CHAPTER 2. WELFARE MEASUREMENT IN HEDONIC MARKETS

a. Introduction

Our interest in hedonic markets stems from the fact that environmental quality can be counted amongst the attributes of a property. Whilst the various attributes which make up environmental quality (e.g. peace and quiet, clean air, access to recreational areas etc.) are frequently not directly traded in markets, hedonic property markets provide an indirect means by which households can express preferences for such goods.

For example, though a household may wish to increase the quality of the air they breathe, there is no independent market in which they could express this preference. Households couldn't, for instance, call up a firm and purchase a month's supply of clean air. On the other hand, the property market provides one channel through which households can express preferences for environmental quality. If a household wishes to improve the quality of the air they breathe they can do so by purchasing a property located in a less polluted area.

Like the other attributes of a property, differences in environmental quality will be reflected in differences in the price paid for a property. Indeed, with information on the implicit price of environmental quality and the residential locations chosen by different households, analysts have access to information from which they can deduce household preferences for environmental goods.

The search for these underlying preferences is the key goal of empirical analysis of hedonic market data. Specifically, establishing the structure of preferences makes it possible to estimate the impact on economic welfare of a change in environmental quality. We shall return to the issue of estimating household preferences from empirical data in the final chapter.

In this chapter we show how the theory of hedonic markets outlined in Chapter 1 allows us to describe the welfare effects of changes in environmental quality.

b. The Hedonic Market and Changes in Environmental Quality

Before we embark on an analysis of welfare measures it is worth developing some intuitive understanding of the impact a change in environmental quality might have in the property market. Let us consider the impacts of an environmental improvement such as a reduction in noise pollution, a fall in levels of crime or an increase in air quality. Of course this change may be a relatively minor or alternatively may represent a significant environmental improvement. Also, the improvement may take place uniformly across the urban area or be restricted to specific neighbourhoods.

Marginal, localised changes may have little impact on the property market as a whole. Of course landlords will be able to increase the rent they charge on properties in the improved area since those properties now enjoy a higher level of environmental quality. As a result, the household's living in those properties will no longer be at their optimal location. Indeed, they could well elect to move to a new house possessing the original bundle of characteristics enjoyed at their previous property. In the real world, however, there are considerable transaction costs associated with moving house. For relatively small changes in rent, therefore, households may elect to remain where they are. Nevertheless, in the long run, perhaps prompted by other changes in the property market, we would expect households to move to a property with an optimal bundle of characteristics.

If the environmental change is neither marginal nor localised then the pattern of changes in the property market may be far more complex. In the simple case discussed previously, the environmental change is not substantial enough to significantly effect the market clearing implicit prices; the hedonic price function for properties in that market is unaffected by the change.

Of course, if the environmental improvement is sufficiently large (in degree and/or geographical area) then this is unlikely to be true. As in markets for any good, changing the conditions of supply and demand will change the market-clearing prices. Naturally for goods traded in large, possibly world markets localised changes in the conditions of supply and demand are unlikely to effect prices. In property markets, on the other hand, the reverse is true. Property markets are inherently constrained to specific geographical regions. As such even relatively small changes in the conditions of supply in one part of that region may well effect the market clearing implicit prices across the whole market. Indeed, we might expect property markets to be particularly responsive to even relatively minor changes.

Bartik (1988) provides a detailed description of how an environmental improvement might impact on property rents, location choices and housing supply. He envisages an environmental improvement in one part of a hypothetical property market. Obviously, the improvement increases the environmental quality of properties in the affected area. Now, if the hedonic price function were unaffected then, as described before, landlords would be able to increase the rents they charge for their properties. However, imagine now that the improvement were sufficiently large to precipitate a shift in the hedonic price function. That is, the added supply of environmental quality in the market would, in general, necessitate a reduction in price per unit (implicit price) of environmental quality across the entire market in order to ensure the market cleared. For any one property, therefore, the change in rent will be determined by the opposing forces of a location-specific environmental improvement that would tend to push rents up and a market-wide increase in supply of environmental quality that would tend to push rents down. Thus even though some properties may not be directly effected by the environmental improvement, market adjustments may well result in changes in their rental value.

Of course the overall impact on the hedonic price function will not be limited to adjustments in the price of environmental quality. It seems likely that a number of concomitant effects will cause shifts in the supply and demand for housing characteristics. For a start, demand for property characteristics that are substitutes for the environmental attribute will decline. For instance, demand for double-glazed properties will decline in an area in which noise pollution has been reduced. Similarly, demand for complementary attributes will increase. For example, a reduction in air pollution might increase demand for houses with gardens. The implicit prices for these substitutes and complements will themselves have to adjust in order to ensure that the demand for these attributes is balanced by the supply.

Further, in response to the shifts in the hedonic price function, households will no longer be at their optimal residential location and will choose to move to a new property. Indeed, we would expect that landlords at certain locations would find that the characteristics of the households wanting to rent their property would change. For example, reductions in the implicit price of environmental quality will encourage lower income households to demand properties in areas that they previously could not afford. Such that at any given level of environmental quality, there will be an increase in demand from lower income households. Bartik (1988) hypothesises, that lower income households will have lower demands for other housing characteristics and landlords will change their levels of investment in properties to maximise their profits. For areas that experience large increases in environmental quality the reverse may be true. High income households will be attracted to the area and their higher demands for other property characteristics will encourage landlords to invest in property improvements that will increase their rental value.

It is evident that the overall change in the hedonic price function and the resulting change in rents and locational choice are extremely complex. For any one property, the eventual rental value will not be determined solely by the change in environmental quality experienced at that location. Instead it will be determined by the complex interaction of supply and demand across the entire market[1]. For our purposes it is sufficient to note that a change in environmental quality will lead to a shift in the hedonic price function.

c. Measuring Changes in Economic Welfare in Hedonic Markets

Our goal in analysing data from hedonic markets is to establish how changes in environmental quality impact upon economic welfare. Of course, before we embark on showing how this might be achieved, it is essential that we establish exactly what is meant by the term ‘a change in economic welfare’.

