analysis we would rephrase this as, "Homebuyers implicitly purchase the right to *rent out* a bundle of local public goods when they buy a house."

In this paper, we contribute to the literature on the hedonic price method by developing a dynamic model of consumers and firms that includes competitive equilibria in an asset market and a closely related rental market. Our dynamic modeling approach emphasizes the adjustment process that follows shocks affecting residential real estate such as unexpected improvements in environmental amenities. Importantly, we develop a theoretical model that uses equilibrium in the rental market to reveal consumer preferences for housing amenities, which is in contrast to the common static approach that uses the price of the housing asset. Nonetheless, we derive measures of total welfare change based on the price of the housing asset that are consistent with the static literature (e.g., Freeman (1999) and Freeman, Herriges, and Kling (2014)). In the existing literature, much attention has been paid to estimating households' willingness to pay for improvements in environmental amenities as owner-occupants, though this assumption is often implicit. The increased granularity of our approach highlights the distributional consequences of improving hedonic assets such as housing, particularly for the approximately one third of households in the United States who rent and do not own.

The connectedness of the rental and asset markets demonstrated in our modeling approach can be thought of as examples of pecuniary externality. And economists arguably tend to de-emphasize these types of spillovers from their analysis (Holcombe and Sobel (2001)). As discussed below, the hedonic price method relies on changes in housing sale prices to quantify the economic values that occupants place on environmental amenities. The fact that the unit of housing as a productive asset has increased in value at (and because of) the expense of future renters due to the improved amenities is generally ignored (e.g., Bishop, et al. (2020)) or glossed over (e.g., Banzhaf (2020)) when assessing ecosystem service benefits. The dynamic model we develop allows us to clearly separate the impacts on firms from the impacts on households; this distinction adds clarity to concerns about environmental justice that arise when public policies enhance property values, potentially leading to increased inequality and environmental gentrification (Banzhaf, Ma, and Timmins (2019)).

We also develop extensions to our dynamic model for households that own houses and for property taxes. Our results agree with existing dynamic models of property taxes in the literature, such as Freeman (1980) and Poterba (1984), but with an entirely different motivation: environmental justice. We apply our model of property taxes to identify a property tax rate and corresponding subsidy to consumers that affords policy makers an option for increasing environmental quality without harming current residents by allowing firms to capture the bulk of these benefits. We also include a brief empirical application of our model to demonstrate the magnitude of the welfare transfers associated with the environmental benefits of the clean air act amendments. Fundamental to our approach is the assumption that people have some basic human rights to environmental quality, and consequently private markets should not be used to exclude non-paying households from enjoying what is rightfully theirs.

2. LITERATURE REVIEW

2.1. *Benefits of Amenities*

Rosen (1974) and Freeman (1974) contemporaneously established a static theoretical relationship between a household's utility and a hedonic price function for residential housing. Freeman (1999) and more recently Freeman, Herriges, and Kling (2014) are common references that continue to use the same theoretical justification for evaluating welfare changes. These authors found that hedonic price regressions were useful for estimating economic benefits because they revealed the implicit marginal price of and a household's willingness to pay for each of the bundled services provided by a house.

The theoretical models developed by Rosen (1974) and Freeman (1974) treat each housing purchase as "pure consumption" (Rosen (1974)), which makes the approach difficult to apply to renters who do not own a house. In their recent paper detailing best practices for hedonic assessments of ecosystem service values, Bishop, et al. (2020) suggest a preference for rental-rate data where the proportion of owner-occupants is low, but they otherwise do not discuss the issue. In empirical applications, one option is to restrict analysis to owner-occupants. This approach is often followed by authors who seek to identify the home-owner's compensated demand curve. Empirical examples include Palmquist (1984), Zabel and Kiel (2000), and Chay and Greenstone (2005). Smith and Huang (1995) focus their widely cited meta-analysis of hedonic valuation studies of clean air on owner-occupants. Kuminoff and Pope (2014) include controls for "block group level ... percent owner occupied", but do not address how the measure might affect MWTP; Chay and Greenstone (2005) and Bento, Lang, and Freedman (2015) include similar controls in their regression models.

A number of recent studies do not address the distinction between owners and renters when reconstructing consumer demand curves. Bishop and Timmins (2018) do not address the question of ownership and discuss only home buyers, without mention of the occupants. Banzhaf (2020) mentions distinctions between landlords and renters when approximating demand functions, but as with Freeman, Herriges, and Kling (2014) those differences cancel during aggregation of the benefits to consumers and firms and receive no further consideration. Banzhaf (2021) considers only owner-occupied housing without explanation. Alternatively, due to the microeconomic and econometric challenges to identifying demand curves, as pointed out in Bishop and Timmins (2018), a number of studies only seek to estimate implicit prices as estimates of marginal willingness to pay (MWTP) and any distinction between owners and renters is ignored (e.g., Bajari et. al. (2012), Bui and Mayer (2003), and Kuminoff and Pope (2014)).

