

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.

KEYWORDS: First keyword, second keyword.

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This research was supported in part by an appointment to the ORISE Fellowship Program at the U.S. EPA, Office of Research and Development, Athens, GA, administered by the Oak Ridge Institute for Science and Education through Interagency Agreement No. DW8992298301 between the U.S. Department of Energy and the U.S. Environmental Protection Agency. This article has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government. The views expressed in this article are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA. The authors would like to thank internal and journal peer reviewers for many useful comments on the manuscript. All remaining errors remain our own.

1. INTRODUCTION

ECONOMIC ASSESSMENTS OF ecosystem service values frequently focus on quantifying direct economic benefits to households or consumers. The consumer oriented approach often follows from the way ecosystem services directly affect human well-being. However, in addition to direct impacts on human well-being, there are often price changes that accompany changes in ecosystem service flows. This is particularly evident with applications of the hedonic price method to residential real estate prices for inferring the economic values placed on environmental amenities by the residents.

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 modeling approach emphasizes the adjustment process that follows unexpected shocks affecting residential real estate such as unexpected improvements in environmental amenities. Our emphasis on using equilibrium in the rental market to reveal consumer preferences contrasts with the common static approach, yet we are able to derive welfare measures consistent with the static literature (e.g., [Freeman, Herriges, and Kling \(2014\)](#) and [Banzhaf \(2020\)](#)) and the user-cost literature (e.g., [Bishop and Murphy \(2019\)](#)). In the existing literature, much attention has been paid to estimating households' willingness to pay for improvements in environmental amenities as owner-occupants. However, the increased granularity of our approach highlights the distributional consequences of improving hedonic assets like housing for households who do not own a house.

The hedonic price method of assessing the private benefits of ecosystem services to the occupants of housing is an apt example of a methodology that typically omits pecuniary spillovers from consideration. As discussed below, the hedonic price method relies on indirect changes in housing 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 renters due to the improved amenities is generally ignored when assessing ecosystem service benefits. The dynamic model we develop allows us to separate the impacts on firms from the impacts on households; This

distinction adds clarity to concerns about environmental justice that arise when public policy enhances property values, potentially leading to increased inequality and environmental gentrification [Banzhaf \(2020\)](#).

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 the tax to demonstrate the magnitude of the welfare transfers resulting from some recent hedonic studies. Key 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 fundamentally theirs.

2. LITERATURE REVIEW

2.1. *Benefits of Amenities*

Freeman and more recently Freeman et al. are commonly cited as a source for theoretical underpinnings of the data and models used for estimating the benefits to housing consumers.

Freeman (1979) describes the process of aggregating the benefits to households of marginal improvements in amenities as a process of summing welfare measures based on analysis of household demand. Freeman (1999) asks, “how can we use the information on prices and preferences that can be extracted from the hedonic housing market to calculate measures of welfare change for changes in environmental amenities?”

[Smith and Huang \(1995\)](#) conducted an early meta-analysis of hedonic studies relating to air quality and considered only MWTP as a source of benefits. They also define MWTP as the “change in the asset value of the house”. [Bishop, et al. \(2020\)](#) provide a broad overview of recent innovations and best practices.

Zabel and Kiel (2000) discuss measuring the benefits to homeowners and their households” and focus exclusively on quantifying benefits related to consumer demand, as evidenced by their discussion of the indirect utility function when aggregating economic benefits for the purpose of benefit cost analysis. In their concluding remarks, Zabel and Kiel (2000) compare their results to Smith and Huang’s (1995) results while describing them as benefits to the home owners.

Bui and Mayer (2003) quantify environmental amenity benefits by assessing their capitalization into housing prices.

Niskanen and Hanke (1977) and Freeman (1980) develop and extend dynamic hedonic models and extend them 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, focusing their model on owner-occupied housing. More recently, Bishop and Murphy (2011, 2019) estimate dynamic models that include a home-buyer’s expectations about future prices. None of these works distinguish between the well-being of the renter and the owner of a housing unit, though Hendershott and Slemrod (1983) does 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 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

while the many effects 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. 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.