Essentially what we are seeking to measure is how greatly changes in environmental quality change the well-being of economic agents in society. In terms of the property market we have defined these economic agents as *households* and *landlords*. Further, we have defined household well-being as the *utility* they derive from their choice of residential location and expenditure on other goods, whilst landlord well-being is defined as the *profits* they realise from rental of their property.

For landlords then, the effect on economic welfare resulting from a change in environmental quality can be measured as the change in their profits (Δp) from renting out a property.

For households, the measure of change in economic welfare is not so obvious. Ideally, we would want to measure the change in utility (ΔU) that the household experienced as a

[1] It is of little surprise that economists have had difficulty developing analytical models that adequately reflect the complexity of these adjustments to the hedonic price function.

result of the change in environmental quality. Of course, describing changes in welfare as changes in utility is merely a theoretical construct. It is not possible to independently measure a household's level of utility before and after a change in environmental quality, nor is it possible to ask a household to report their change in welfare in units of utility.

Instead, economists have posited an alternative measure, a household's own monetary valuation of the change in welfare they experience. A monetary measure of welfare change has a number of advantages chief amongst which is that it can be summed across households to form an aggregate measure that can be used in cost/benefit analysis.

In the following discussion we focus on one such monetary measure known as a *compensating measure* of welfare change. Compensating measures take the current level of household utility as a baseline.

- For an environmental improvement, the compensating measure would be the maximum quantity of money that the household would willingly give up in order to ensure that they enjoyed the environmental improvement. This is often referred to as the household's maximum willingness to pay (WTP) to achieve an improvement.
- For a fall in environmental quality, the compensating measure would be the minimum amount of money that the household would accept in order to endure the deterioration in environmental quality. This is often referred to as the household's minimum willingness to accept (WTA) compensation for a deterioration

With these measures in mind, let us consider a property market and examine the welfare impacts of a change in environmental quality. As shall become apparent in the following two sections, this is not as straightforward as might be hoped. It turns out that there are a number of ways in which the change in economic welfare might be evaluated; each evaluation differing according to the assumptions that are made concerning the response of households and landlords to the change in environmental quality. As might be expected, the fewer assumptions we make, the more comprehensive the measure of the welfare change. At the same time, however, the fewer assumptions made the greater the informational requirements involved in calculating the welfare measure.

d. Changes in Economic Welfare for Households

Let us assume that the property market we are considering is in equilibrium. In this market both landlords and households are assumed to have made optimal decisions; landlords can't improve profits by altering the characteristics of their property and households can't increase their utility by choosing to rent a different property.

In this market we shall denote the original equilibrium hedonic price function by $P^b(\mathbf{z})$, where the superscript *b* indicates that this is *before* any changes in conditions in the hedonic market. Following a change in environmental quality, the market settles at a new hedonic price function that we shall denote $P^a(\mathbf{z})$. Once again the superscript *a* indicates that this is *after* the change in conditions in the hedonic market.

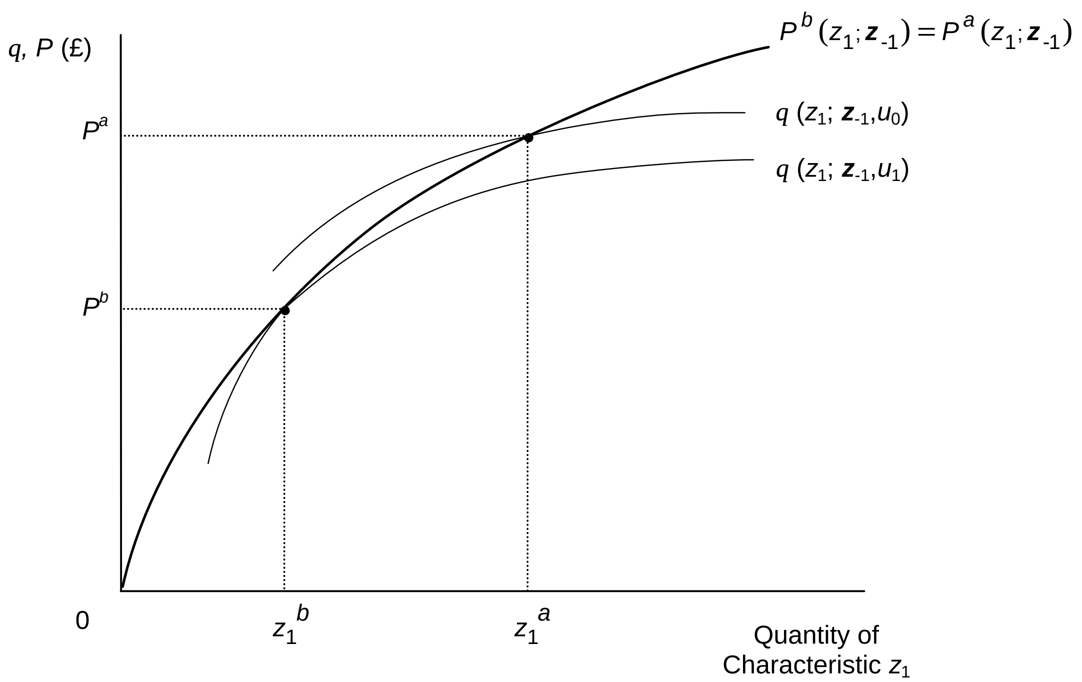
i. Household welfare changes from a localised environmental improvement

To begin with let us consider the welfare impact of a localised environmental improvement. As discussed in the previous section such a change should not impact on the property market as a whole and the hedonic price function will not need to adjust in order to clear the market. Thus, in this case, $P^a(\mathbf{z}) = P^b(\mathbf{z})$.

Let us focus on just one property located in the area experiencing the environmental improvement. If we designate attribute z_1 to be the level of environmental quality, then the initial level of environmental quality at this property can be represented by $z_1{}^b$. As illustrated in Figure 10, at this level of environmental quality the property commands a rental price of P^b.

The household choosing to reside in this property will have a bid curve tangential to the hedonic price function at this level of environmental quality. In Figure 10, this utility maximising choice places the household on their lowest bid curve compatible with the hedonic price function and results in a level of utility u_1.