A variety of theoretical dynamic models have been developed for hedonic analysis of real estate prices. These models tend to include more realistic treatment of taxation and interest rate issues but they lack a theoretical connection to a dynamic counterpart to MWTP. Early on, Niskanen and Hanke (1977) and Freeman (1980) develop and extend dynamic hedonic models to quantify benefits in the presence of taxes. Around the same time, Sonstelie and Portney (1980) develop a dynamic approach to hedonic modeling that incorporates interest rates and tax rates and the user costs a landlord experiences. Hendershott and Slemrod (1983) distinguish between owners and renters when modeling the impacts of tax treatment on households. Poterba (1984) take a similar approach and use the concept of user cost to assess how inflation and tax rates impact housing prices and investment in new construction in the context of macroeconomic asset markets, limiting their model to owner-occupied housing. More recently, Bishop and Murphy (2011) and Bishop and Murphy (2019) estimate dynamic models that include a consumer as a home-buyer's expectations about future prices. None of these works distinguish between the welfare of the renter and the owner of a housing unit, though Hendershott and Slemrod (1983) distinguish between the income of a renter and an owner.

2.2. *External Economies*

In Economics, pecuniary and technological externalities have been defined to characterize interactions among market participants as well as political participants (Holcombe and

Sobel (2001)). Scitovsky (1954) discussed external economies in the context of industrial organization, distinguishing between technological and pecuniary externalities. Buchanan and Stubblebine (1962) generalized technological externalities to include consumers. Technological externalities have a directly impact on an external party other than through prices; the numerous, rippling consequences of price changes are pecuniary externalities. Holcombe and Sobel (2001) suggest that because pecuniary externalities do not result in economic inefficiency, the associated losses and gains have received much less attention than non-pecuniary externalities. The direct mentions of pecuniary externalities in recent literature (e.g., Dávila and Korinek (2018)) are largely confined to macroeconomic discussions related to investment and finance.

The relatively rare investigations of pecuniary externalities in environmental economics often focus on indirect policy effects. The debate over the indirect effects of biofuel subsidies provides a complex example of the deliberations over the ways relative price changes may be included in policy design. Zilberman, Hochman, and Rajagopal (2011) examine the impact of biofuel subsidies on indirect land use change through increased food prices, and they begin by noting the validity of considering pecuniary externalities in policy design. In Zilberman, Hochman, and Rajagopal (2011) and other studies such as Zilberman, et al. (2013) a similar group of authors cast doubt on the inclusion of indirect land use change in biofuel subsidy planning largely because of the myriad other indirect effects also left out.

2.3. *Environmental Justice*

Mohai, Pellow and Timmons Roberts (2009) broadly review the history of Environmental Justice, including both academic attention and societal attention to the topic. Much of the focus is on the intersection of race, poverty, and toxic waste disposal. Several of the sources they review illustrate a growing awareness of pollution and a consequent push by more affluent, whiter populations to maintain their own local environmental quality. Aaronson et. al. (2021) discuss redlining and the consequent lack of access to credit and disinvestment in black neighborhoods that began in the 1930's and which continue to negatively affect a variety of measures of well-being for occupants of those neighborhoods.

Gervais (2002) found that favorable tax treatment of homeowners encourages them to over consume housing at the expense of the stock of rental housing. This evidence suggests that favorable treatment of homeowners relative to landlords in the tax code may compound the negative effects of low home ownership rates.

In the context of applying the hedonic price method to residential real estate, environmental justice concerns and the search for causal connections face many challenges due to the numerous connections and feedback effects, as exemplified by the pyramid of environmental gentrification (Banzhaf, Ma, and Timmins (2019)). Banzhaf, Ma, and Timmins (2019) provide an overview of environmental justice in a spatial context that focuses on the use of hedonic price modeling for revealing preferences and disentangling the mechanisms that expose lower income households to higher levels of pollution. The same authors also recognize that For example, improved environmental quality can lead to gentrification, displacing lower income households that tend to rent rather than own their homes.

Environmental justice concerns discussed in the recent executive order 14008 of Jan 27, 2021 discusses communities as the target of restorative justice, suggesting that concerns about environmental gentrification should be reflected in policy design. Curran and Hamilton (2012) describe a "just green enough" approach to enhancements in environmental quality that lead to reduced environmental gentrification by targeting enhancements at current residential and industrial occupants rather than new developments that tend to be "parks, cafes, and a riverwalk". Wolch, Byrne, and Newell (2014) advocate for increased adoption of "just green enough" approaches to public enhancements of environmental quality after reviewing the literature on environmental gentrification in the US and China and concluding that displacement of working-class communities is a broadly relevant, ongoing concern.

3. THEORETICAL MODEL

3.1. *Owners and Renters*

In this section, we develop a dynamic model of a typical profit maximizing firm that buys and sells units of housing in an asset market and a typical utility maximizing households who rent units of housing in a rental market. Each unit of housing is a bundle of attributes,

z, and a separate attribute, q, of primary interest which we might imagine is an environmental amenity such as clean air. We assume that the asset and rental markets are each in a competitive equilibrium and that participants have complete information, aside from any unexpected shocks.