Investigations of pecuniary externalities in environmental economics often focus on indirect effects. The debate over the indirect effects of biofuel subsidies provides a template for considering some of the ways relative price changes may be included in policy design. Zilberman et al. (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 et al (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 that add to uncertainty and which should also be included in an ideal world but are left out in practice.

2.3. *Environmental Justice*

Improved environmental quality can lead to gentrification, displacing lower income households that tend to rent rather than own their homes (Banzhaf et al 2019).

3. THEORETICAL MODEL

3.1. *Owners and Renters*

In this section, we develop a dynamic model of profit maximizing firms that buy and sell units of housing in an asset market and 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.

We assume that the household is maximizing a utility function constrained by their budget and conditional on prices and income, and we assume that there is a corresponding indirect utility function. The household's optimization problem is over a set of houses with continuously variable attributes, leading to the outcome where each household's marginal willingness to pay for an attribute is equal to the implicit rental price of that housing attribute for each time period, as will be discussed below.

The firm and the household make decisions at each time period to buy/sell and to rent. We focus our analysis on a typical housing unit which may be owned and rented by different firms and households each year. The household and the firm interact at the beginning of each time period when the household pays rent. The transaction is the result of the household maximizing the present value of their utility. Included in the household's first order conditions would be the The firm purchases a house at time t for P_t borrowed at interest rate r . Later, at $t + 1$, the firm sells the house for P_{t+1} and repays the loan plus interest, $(1 + r)P_t$. After purchasing the house, the firm rents out the unit of housing to a household for, R_t and pays costs C_t . The present value of the firm's profit for a single time period will be,

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

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 $t = 0$) 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, $WTP_t = WTP(q_t, z_t, y)$ for that same housing unit. For simplicity in our mathematical exposition, we assume that consumers have identical WTP functions conditional on income and housing attributes. We can assume that there is an equilibrium rent function, $R_t = R(q_t, z_t, P_t, C_t)$ and that $WTP_t \geq R_t$. One might estimate this function using the hedonic price method and time series rent data, though as we will show this is not necessary and house prices can be used to quantify the welfare impacts of a policy or treatment. 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 ,

$$\frac{\partial WTP_t}{\partial q_t} = \frac{\partial R_t}{\partial q_t} \quad (2)$$

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,

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

Further, we assume arbitrage in the asset market causes $\pi_t = 0$, 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. This equation is the arbitrage condition given our assumption that markets are in their steady-state (Poterba (1984)). If rent were lower than this value, profits would be negative, firms would exit, house prices would fall, and the interest payments and other costs 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 a house 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 arbitration, but in the period where the treatment occurs,

$$\Delta \pi_0 = \frac{P'_1 - P_0}{1+r} = \frac{\Delta P_1}{1+r} \quad (4)$$

Now we can calculate the present value of the change in total welfare due to the treatment,

$$\begin{aligned} \Delta W_{PV} &= \Delta \pi_0 + \sum_{t>0} \Delta w_t (1+r)^{-t} \\ &= \frac{\Delta P_1}{1+r} + \sum_{t>0} (\Delta WTP_t - \Delta R_t) (1+r)^{-t} \end{aligned} \quad (5)$$

$$= \Delta P_{1PV} + \Delta WTP_{PV} - \Delta R_{PV}$$

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 is immediate and has a clear value, while the sign on the individual differences in the sum of future consumer benefits is indeterminate. This result may seem inconsistent with the usual measure of welfare change, such as in [Freeman, Herziges, 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,

$$\begin{aligned}\Delta\pi_t &= \Delta R_t - \Delta C_t - \Delta P_t \left(\frac{r}{1+r} \right) = 0 \text{ for } t > 0 \\ \Delta R_t &= \Delta C_t + \Delta P_t \left(\frac{r}{1+r} \right) \text{ for } t > 0\end{aligned}\tag{6}$$