Figure 10: Change in household welfare from a localised change in environmental quality and costless moving



Now, the exogenous improvement increases the environmental quality of the property from z_1^b to z_1^a (where once again *b* superscript stands for *before* and *a* superscript stands for *after*). Of course, improving the attributes of the property enables the landlord to charge a higher rental price. Indeed, the rent on the property following the environmental improvement would increase from P^b to P^a. Clearly, this represents a benefit to the landlord but we shall postpone a discussion of this welfare gain until the next section.

What then are the welfare impacts on the household residing at this location? Clearly, the household enjoys an improvement in environmental quality, however this is accompanied by an increase in rental price. As illustrated in Figure 10, the household will find itself at a less than optimal residential location. Indeed, continuing to live at the property would mean their level of utility would fall from u_1 to u_0.

Since the hedonic price function has not changed, we know that the household's optimal choice of property would be one boasting the original level of environmental quality at that property. Indeed, if we assume that moving house is costless then the household would be best off simply moving to a property with identical characteristics to their present property, except with the level of environmental quality enjoyed previous to the improvement. Moving to such a property would return them to their original level of utility, u_1. Overall then, under the assumption of costless moving, the environmental improvement will have no impact on the welfare of households.

In the real world, however, there are considerable transaction costs associated with moving house. Incorporating such transaction costs complicates the analysis. For a start, we should note that households only envisage living in any one property for a limited period of time. At the end of such a period, the household foresees that changes in their characteristics (e.g. marriage, the birth of children, retirement etc.) will have changed the nature of their preferences for properties. We can assume, therefore, that the household foresees a series of property relocations each incurring a transaction cost. Consequently, we can express the sum of these payments as an equivalent per period cost, *TC*, such that the per period price of living in a particular residential location is in fact the market rental price plus this added cost (i.e. $P(\mathbf{z}) + TC$). In effect, foreseeable changes in preferences allow the household to write-off moving costs over the duration of their expected tenureship of a series of properties.

Moving house in response to an exogenous change would mean incurring unexpected transaction costs at an earlier date causing the value of *TC* to increase. Let us call this added per period transaction cost *tc*. Rather than follow through the complex arguments that including transaction costs entails, let us simply note that two possibilities present themselves;

- If the benefits of moving outweigh the moving costs then the household will relocate to a new property with the attributes of their original choice.[2] In welfare terms, the household ends up enjoying the same level of utility as prior to the environmental improvement but are worse off by an amount equal to the costs of moving. Thus the quantity *tc*, measures the per period welfare loss of the environmental improvement.

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[2] More correctly, moving house in response to an exogenous change causes the value of *TC* to increase by an amount labelled *tc*. It would appear to a household considering a change of location as if the per period price of property rental had shifted upwards. Since the per period price of property rental is different from that faced in making their original decision, it is unlikely that the household's optimal response will be to relocate to a property with identical attributes to those enjoyed at their previous optimal choice. We do not follow these considerations further here. The interested reader is referred to Freeman (1993, p398-400).

- If, on the other hand, the benefits of moving do not exceed the transaction costs then the household will decide to remain in their original, though now sub-optimal, residential location.[3] Clearly, the loss in welfare associated with remaining in this improved property paying a higher rent is not as great as the transaction costs. Consequently, *tc* must represent an upper bound on the welfare loss to the household.

To summarise, the environmental improvement will result in households in the improved region being at less than optimal residential locations. If we ignore transaction costs then households will relocate to properties with identical attributes as those enjoyed at their original residential locations. The environmental improvement will have no impact on their welfare. If we include transaction costs then we can assume that the environmental improvement may cause households to move property earlier than they would otherwise have anticipated. Such premature relocation would increase the equivalent per period costs of moving house by a quantity *tc*. This quantity must represent an upper bound on the household's welfare loss resulting from the environmental improvement since they could always pay this amount so as to relocate to a property offering the level of welfare enjoyed prior to the change.

If the total number of properties in the market is labelled *H* then the small subset of properties affected by the environmental improvement can be labelled H_1. Further, if we index all the households in the market by $h = 1$ to H, then the welfare change experienced by households from a localised environmental improvement can be expressed;

$$\sum_{h \in H_1} -tc_h \leq W_H \leq 0 \qquad (19)$$

Where W_H is the total welfare change experienced by households in the market and the expression $h \in H_1$ tells us to include only households living in the H_1 properties affected by the environmental improvement.

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[3] Of course remaining at a sub-optimal residential location is only a short-term solution. Indeed, at some point in the future we would expect the household to move to an optimal residential location. Two possible stimuli may precipitate such a move;

- First, it can be assumed that a household foresees that changes in their characteristics (e.g. marriage, the birth of children, retirement etc.) will change the nature of their preferences for properties. At some point in the future, therefore, the household would expect to move and will have anticipated the transaction costs of such relocation. As such, at some point in the future transaction costs will no longer represent a barrier to relocation.
- Second, unforeseeable changes such as further exogenous changes in the attributes of the property or unexpected changes in the household characteristics (e.g. becoming unemployed) may tip the balance in favour of relocation. In other words, cumulative unforeseen changes may mean that the benefits of relocation outweigh the costs of moving.

In either case, the household will have incurred a welfare loss from the change in environmental quality that must be less than the full transaction costs of moving. Hence we can always take the value *tc* as the upper bound of this welfare loss.

ii. Household welfare changes from a non-localised environmental improvement

Imagine now, that we are dealing with an environmental improvement that has more than a purely localised impact. If the change we are considering represents a major improvement and/or is widely spread across the urban area then the consequences for the property market may extend beyond a simple increase in the price of affected properties.

One possibility is to assume away these wider implications and use Equation (19) to measure the welfare change of households. In economics such a measure would be described as a partial equilibrium solution since it does not allow for the complex pattern of changes in the hedonic price function and choices of residential location that would allow the market to come back into a state of general equilibrium.