Our approach follows the standard hedonic approach (e.g., Rosen (1974)) to consumer decision making, but rather than being motivated by the price or user cost of homeownership, the representative consumer or household in our model decides where to rent. We assume that when deciding where to live each time period, a household is maximizing a utility function constrained by their budget and conditional on prices and income. Competing with similar demanders of housing over a set of houses with continuously variable attributes leads to an equilibrium market outcome where each household's marginal willingness to pay for an attribute is equal to the implicit rental price of that housing attribute.

At the start of each time period, t, the firm purchases a house for P_t which is borrowed at interest rate r. After purchasing the house, the firm rents out the unit of housing to a household for, R_t and pays costs C_t. Later, at $t+1$, the firm sells the house for P_{t+1} and repays the loan plus interest, $(1+r)P_t$. The present value of the firm's profit for a single time period will be,

$$\pi_t = (R_t - C_t) + \left(\frac{P_{t+1}}{1+r} - \frac{P_t(1+r)}{1+r}\right). \tag{1}$$

Where the first term is the net revenue from rent and costs for the time period and the second term represents the present value (i.e., at the start of the time period, t) of house price returns.

Over the same time period, a household rents the house for R_t and has a willingness to pay for housing, $WTP_t = WTP(q_t, z_t, y_t)$ for that same housing unit, where y_t is the renter's income. For simplicity in our mathematical exposition, we assume that consumers have identical WTP functions conditional on income and housing attributes. We assume that there is an equilibrium rent function, $R_t = R(q_t, z_t, P_t, C_t, \bar{y}_t)$, that depends on characteristics of the house and the average income of the population of renters each time period, $\bar{y}_t$. One might estimate this function using the hedonic price method and time series rent data rather than housing price data, though as we will show this is not necessary because house prices can be used to quantify the welfare impacts of a policy or treatment that fundamentally affects the consumers in the rental market.

Each time period, the consumer's monetized benefit is:

$$w_t = WTP_t - R_t$$

Here we can see that optimization will result in a first order condition that reveals marginal willingness to pay for a single point on the household's demand curve for housing in time period, t,

$$\frac{\partial WTP_t}{\partial q_t} = \frac{\partial R_t}{\partial q_t} \tag{2}$$

For the moment, we ignore the relationship between average income, willingness to pay rent, and equilibrium rent, returning to that question when we consider home ownership below. Returning to the firm, if we assume the market uses information to price houses efficiently, today's price will equals tomorrow's price,

$$P_t = P_{t+1}.$$

Future work might consider relaxing this assumption by incorporating the impacts of a stochastic specification and including short run macroeconomic effects. We can rewrite the profit equation in 1 as,

$$\pi_t = (R_t - C_t) - P_t * \frac{r}{1+r}. \tag{3}$$

Further, we assume arbitrage in the asset market leads to a steady-state with $\pi_t = 0$, allowing us to solve for the equilibrium rent,

$$R_t = C_t + P_t * \frac{r}{1+r}.$$

Which says that over a time period rent is equal to costs during the time period plus the present value of the interest payment on the cost of the house as capital. If rent were lower than this value, profits would be negative, firms would exit, house prices would fall, and the interest payments would decline until profits were no longer negative.

For each housing unit we can characterize the total welfare, W_t associated with a firm owning and a household renting for a time period,

$$\begin{aligned} W_t &= w_t + \pi_t, \\ &= WTP_t - R_t + 0. \end{aligned}$$

3.2. *Assessing a Shock*

We define a shock, such as an unexpected treatment, that improves environmental quality from q to q' that happens at the end of $t = 0$ causing q to increase uniformly in future time periods such that $\Delta q_t = q'_t - q_t > 0$ for $t > 0$. The post-shock willingness to pay for the higher amenity level, $WTP'_t = WTP(q'_t, z_t, y)$ along with the post-shock equilibrium rent, $R'_t = R(q'_t, z_t, P'_t, C'_t)$ allows us to write the post-shock welfare measure,

$$w'_t = WTP'_t - R'_t \text{ for } t > 0$$

The difference between the treated and untreated states for the consumer is,

$$\begin{aligned} \Delta w_t = w'_t - w_t &= WTP'_t - WTP_t - (R'_t - R_t) \\ &= \Delta WTP_t - \Delta R_t \end{aligned}$$