Returning to our measure of welfare change in equation 5, we can substitute for ΔR_t from 6 and rearrange,

$$\begin{aligned}\Delta W_{PV} &= \frac{\Delta P_1}{1+r} + \sum_{t>0} \left(\Delta WTP_t - \left(\Delta C_t + \Delta P_t \left(\frac{r}{1+r} \right) \right) \right) (1+r)^{-t} \\ &= \frac{\Delta P_1}{1+r} + \sum_{t>0} (\Delta WTP_t - \Delta C_t)(1+r)^{-t} - \frac{\Delta P_1}{1+r} \\ &= \Delta WTP_{PV} - \Delta C_{PV}\end{aligned}\tag{7}$$

Which is the dynamic counterpart to the usual welfare measure. 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. I take a similar approach using the dynamic model described above, but with an infinitesimally small treatment, $\partial q_{t>0}$ applied to all future time periods. I 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 ,

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

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

$$\frac{\partial P_{1PV}}{\partial q_{t>0}} = \frac{\partial WTP_{PV}}{\partial q_{t>0}} - \frac{\partial C_{PV}}{\partial q_{t>0}} \quad (8)$$

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 consider the effects on the market of increased wealth due to a shock (e.g., an unexpected policy or treatment) that increases profits. If we consider the willingness to pay for

housing function and that increases in wealth 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 house, such as q . So we can define WTP for renters who own,

$$\begin{aligned} WTP_t^{owner} &= WTP(q_t, z_t, y_t(q_t)) \text{ and} \\ WTP_t'^{owner} &= WTP(q'_t, z_t, y(q'_t)) \text{ for } t > 0 \\ &= WTP(q'_t, z_t, y + \pi_t * r) \text{ for } t > 0. \end{aligned}$$

Implicitly, the previous WTP measures are for renters who do not own a house.

Now we can consider the marginal welfare measure for this market of renter-owners,

$$\begin{aligned} \frac{\partial WTP_{PV}^{owner}}{\partial q_{t>0}} &= \sum_{t>0} \frac{\partial WTP_t^{owner}}{\partial q_t} (1+r)^{-t} \\ &= \sum_{t>0} \frac{\partial WTP_t^{owner}}{\partial q_t} \Big|_{\partial y=0} * (1+r)^{-t} \\ &\quad + \sum_{t>0} \frac{\partial WTP_t^{owner}}{\partial y_t} * \frac{\partial y_t}{\partial q_t} (1+r)^{-t} \\ &= \sum_{t>0} \frac{\partial WTP_t}{\partial q_t} * (1+r)^{-t} \\ &\quad + \sum_{t>0} \frac{\partial WTP_t}{\partial y_t} * \frac{\partial y_t}{\partial q_t} (1+r)^{-t} \end{aligned}$$

Next we assume $\partial WTP_t / \partial y_t = \lambda$, where λ is constant over time, allowing us to write,

$$\begin{aligned} \frac{\partial WTP_{PV}^{owner}}{\partial q_{t>0}} &= \sum_{t>0} \frac{\partial WTP_t}{\partial q_t} \Big|_{\partial y=0} * (1+r)^{-t} \\ &\quad + \sum_{t>0} \frac{\partial WTP_t}{\partial y_t} * \frac{\partial y_t}{\partial q_t} (1+r)^{-t} \\ &= \sum_{t>0} \frac{\partial WTP_t}{\partial q_t} \Big|_{\partial y=0} * (1+r)^{-t} \end{aligned}$$

$$\begin{aligned}
& + \sum_{t>0} \frac{\partial WTP_t}{\partial y_t} * \frac{r}{1+r} * \frac{\partial P_t}{\partial q_t} (1+r)^{-t} \\
& = \frac{\partial WTP_{PV}}{\partial q_{t>0}} + \frac{\lambda}{1+r} * \frac{\partial P_1}{\partial q_{t>0}}
\end{aligned} \tag{9}$$