In this section we discuss welfare measures that account for these general equilibrium effects. Perhaps surprisingly, therefore, we begin this section by introducing another partial equilibrium measure of household welfare. This simple measure will prove to be of major importance since it can be shown to represent a lower bound to the entire general equilibrium welfare impact experienced by both households and landlords. But we shall return to demonstrate this anon.

Figure 11 presents the situation facing a household living in the area witnessing an environmental improvement. At the original level of environmental quality the household faces the old hedonic price schedule, $P^b(\mathbf{z})$, and maximises its utility by choosing a property with a level of environmental qualtiy indicated by z_1^{bo}. Here we have expanded the notation such that the superscript *bo* indicates that this is the quantity chosen *before* the change in environmental quality in the households *old* choice of property. At this point, the household reaches its lowest bid curve that is still compatible with the prices it faces in the market, $q(\mathbf{z};u_1)$.[4] The household's WTP or bid, indicated by q^{bo}, is equal to the market price, P^{bo}, and the household enjoys a level of utility labelled u_1.

An exogenous change increases the environmental quality enjoyed at this location to z_1^{ao}, where the superscript *ao* indicates that this is the environmental quality *after* the change in the household's *old* choice of property.

Since we are now considering a non-localised change we would imagine that the hedonic price function would shift in response to this environmental improvement. However, for the moment, we shall ignore this general equilibrium response. Further we shall consider the situation in which landlords continue to charge the rental price associated with old level of provision of z_1. In this case, the household has effectively been given the benefits that come from living in a location with an improved environment. Indeed, at this location paying the original level of rent for that property they would find themselves on the bid curve $q(\mathbf{z};u_2)$ realising a higher level of utility labelled u_2.

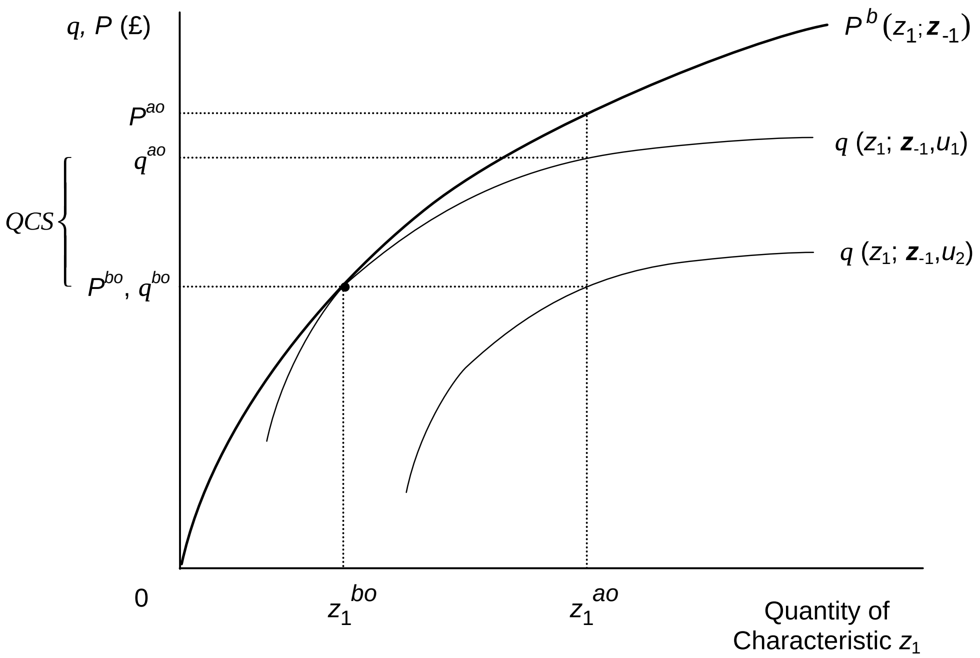
One possible compensating monetary measure of the welfare that the household gains from this improvement is the amount of money that if taken away from the household whilst living in the property in the improved location would make them as well off as

[4] Income and socioeconomic characteristics have been suppressed to simplify notation.

they had been previous to the change. In other words, the household's WTP to achieve the improvement in environmental quality.

This measure can be shown simply in Figure 11. The bid curve on the diagram traces out all combinations of WTP and levels of environmental quality that result in the household enjoying a level of utility labelled u_1. Of course this is also the level of utility that the household realised prior to the environmental change by locating at their optimal residential location. To achieve this level of utility the household was willing to pay q^{bo}. Following the environmental improvement the household would be willing to pay q^{ao} to achieve the same level of utility. A measure of the household's WTP for the change in environmental quality is the difference between these two amounts.

Figure 11: The Quantity Compensating Surplus measure of the welfare change resulting from an improvement in environmental quality



This amount has been termed the *quantity compensating variation*, by Palmquist (1988). However, following Freeman's definitions (see Freeman, 1993; p 48-9) this is probably best thought of as a *compensating surplus* measure since it allows for no adjustment in household residential location following the change in environmental quality. Hence here we label this amount as the *quantity compensating surplus* (*QCS*). This amount is shown graphically in Figure 11 and can be stated mathematically as;

$$QCS = ?\left(z_1^{ao},\ \mathbf{z}_{-1}^{bo}; y, \mathbf{s}, u_1\right) - ?\left(z_1^{bo},\ \mathbf{z}_{-1}^{bo}; y,\ \mathbf{s}, u_1\right) \qquad (20)$$

Since, the *QCS* measure assumes there are no adjustments in the hedonic property market the welfare change is assumed to impact only households in the affected area. Indeed, using this measure, the total welfare impact of the environmental improvement is given by;

$$W_H = \sum_{h \in H_1} QCS = \sum_{h \in H_1} ?\left(z_{1h}^{ao},\ \mathbf{z}_{-1h}^{bo}; y, \mathbf{s}, u_{1h}\right) - ?\left(z_{1h}^{bo},\ \mathbf{z}_{-1h}^{bo}; y, \mathbf{s}, u_{1h}\right) \qquad (21)$$

Notice that the informational requirements of the *QCS* measure are relatively undemanding. To evaluate W_H using this measure, a researcher would simply have to know the environmental quality at all affected properties before and after the improvement and be able to evaluate the bid function for each household at these two values of environmental quality.