For the producer's alternative profit in the treated state of reality we write,

$$\pi'_t = (R'_t - C'_t) + \left(\frac{P'_{t+1}}{1+r} - \frac{P'_t(1+r)}{1+r} \right) \text{ for } t > 0.$$

which can be simplified in the manner of 3 by assuming competition returns profits to zero and markets function efficiently,

$$\pi'_t = (R'_t - C'_t) - P'_t * \frac{r}{1+r} \text{ for } t > 0.$$

The difference between the treated and untreated states for the producer is zero in all subsequent periods due to the effects of competition and arbitrage, but in the period where the treatment occurs profits are non-zero,

$$\Delta \pi_0 = \frac{P'_1 - P_0}{1+r} = \frac{\Delta P_1}{1+r}. \tag{4}$$

In the context of competitive markets for conventional goods like corn, the existence of profits from enhanced production would attract competition, boosting supply, leading to a lower equilibrium price of corn along with more production, more consumption, and more consumer surplus. However due to zoning and fundamental constraints to free entry in land markets, the profits are capitalized into the price of the real estate. In many log-transformed empirical applications, the implicit prices of all bundled characteristics including the amenity in question increase. Now we can calculate the present value of the change in total welfare due to the treatment,

$$
\begin{aligned}
\Delta W_{\mathrm{PV}} &= \Delta\pi_0 + \sum_{t>0} \Delta w_t (1+r)^{-t} \\
&= \frac{\Delta P_1}{1+r} + \sum_{t>0} (\Delta\, WTP_t - \Delta R_t)(1+r)^{-t} \qquad (5)\\
&= \Delta P_{1_{\mathrm{PV}}} + \Delta\, WTP_{\mathrm{PV}} - \Delta R_{\mathrm{PV}} \qquad (6)
\end{aligned}
$$

This is an intriguing result that helps refine how we compute the distribution of benefits from public projects that enhance amenities. The house price return is an unexpected profit enjoyed by the owner. This benefit to the firm is immediate and has a clear value, while the sign on the individual differences in the sum of future consumer benefits is indeterminate. the result in 6 result may seem inconsistent with the usual measure of welfare change, such as in Freeman, Herriges, and Kling (2014) and Banzhaf (2020), but next we consider the pattern of changing rent that accompanies the change in price to derive a more familiar measure.

While $\Delta\pi_t = 0$ for $t > 0$, it is still helpful to consider the equation for the change in profits because it can help us understand how rents will change,

$$
\begin{aligned}
\Delta\pi_t &= \Delta R_t - \Delta C_t - \Delta P_t \left(\frac{r}{1+r}\right) = 0 \text{ for } t > 0 \\
\Delta R_t &= \Delta C_t + \Delta P_t \left(\frac{r}{1+r}\right) \text{ for } t > 0 \qquad (7)
\end{aligned}
$$

Returning to our measure of welfare change in equation 5, we can substitute for ΔR_t from 7 and rearrange,

$$
\begin{aligned}
\Delta W_{\text{PV}} &= \frac{\Delta P_1}{1+r} + \sum_{t>0}\left(\Delta\, WTP_t - \left(\Delta C_t + \Delta P_t\left(\frac{r}{1+r}\right)\right)\right)(1+r)^{-t} \\
&= \frac{\Delta P_1}{1+r} + \sum_{t>0}(\Delta\, WTP_t - \Delta C_t)(1+r)^{-t} - \frac{\Delta P_1}{1+r} \\
&= \Delta\, WTP_{\text{PV}} - \Delta C_{\text{PV}}
\end{aligned}
$$

Which is the dynamic counterpart to the usual welfare measure (e.g., Freeman, Herriges, and Kling (2014)). It is important to note that this measure does not convey the imbalanced flow of benefits to the owner and the renter. Indeed, because the public policy that improved the amenity was targeting consumers who would directly benefit, it is a pecuniary externality that competition among renters allows the homeowner to capture a large share of the benefits through rising rent that propels a rising asset value.

3.3. *Marginal Effects*

We are ultimately interested in understanding the relationship between price changes and welfare measures. In the usual approach that is static and does not distinguish between owner and renter, consumer optimization leads to a first order condition, $\frac{\partial\, WTP}{\partial q} = \frac{\partial P_h}{\partial q}$, which is the theoretical result that connects observable prices to WTP. We take a similar approach using the dynamic model described above, but with an infintesimally small treatment, $\partial q_{t>0}$ applied to all future time periods. We rely on the first order condition in equation 2 from the renter's optimal choice to reveal information about the consumer's marginal willingness to pay for q,

$$
\begin{aligned}
\frac{\partial\, WTP_{\text{PV}}}{\partial q_{t>0}} &= \sum_{t>0}\frac{\partial\, WTP_t}{\partial q_t}(1+r)^{-t} \\
&= \sum_{t>0}\frac{\partial R_t}{\partial q_t}(1+r)^{-t}
\end{aligned}
$$

$$= \sum_{t>0} \frac{\partial C_t}{\partial q_t}(1+r)^{-t} + \frac{r}{1+r} \sum_{t>0} \frac{\partial P_t}{\partial q_t}(1+r)^{-t}$$

Which can be rearranged to help us understand the partial derivative of the price function,

$$\frac{\partial P_{1_{\mathrm{PV}}}}{\partial q_{t>0}} = \frac{\partial WTP_{\mathrm{PV}}}{\partial q_{t>0}} - \frac{\partial C_{\mathrm{PV}}}{\partial q_{t>0}}. \tag{8}$$

If we assume that costs do not change, then we have, in present value terms, the standard tangency condition used in the static ownership literature. If marginal costs are positive (e.g., increased property taxes), then the implicit price tends to underestimate marginal WTP. On the other hand, if marginal costs are negative (e.g., reduced defensive expenditures), then the implicit price tends to overestimate marginal WTP.