Where we have used $\frac{\partial y_t}{\partial q_t} = \frac{\partial \pi_t}{\partial q_t}$ to connect the equations of the firm and household for the renter-owner. Next, the first term in the right hand side of 9 describes the renter's experience in the rental marketplace (whether or not they are an owner), so we can solve equation 8 for marginal WTP and substitute it into the first term of 9,

$$\frac{\partial WTP_{PV}^{owner}}{\partial q_{t>0}} = \frac{\partial C_{PV}}{\partial q_{t>0}} + \frac{1+\lambda}{1+r} * \frac{\partial P_1}{\partial q_{t>0}}$$

which can be rearranged to highlight the relationship between marginal willingness to pay and marginal sale price for permanent changes in an amenity,

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

When the renter-owner is choosing the optimal levels of z_t and q_t by varying the house they rent each time period (i.e., sorting), there is no change in profits, so the tangency condition in equation 2 implied by a utility maximizing renter is not affected by ownership because the owner will be paid the same regardless of who lives in the house. However, if an increase in q comes as a shock to future renters' WTP and consequent re-sorting, then this does affect the owner's profits. Thus the marginal price under-estimates the benefit of the amenity change to renter-owners. Importantly, because a renter-owner's decision about where to rent does not influence rent or the profits from homeownership, the wealth impacts on price that result from this are smaller than otherwise. Given our assumption of an MPC equal to one, pecuniary externalities do not transmit wealth effects into higher rents. To the extent that the MPC is below one and households do accumulate wealth, we expect wealth effects to drive up rent and house prices in a pattern analogous to multiplier effects in short-run macroeconomic analysis (Samuelson (1939)), particularly in locations where renter-owners tend to live.

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, T_t at the end of each time period on P_{t+1} , where $T_t = g * P_{t+1} * \frac{1}{1+r}$. We can incorporate this into the firm's profit equation from 1,

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

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,

$$R_t^T = C_t^T - \left(\frac{P_{t+1}^T(1-g)}{1+r} - P_t^T \right) \text{ for } t > 0$$

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 is a consequence 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,

$$\Delta^T R_t = \Delta^T C_t + P_t^T \frac{g+r}{1+r} - P_t \frac{r}{1+r},$$

$$0 = 0 + P_t^T \frac{g+r}{1+r} - P_t \frac{r}{1+r},$$

$$P_t^T = P_t \frac{r}{g+r}.$$

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 payment 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 annual tax payment and the second term is the rental payment reduction due to a lower house price. The two terms exactly offset each other.

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 the benefits of the amenity change from renter to owner.

Consider an increase in amenities that causes a change in welfare, as described in 7. 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 7,

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

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,

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

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

$$g = \frac{\% \Delta P_1 * r}{1 + r - \% \Delta P_1} \quad (10)$$

Because hedonic models are often estimated with a log-transformed dependent variable, estimating 10 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,

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

Where the first term is the change in profits from the tax and the last term is the government's tax revenue.

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 change in $\% \Delta P_1$.

Additionally, quantification of the additional marginal benefits experienced by renter-owners due to the income effects requires relatively little data if an existing hedonic price study estimates a coefficient for the income of the occupant that can be used as an estimate of λ .

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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. At the same time, we expect that the enhanced clarity that comes from separating the renter from the owner will ultimately determine the appropriate technique for quantifying Hicksian and Marshallian measures of welfare change.

We emphasize that the capitalized values related to housing, e.g., the price of the house, are the result of expected interactions between households and firms with probabilities of buying/selling and renting/moving that are generally strictly between zero and one. 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. In the context of horizontal sorting equilibrium models for occupants of housing, 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 to better understand the impacts of frequent moving on renters (Bishop and Murphy (2019))

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.

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. 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.

An important limitation of this work is the absence of investment in the model, which we expect would be sensitive to 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 increasing profitability if competition .

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.

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