However, the *QCS* measure of welfare change is relatively restrictive in the assumptions it makes concerning how the market and the economic agents in the market react to a change in environmental quality. All the benefits of the change accrue to households occupying properties in improved locations since landlords are assumed not to change property rents. Of course this is most unrealistic; a landlord is hardly likely to remain charging the same rent (P^{bo}) when the market price for a property with that level of environmental quality is actually (P^{ao}). Further, the *QCS* measure takes no account of the fact that an exogenous change in the level of environmental quality enjoyed at some (or possible all) locations in the urban area will have the effect of changing supply conditions in the market. Indeed, our analysis in the previous section indicates that an increase in environmental quality in the urban area may well precipitate a shift in the hedonic price function.

Figure 12 shows just such a shift. The environmental improvement has lead to an adjustment in the hedonic market that has reduced the price of property at any given level of environmental quality. As described earlier, the hedonic function *after* this adjustment is labelled $P^a(\mathbf{z})$.

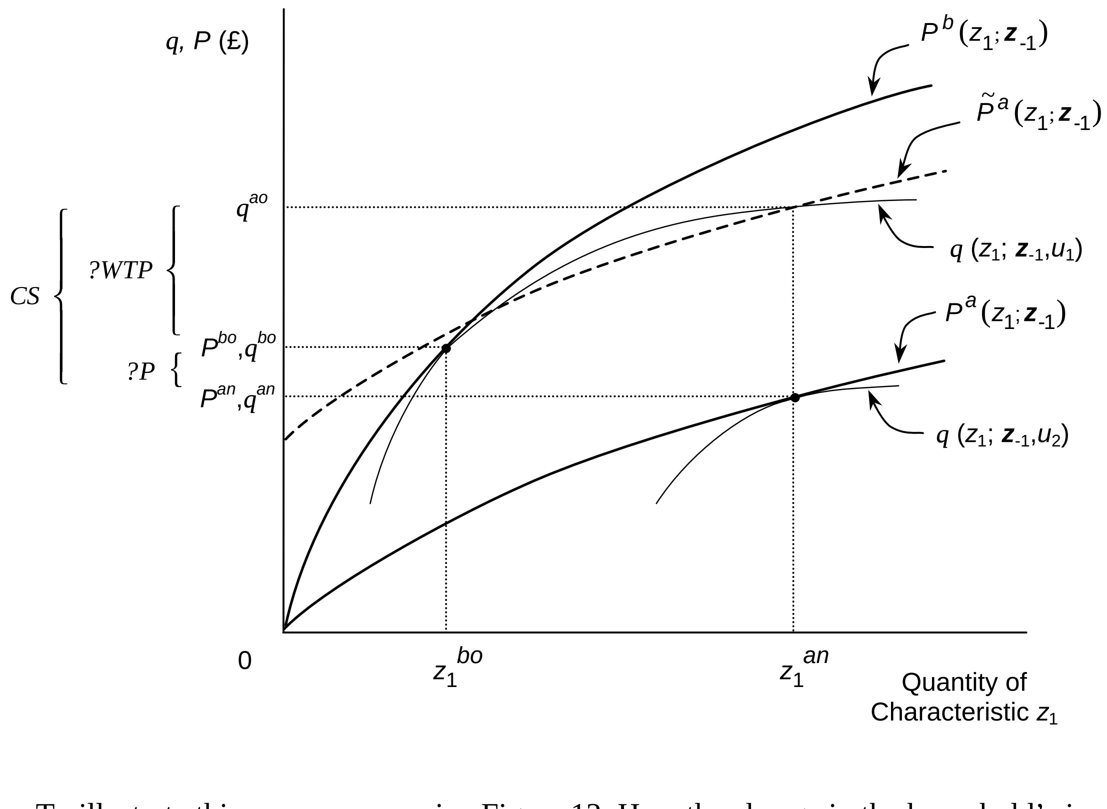
It is important to note that since the hedonic function has changed the environmental improvement has an impact on all households in the property market. Indeed, as a consequence we would expect each household in the property market to adjust to the new hedonic price function by choosing a new residential location. As before we assume they move to the property amongst those that they can afford which provides them with the highest level of utility.

In the figure this is illustrated for one household as the tangent of a bid curve and the new hedonic price function. This particular household will move to a new property with a level of environmental quality given by z_1^{an}. Where the superscript *an* indicates that this is the level of environmental quality enjoyed *after* the change at their *new* choice of residential location. By moving property, the household moves on to a lower bid curve and manages to achieve a higher level of utility, u_2.

Since, households are allowed to respond optimally to the changes in the hedonic market by moving residential location, our previous measure of welfare change, the *QCS*, is no longer an adequate measure of the benefits of an environmental improvement. Figure 12 can be used to illustrate a second compensating measure of welfare change that accounts for household relocation.

As the household has been made better off we assume that they would be willing to pay out some money to ensure that they continued to enjoy their new level of well-being, u_2, rather than returning to that enjoyed prior to the environmental improvement in their original location, u_1. Let us constrain the household to remain at their new choice of property. Thus the compensating monetary measure we seek is the amount of money that once taken away from the household in their new residential location would return them to their original level of well-being.

Figure 12: The Compensating Surplus measure of the welfare change resulting from an improvement in environmental quality



To illustrate this measure, examine Figure 12. Here the change in the household's income that would result from paying out a compensating monetary measure, is shown as a vertical shift in the hedonic price function. In effect, paying out money is equivalent to making all properties more expensive[5]. The maximum amount the household would be

[5] Readers familiar with the illustration of welfare measures in diagrams with indifference curves and income constraints will recognise this procedure. Indeed, this parallel is made explicit by remembering that

willing to pay to ensure the change in environmental quality whilst constrained to remain at their new residential location, will be the amount that shifts the hedonic price function to the point where it intersects the original bid curve.

As illustrated in Figure 12, the vertical distance between the hedonic function $P^a(\mathbf{z})$ and the hedonic function as it would appear to the household once it had paid out its maximum WTP, $\tilde{P}^a(\mathbf{z})$, gives a second measure of welfare change. This distance is the *compensating surplus* (*CS*) measure of the household's welfare change described by Bartik (1988).