3.4. *Renters Who Own*

If we consider renters who also own a home (though not necessarily the one they rent), we can evaluate the effects on the market of increased wealth due to a shock (e.g., an unexpected policy or treatment) that increases profits. Below we use ρ and o superscripts to indicate the housing asset the individual rents or owns respectively. If we assume that increases in wealth due to profits from homeownership translate to smooth increases in consumption in perpetuity (implying the household's marginal propensity to consume (MPC) the perpetuity payment equals one), then consumption becomes a function of attributes of the rented and owned houses, such as q^ρ and q^o. So we can define WTP for a renter who also own a house,

$$\begin{aligned} WTP_t'^{owner} &= WTP(q_t'^{\rho}, z_t^{\rho}, y_t') \\ &= WTP(q_t'^{\rho}, z_t^{\rho}, y_t + r * \pi^o_{\mathrm{PV}}) \end{aligned}$$

Where $r * \pi^o_{\mathrm{PV}}$ is the perpetual income payment from any profits associated with homeownership. Implicitly, the previous WTP measures are for renters who do not own a house.

Now we can consider the marginal welfare measure from an increase in the amenity at all relevant houses for a market that includes renter-owners. We start by defining a idiosyncratic and systematic component for each house's amenity, such that $q_t^i = \eta_t^i + \epsilon_t$, where the superscript, i, indexes the houses in a region. Next we consider a small shock to future levels of the systematic component of the amenity, ϵ_t,

$$\begin{aligned}
\frac{\partial WTP_{\text{PV}}^{owner}}{\partial \epsilon_{t>0}} &= \sum_{t>0} \frac{\partial WTP_t}{\partial q_t^{\rho}} * (1+r)^{-t} \\
&\quad + \sum_{t>0} \frac{\partial WTP_t}{\partial y_t} * \frac{\partial y_t}{\partial q_t^{o}} (1+r)^{-t} \\
&= \sum_{t>0} \frac{\partial WTP_t}{\partial q_t^{\rho}} * (1+r)^{-t} \\
&\quad + \sum_{t>0} \frac{\partial WTP_t}{\partial y_t} * r * \frac{\partial P_{1_{\text{PV}}}^{o}}{\partial q_t^{o}} (1+r)^{-t} \qquad (9)
\end{aligned}$$

Where $P_{1_{\text{PV}}}^{o}$ is the present value of the house the individual owns at the start of $t = 1$. Next we assume for the moment that the number of renter-owners is small, so their actions do not lead to indirect effects elsewhere in the housing market such as through increased average income. We also assume $\partial WTP_t / \partial y_t = \lambda$, where λ is constant over time, allowing us to write,

$$\frac{\partial WTP_{\text{PV}}^{owner}}{\partial \epsilon_{t>0}} = \frac{\partial WTP_{\text{PV}}}{\partial q_{t>0}^{\rho}} + \lambda * \frac{\partial P_{1_{\text{PV}}}^{o}}{\partial q_{t>0}^{o}}. \qquad (10)$$

The first term in the right hand side of 10 describes the renter's future optimizing decisions in the rental market, where choosing from housing options causes q_t^{ρ} to vary, so we can solve equation 8 for marginal WTP and substitute it into the first term of 10. Then we assume that the derivatives of the cost and price functions with respect to the amenity are the same for the house that the individual rents and the house they own, abstracting away from the distinction between the two houses,

$$\frac{\partial WTP_{\text{PV}}^{owner}}{\partial \epsilon_{t>0}} = \frac{\partial C_{\text{PV}}}{\partial q_{t>0}} + (1+\lambda) * \frac{\partial P_{1_{\text{PV}}}}{\partial q_{t>0}}. \qquad (11)$$

Rearranging the result highlights the relationship between marginal willingness to pay and marginal sale price for permanent changes in an amenity,

$$\frac{\partial P_{1_{\mathrm{PV}}}}{\partial q_{t>0}} = \left(\frac{\partial WTP^{owner}_{\mathrm{PV}}}{\partial q_{t>0}} - \frac{\partial C_{\mathrm{PV}}}{\partial q_{t>0}}\right)\left(\frac{1}{1+\lambda}\right) \tag{12}$$

In the narrow case of housing markets where few renters own, the marginal willingness to pay of renter-owners is underestimated by the implicit price from the hedonic price function due to the exclusion of income effects.

3.5. *Taxes*

It can be useful to separate taxes out as a component of costs to consider how changes in property tax rates impact renters and owners. Assume firms pay a property tax at the end of each time period on P_t, such that the value of the tax at time period t is $T_t = g * P_t * \frac{1}{1+r}$. We can incorporate this into the firm's profit equation from 1,

$$\pi^T_t = (R^T_t - C^T_t) + \left(\frac{P^T_{t+1}}{1+r} - \frac{P^T_t(1+r+g)}{1+r}\right).$$

The tax is imposed at the end of $t = 0$. Markets subsequently adjust to a new equilibrium with competition returning profits to zero and allowing us to express equilibrium rents as a function of the new tax,

$$R^T_t = C^T_t - \left(\frac{P^T_{t+1}}{1+r} - \frac{P^T_t(1+r+g)}{1+r}\right) \text{ for } t > 0$$

Then efficient use of information and competition cause prices in the next period to equal prices in this period, allowing us to simplify the rental equation,

$$R^T_t = C^T_t - \frac{P^T_t(g+r)}{1+r} \text{ for } t > 0.$$

Because the tax does not influence decisions made at the margin, we assume rents and costs do not change due to the property tax.

The firm's profits are driven by competition to zero in subsequent years, but in year 0 the firm's profits will be non-zero due to the adjustment in price after $t = 0$ that occurs because of the tax,

$$\pi_0^T = (R_0^T - C_0^T) + \left(\frac{P_1^T(1-g)}{1+r} - P_0 \right).$$

Because of our assumption that rents and costs do not change due to the property tax, we can solve for the change in price due to the tax,

$$\begin{aligned} \Delta^T R_t &= \Delta^T C_t + P_t^T \frac{g+r}{1+r} - P_t \frac{r}{1+r}, \\ 0 &= 0 + P_t^T \frac{g+r}{1+r} - P_t \frac{r}{1+r}, \\ P_t^T &= P_t \frac{r}{g+r}. \end{aligned} \tag{13}$$

Where Δ^T denotes the difference between the state of reality with the tax and without. As long as g and r are positive, the property tax will cause the price of the house to fall to a new equilibrium level. Next we can consider the change in profits during $t = 0$ as a function of g and P_0,

$$\begin{aligned} \Delta^T \pi_0 &= P_1^T \frac{1-g}{1+r} - P_1 \frac{1}{1+r} \\ &= P_1 \left(\frac{r(1-g)}{(g+r)(1+r)} - \frac{1}{1+r} \right) \\ &= -P_0 \frac{g}{g+r} \end{aligned}$$

Where we have relied on equality of prices between the two scenarios in $t = 0$ and also that without a tax $P_t = P_0$. The total welfare impact on the firm and household is simply this change in profits in time period zero. Given that rents do not change but the interest payments on the price of the house decrease, we can decompose the change in rents due to the tax,

$$\begin{aligned} \Delta^T R_t &= P_t^T \frac{g+r}{1+r} - P_t \frac{r}{1+r} \\ 0 &= P_t^T \frac{g}{1+r} - (P_t - P_t^T) \frac{r}{1+r}. \end{aligned}$$

The first term is the present value of the future annual tax payments and the second term is the present value of future reductions in rent due to a lower house price. The two terms exactly offset each other, so the renter is unaffected by the property tax.

Our analysis of welfare effects above do not consider the possibility that taxes already exist. Because property taxes distort the information about the occupant's preferences, it is important to correct this effect when quantifying benefits. We can return to 8 and substitute for P_1 using 13 to find the welfare effect when observed prices include adjustments to existing property taxes,

$$\frac{\partial P^T_{1_{\text{PV}}}}{\partial q_{t>0}} = \frac{r}{g+r} * \left(\frac{\partial WTP_{\text{PV}}}{\partial q_{t>0}} - \frac{\partial C_{\text{PV}}}{\partial q_{t>0}}\right).$$

This equation tells us that in the presence of existing property taxes, marginal implicit prices should be scaled up by the ratio $\frac{g+r}{r}$ when measuring net marginal benefits. This result is identical to equation 4 in Niskanen and Hanke (1977), but our approach emphasizes the source of these values is derived from a home occupant's willingness to pay rent, while their interest is focused on including in welfare assessments the increased value of property taxes that comprise the government's share of a home.

Similarly, we can compute the necessary adjustment for owner-occupied housing where the owner experiences income effects by substituting 13 into 12,

$$\frac{\partial P^T_{1_{\text{PV}}}}{\partial q_{t>0}} = \frac{r}{(1+\lambda)(g+r)} * \left(\frac{\partial WTP^{owner}_{\text{PV}}}{\partial q_{t>0}} - \frac{\partial C_{\text{PV}}}{\partial q_{t>0}}\right) \tag{14}$$

Which illustrates that for renter-owners, the existence of property taxes and income effects further divides implicit price from net marginal benefits.

3.6. *A Corrective Tax*

While pecuniary externalities are not an inefficiency that merits correction on the grounds of economic efficiency, political and ethical perspectives may call for such a correction. For example, a public expenditure that enhances air quality is likely designed to benefit the households in a region, regardless of whether or not they own a house. We are interested in identifying a property tax rate that can be designed to exactly offset the pecuniary externality that transfers a portion of the benefits of the amenity change from renter to owner.