It can be shown that this *CS* measure can be decomposed, in an intuitively appealing manner, into two separate values. The first value is the household's WTP for the change in housing attributes. That is, the difference between the household's WTP to achieve a level of well-being u_0, at the old and new residential locations (*DWTP*)[6]. The second value is simply the difference in rental payments at the old and new residential locations (*DP*). In mathematical terms, therefore, *CS* can be written as;

$$CS = \Delta WTP - \Delta P = \begin{pmatrix} q\left(z_1^{an}, \mathbf{z}_{-1}^{an}; u_1\right) - q\left(z_1^{bo}, \mathbf{z}_{-1}^{bo}; u_1\right) \\ -\left[P^a\left(z_1^{an}, \mathbf{z}_{-1}^{an}\right) - P^b\left(z_1^{bo}, \mathbf{z}_{-1}^{bo}\right)\right] \end{pmatrix} \tag{22}$$

Since all households are assumed to relocate in response to the shift in the hedonic price function the total welfare benefits of the environmental improvement will include a measure for each of the *H* households in the urban area;

$$W_H = \sum_{h=1}^{H} CS_H = \sum_{h=1}^{H} \begin{pmatrix} q\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}; u_{1h}\right) - q\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right) \\ -\left[P^a\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}\right) - P^b\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}\right)\right] \end{pmatrix} \tag{23}$$

Notice that in comparison with the *QCS* measure, evaluating the *CS* measure of welfare change imposes far greater informational requirements on the researcher. Not only must the researcher be able to evaluate the bid function, but also predict how the hedonic price function will adjust in response to the environmental improvement. Further, the researcher must anticipate the characteristics of the property that each household will choose to rent in response to the new hedonic price function. If the welfare evaluation is

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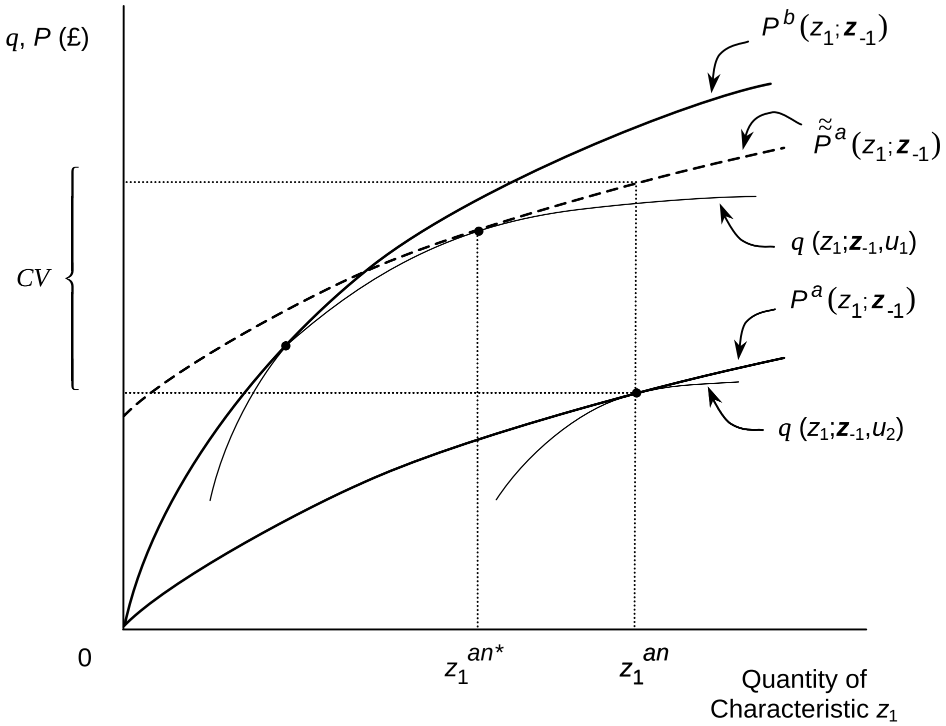
the bid curve and hedonic price function are simply inversions of corresponding indifference curves and income constraints (see Chapter 1).

[6] This is similar to <u>though not the same</u> as the *QCS* measure described above, but here the household is no longer constrained to the level of environmental quality at their original location. Rather the household selects a new level of environmental quality by selecting a new property which maximises their well-being in response to the new hedonic price function.

to be carried out prior to the environmental improvement, as would be the case in a cost-benefit analysis, these requirements are so onerous as to make the measure practically impossible to evaluate in the real world.

For the sake of completeness we present one further measure of household welfare change. It transpires that even Bartik's *CS* measure of household welfare change is not the most comprehensive measure. In paying out the amount *CS* the household is experiencing a change in income. As their income changes, their optimal choice of residential location will also change. However, in measuring *CS* we have constrained the household to remain in the same residential location. If we relax this constraint then the household can respond optimally by changing their location in response to a change in income. Indeed, allowing the household to respond optimally means that they would be able to pay out a greater amount to achieve the improvement in environmental quality[7].

Figure 13: The Compensating Variation measure of the welfare change resulting from an improvement in environmental quality



In Figure 13 we have again illustrated the change in income that would result from paying out a compensating measure as a vertical shift in the hedonic price function.. The

[7] As Palmquist (1986) points out, whenever, we release a constraint on household behaviour we increase their ability to react optimally, thus increasing the quantity of money they would be willing to pay to secure an improvement in environmental quality.

maximum amount the household would be willing to pay to ensure the change in environmental quality will be the amount that shifts the hedonic price function to the point where it is just tangent with the original bid curve. The point of this tangency would determine the characteristics of the property that the household would decide to rent if it were forced to pay out its maximum willingness to pay to achieve the improvements in environmental standards. We denote the characteristics of this property z^{an*}.

As illustrated in Figure 13, the vertical distance between the hedonic function $P^{a}(\mathbf{z})$ and the hedonic function as it would appear to the household once it had paid out its maximum WTP, $\tilde{\tilde{P}}^{a}(\mathbf{z})$, gives a third measure of welfare change that we shall identify as the *compensating variation* (*CV*). This is the measure presented in Palmquist (1986).