Consider an increase in amenities that causes a change in welfare, as described in 6. Next, let T_t for $t > 0$ be a tax on the home owner, and let, S_t for $t > 0$, be an equivalent subsidy paid to the renter. We can incorporate these into the welfare measure in 6,

$$\Delta W_{\text{PV}} = (\Delta P_{\text{PV}} - T_{\text{PV}}) + (\Delta\, WTP_{\text{PV}} - \Delta R_{\text{PV}} + S_{\text{PV}})\,.$$

To offset the owner's unexpected profits due to the increased amenities in 4, we set the tax equivalent to the change in profits, that come about due to the change in amenities,

$$\begin{aligned} \Delta\pi_{\text{PV}} &= T_{\text{PV}} \\ \frac{\Delta P_1}{1+r} &= P_1 \frac{g}{g+r} \end{aligned}$$

which can be solved for the corrective property tax rate, g,

$$g = \frac{\%\Delta P_1 * r}{1 + r - \%\Delta P_1} \tag{15}$$

Because hedonic models are often estimated with a log-transformed dependent variable, estimating 15 is straightforward, particularly for small changes in $q_{t>0}$ when regression coefficients approximate measures of percentage change.

To avoid the situation where the firm captures the benefits of the subsidy, the payment of the subsidy would need to be independent of the renter's decision about where to live. Renter-owners would experience no price change and they would receive a subsidy as well as pay a tax. Firms that own multiple houses would pay the tax multiple times while households receive all of the subsidies. Firms would experience no change in profits because the pecuniary impact of the corrective tax would cancel out the pecuniary impact of the amenity improvement. Notably, this policy is revenue neutral for the government and the firm because,

$$P_0 * \frac{g}{g+r} = T_{\text{PV}} = S_{\text{PV}} = \Delta\pi_{\text{PV}} = -\Delta^T \pi_{\text{PV}} = \sum_{t>0} \frac{g * P_t^T}{(1+r)^{-t}}.$$

Where the first term is the change in profits from the tax and the last term is the government's tax revenue. It is also important to note that our approach to taxation

4. EMPIRICAL APPLICATION

Empirical applications of the hedonic price method that identify measures of willingness to pay can be used to quantify the tax rate, g, that generates tax revenue T_t and subsidy S_t. Because logarithmic transformations of the dependent variable, the house price, are standard in empirical applications, it is straightforward to estimate g for a known value of $\%\Delta P_1$.

Chay and Greenstone (2005) quantified the benefits to households of increased air quality, using non-attainment status under the Clean Air Act Amendments as an exogenous instrument for quantifying the causal impact of total suspended particulates (TSPs) on housing values. They find that the amendments decreased TSP concentrations by about 10 $\mu g/m^3$ during the 1970s, and they use a variety of econometric techniques for estimating hedonic models to estimate that housing prices increase by about 0.28 percent for each $\mu g/m^3$ decrease in TSP concentrations. Then they assume constant marginal WTP and infer that the improved air quality of 10 $\mu g/m^3$ increased housing values by \$45 billion (in 2001 dollars) or 2.8%, an aggregate of the estimated 19 million houses in non-attainment counties during the 1970s. Chay and Greenstone (2005) go on to discuss how the resulting value represents both an estimate of willingness to pay and an estimate of the increased price of houses. We would add to that list that this value estimates the present value of the increase in future rental prices that consumers will pay (implicitly for owner-occupants) for cleaner air.

Chay and Greenstone (2005) provide helpful summary statistics including mean % owner occupied across the 988 counties in their sample, which fell from about 68% to 62% in the non-attainment counties during the 1970s. Assuming that the renter-occupied housing values respond to TSP concentrations in the same manner as the owner-occupied housing used in their regressions, this implies that about 35% of the \$45 billion (i.e., about \$24 Billion in 2021 dollars) in increased housing values come from increased present and future rental payments from renters to their landlords.

Using 15 we can estimate a corrective property tax rate of $g \approx 0.13\%$ at a 5% interest rate and $g \approx 0.084\%$ at a 3% interest rate. Applied to the mean housing value of $86,900 ($134,000 in 2021 dollars), this represents an average annual property tax increase in 2021 dollars of $183 at a 5% interest rate or $112 at a 3% interest rate, which applied to the 19 million homes in the unattaining counties, translates to annual tax revenue of $3.48 billion or $2.13 billion , respectively. The average property tax increase would also be the average annual subsidy per household that the tax could fund.

5. DISCUSSION

Throughout this paper we have mostly ignored the methodological challenges associated with quantifying changes in WTP that dominate the literature. It seems likely to us that the way future willingness to pay, future rents, future costs, etc. are capitalized into today's prices increase the challenge associated with identifying an individual's demand. Efficient markets form expectations about future values, so welfare estimates derived from the asset market provides something of a market consensus about how future conditions and future preferences will translate into the relevant measures of future supply and demand in rental markets. Ultimately, we expect that the enhanced clarity that comes from separating the renter from the owner will determine the appropriate technique for fully quantifying welfare change.

The scope of a property owner's legal rights is an important component of evaluating the feasibility of applying a corrective tax like we describe above. For example, even if tenants have a human right to the health benefits of clean air, it is less clear that tenants are entitled to all benefits of clean air, such as reduced maintenance costs from lower levels of suspended particulates (Bajari et. al. (2012)).

The non-zero probability of moving that renters face each time period is built into consumer decision making and is thus reflected by housing prices. The expectations of firms and households about this process are built into observed prices. Our simple model omits this information, which we expect would lead to underestimation of benefits due to underestimated costs such as moving costs. It would be interesting to extend our model to include forward looking renters (e.g., Bishop and Murphy (2019)) to better understand the impacts of frequent moving on renters and to assess the comparative benefit to owners.

The effects on house prices and owner well-being identified in this paper suggest an import consideration in the development of sorting models such as the single cross (Banzhaf (2020)). Enhanced amenity values in a locality, may lead to re-sorting because the affected house are relatively more valuable, a re-ordering of houses. Simultaneously, the sorting order of the households will change if some of them are owners too, as their willingness to pay may rise enough to change the ordering of households. Furthermore, if higher income households tend to live in areas with the highest concentration of homeownership, multiple sub-populations of homeowners and homes may arise without any underlying difference in preferences. Alternatively, if households have already segregated based on ownership, sorting may be mature and household ordering may be stable.

A key assumption behind our use of the term, pecuniary externality, is that the policy in consideration is targeting households not property owners. While property taxes are familiar, subsidies targeting renters are uncommon, likely because they would effectively be an amenity that would be captured by the owner. A lump sum transfer to all resident in the affected region of the total tax receipt divided across all houses would be one approach to paying out the subsidy to renters. Renters in low-rent housing, who are likely to have a high marginal utility of income and a high marginal propensity to consume would also receive a larger subsidy than their landlords would pay in property taxes, a potential path toward restorative justice.

Considering the spatial correlations that exist between poverty and pollution (Banzhaf, Ma, and Timmins (2019)), environmental cleanup and various publicly provided services, the designers of the subsidy would have numerous opportunities to target payments at individuals with a high marginal utility of income.

In the context of the "just green enough" Curran and Hamilton (2012) approach to avoiding environmental gentrification, the taxation and subsidy approach described here does not affect the impacts of environmental enhancements on industry, so working class households may be negatively affected through reduced employment opportunities and increased commuting costs. Alternatively, subsidies may facilitate access to education that increases opportunities for families, offsetting changes in local employment opportunities. More generally, an important limitation of this work is the absence of investment, which we expect would be sensitive to corrective property taxes, leading to a trade-off in well-being for residents of an area that institute a corrective tax as developed above. We expect the optimal tax would be lower than presented here when the incentives to invest in new housing are taken into account.

While we have focused on single family homes in the development of our model, these results are applicable to any productive asset, such as a factory. For example, if an industry uses natural resources in production, then public enhancements to natural resources will tend to reduce production costs and to the extent that competition is not perfect, this would increasing annual profits and equity. Equity markets likely benefit tremendously from enhanced environmental quality, suggesting further opportunities for redistributing the private benefits of public goods back to the public.

A number of expansions of the theoretical model presented here can be developed to better accommodate empirical applications. Future work may quantify how ownership effects induce sorting and segregation in the absence of distinct preferences (i.e., Tiebout sorting). Extensions similar to Bishop and Murphy (2019) might be used to modify the consumer's first order condition to assess how forward looking consumers respond to varying ammenity levels or moving costs when choosing the optimal home to rent. Extending the work of Kanemoto (1988) to distinguish between renter-owners and renters in a dynamic, general equilibrium framework would be another interesting extension of this work. Similarly, the analysis of Gervais (2002) might be modified to incorporate income effects and multiplier effects associated with groups of asset buying households who bid up each other's housing prices. And finally, incorporating price inflation and the distinct tax treatments of owner-occupied houses (e.g., Poterba (1984)) into this model will help clarify the full benefits and consequences of homeownership (or a lack thereof), providing a useful means for anticipating and offsetting environmental injustice.

6. CONCLUSIONS

The contributions in this paper provide a foundation for identifying and rectifying past social injustices. In this paper, we demonstrate how the fundamentally monopolistic nature of land gives rise to pecuniary externalities that allow landowners to take public goods like air quality and sell them in a private rental market. For renter occupants, permanent enhancements to public goods increase rent and transfer the bulk of measurable benefits to landowners as increased rents in perpetuity. Simultaneously, user costs consume these increased rents, but landowners enjoy an instantaneous increase in wealth. Society has the option of capturing the increased wealth in the form of increased property taxes, which can be calculated to exactly offset the wealth increases and subsidies that can offset the increases in rent that comprise the landowners increased wealth. A carefully designed policy would be necessary to avoid excessive reductions in investment spending on new housing. In the absence of corrective transfers, this research highlights

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