CV is the most comprehensive measure of welfare change since it allows the household to react optimally in adjusting to changes in the prices it faces in the market and in adjusting to changes in its own income. The *CV* measure of a welfare change resulting from an improvement in environmental quality will always be greater than the *CS*. However, the informational requirements of the *CV* measure are even greater than those of the *CS* measure. As a consequence we do not consider this measure further.

The various measures of household welfare discussed in this section are summarised in Table 1.

Table 1: Measures of household welfare change

Welfare Measure	Description	Computation of Total Welfare Change for Households	Informational Requirements
Localised:			
No Moving Costs	• No shift in hedonic • Households incur no transaction costs in moving property	$W_H = 0$	• None
Moving Costs	• No shift in hedonic • Households incur transaction costs in moving property	$\sum_{h \in H_1} -tc_h \leq W_H \leq 0$	• Only affected households • Increase in equivalent per period transaction costs
Non-Localised:			
Quantity Compensating Surplus	• Hedonic shifts • Landlords do not change rental on properties • Households remain in their original properties	$W_H = \sum_{h \in H_1} ?\left(z_{1h}^{ao}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right) - ?\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right)$	• Only affected households • Environmental quality at each affected property before and after improvement • Household bid function
Compensating Surplus	• Hedonic shifts • Landlords change property rents in accordance with the new hedonic • Households relocate to optimal residential locations	$W_H = \sum_{h=1}^{H} \left(\begin{matrix} q\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}; u_{1h}\right) - q\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right) \\ -\left[P^a\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}\right) - P^b\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}\right)\right] \end{matrix} \right)$	• All households • Hedonic before and after change • Environmental quality at each affected property before and after improvement • Households choice of residential location in response to new hedonic • Household bid function

e. Changes in Economic Welfare for Landlords

So far we have considered only the demand side of the market. A comprehensive measure of the welfare change resulting from an exogenous environmental improvement should also take account of changes in the profits realised by landlords.

As Bartik (1988) points out, there are four reasons why we would expect a landlord's profits to change after a change in environmental quality;

- If environmental quality at the property's location changes, the property's rental value will change even if the overall hedonic price schedule does not shift
- Environmental quality changes may affect a landlord's costs (e.g. an increase in air pollution may necessitate more frequent cleaning of the property).
- Any shift in the hedonic function resulting from the environmental improvement affects rents received by all landlords, even those whose property did not directly experience a change in environmental quality
- Landlords may respond to all these changes by altering the levels of attributes associated with their property. In so doing they will alter the rental price of the property and also the cost of supplying this property to the market.

As with the discussion for households, we shall work from less comprehensive measures of landlords' welfare change through to a fully comprehensive measure.

i. Landlord welfare changes from a localised environmental improvement

To begin with let us consider the welfare impact of a localised environmental improvement. As before, such a change is insufficient to provoke a change in the hedonic price function. This then represents our first assumption.

- **Assumption 1**: The *environmental improvement is localised* and hence does not change the market clearing hedonic price function.

Further, let us assume that the level of this environmental attribute at any property is entirely determined by exogenous factors.

- **Assumption 2**: The *landlord cannot independently influence the property's environmental quality*. It is entirely determined by exogenous factors.

Assumption 2 results in the corner solution discussed in relation to the right hand panel of Figure 8. A similar diagram is reproduced here as Figure 14 where z_1 represents levels of environmental quality. Since the landlord is unable to alter the level of environmental quality through his own actions, the offer curves in Figure 14 reduce to points above the exogenously determined level.

Let us focus on the property of one landlord in the area experiencing the environmental improvement. Initially, the landlord's property enjoys a level of environmental quality z_1^b, where, once again the *b* superscript indicates that this is *before* the environmental improvement. Since this is supplied without cost to the landlord, the quantity $\bar{z}_1^b = z_1^b$ is the baseline level of environmental quality. This quantity enters the cost and thence offer functions as an element in the vector $\bar{\boldsymbol{z}}$.

Given the hedonic price function $P^b(\boldsymbol{z})$, the best the landlord can do is move to the point labelled *X*, coinciding with the offer curve $f\left(\boldsymbol{z};\bar{z}_1^b,\bar{\boldsymbol{z}}_{-1},p^b\right)$. Here the landlord supplies his property with z_1^b of the environmental attribute and levels of the other property attributes given by the vector, $\boldsymbol{z}_{-1}^b$. As a result, the landlord can charge a rent of P^b and earns a profit of p^b.

Now, imagine a public programme that increases the level of environmental quality enjoyed at the landlord's property to z_1^a, where the *a* superscript indicates that this is *after* the environmental improvement. Let us make a further assumption;

- **Assumption 3**: The *level of environmental quality does not affect the optimal level of provision of other property characteristics*. Technically, this amounts to assuming that the attribute z_1 does not interact with other arguments in the hedonic price function.

Thus after the environmental improvement, the landlord will maintain the levels of other environmental attributes at $\boldsymbol{z}_{-1}^b$.

The first welfare measure we consider requires one further assumption;

- **Assumption 4**: The *level of environmental quality does not affect the costs of supplying other property attributes.* Technically this amounts to assuming that the attribute z_1 does not interact with other arguments in the cost function.

Given our four assumptions, measuring the benefits to landlords of the environmental improvement is a relatively straightforward task.

To illustrate the welfare change experienced by a landlord owning a property in the improved area, observe Figure 14.

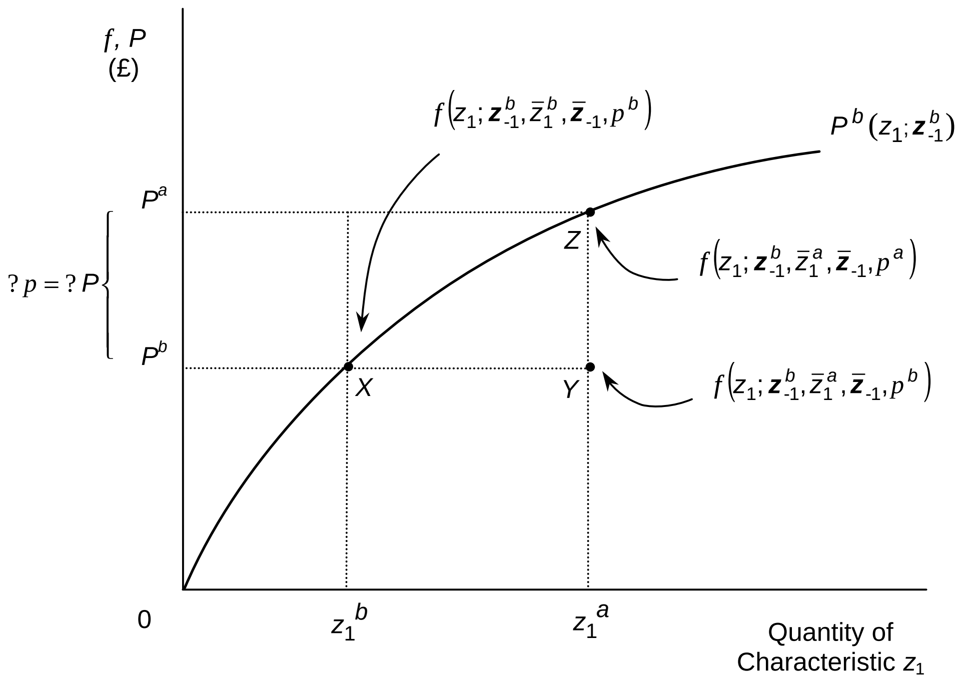
Following the environmental improvement, the landlord could continue to charge a rental price of P^b. This would correspond to the point marked *Y* in Figure 14. There are a number of things to note about this point.

- First, since the improvement is determined by exogenous factors (Assumption 2), the landlord incurs no added cost in supplying the extra environmental quality.
- Second, we have assumed that the environmental improvement would not encourage the landlord to change levels of supply of other attributes (Assumption 3). Thus following the environmental improvement, the landlord continues to supply the other housing attributes at levels given by the vector $\boldsymbol{z}_{-1}^b$.
- Finally, we have assumed that changes in environmental quality do not change the costs of supplying the other property characteristics (Assumption 4). Since these are still supplied at $\boldsymbol{z}_{-1}^b$, the landlords costs in supplying other property attributes will also remain unchanged.

We can conclude that the landlord incurs the same costs after the improvement as before. As a result, the profit associated with point *Y* is identical to that associated with point *X*, namely p^b.

Of course, the property now boasts a higher level of environmental quality. Indeed, the landlord is in a position whereby he can increase profits by increasing the rental price of the property. Indeed, given the hedonic price function, the landlord could increase the rental price up to the point marked *Z*. Notice that this increase in rental price adds directly to the landlord's profits. At *Z*, the landlord charges a rental price of P^a and realises a profit p^a.

Figure 14: Landlord welfare change for a localised change in an exogenously determined environmental attribute when costs do not change



The welfare measure we seek, therefore, is the difference between profits before the improvement, p^b, and profits after the improvement, p^a. We know from the previous chapter that, provided all else stays the same, the vertical distance between two offer curves equates to the difference in profits associated with the two curves (see Figure 6). Accordingly, the vertical distance *YZ* measures the increase in profits enjoyed by the landlord. Conveniently, this vertical distance is also the difference between the hedonic price function evaluated at the original and improved levels of attribute z_1.

Given our four original assumptions, therefore, the change in profits for the landlord can be written;

$$\Delta p = p^a - p^b = P^b\left(z_1^a, \boldsymbol{z}_{-1}^b\right) - P^b\left(z_1^b, \boldsymbol{z}_{-1}^b\right) \tag{24}$$

Of course, we could also derive this result analytically. We know from Equation (15) that the profit realised by the landlord for a property with characteristics **z** will equal the rental price of such a property minus the cost of providing the property. Thus we could just as easily write;

$$\Delta p = p^a - p^b = \begin{pmatrix} P^b\left(z_1^a, \boldsymbol{z}_{-1}^b\right) - c\left(z_1^a, \boldsymbol{z}_{-1}^b; \bar{z}_1^a, \bar{\boldsymbol{z}}_{-1}\right) \\ -\left[P^b\left(z_1^b, \boldsymbol{z}_{-1}^b\right) - c\left(z_1^b, \boldsymbol{z}_{-1}^b; \bar{z}_1^b, \bar{\boldsymbol{z}}_{-1}\right)\right] \end{pmatrix} \tag{25}$$

Now, we have already assumed that attribute z_1 is provided without cost to the landlord (Assumption 2) and that the level of this attribute has no effect on the costs of providing other property attributes (Assumption 4). As a result, we can conclude that $c\left(z_1^a, \boldsymbol{z}_{-1}^b; \bar{z}_1^a, \bar{\boldsymbol{z}}_{-1}\right)$ and $c\left(z_1^b, \boldsymbol{z}_{-1}^b; \bar{z}_1^b, \bar{\boldsymbol{z}}_{-1}\right)$ take on the same value and fall out of Equation (25) leaving the desired result, Equation (24).

This is, of course, very intuitive. If the improvement allows the landlord to increase the rental price from P^b to P^a but leaves all costs unchanged, the increase in profits for the landlord will simply be the increase in rental price charged on the property.

Given our assumptions, the total welfare gain to landlords will be given by summing Equation (24) across all landlords. Of course, one of those assumptions is that there are no adjustments in the hedonic property market (Assumption 1). Consequently the welfare change will only be experienced by landlords owning properties in the affected area. In the previous section, we denoted this set of properties H_1. Thus, indexing landlords in the market by $l = 1$ to L, the welfare change experienced by landlords can be expressed;

$$W_L = \sum_{l \in H_1} P^b\left(z_{1l}^a, \boldsymbol{z}_{-1l}^b\right) - P^b\left(z_{1l}^b, \boldsymbol{z}_{-1l}^b\right) \tag{26}$$

where W_L is the total welfare change experienced by landlords in the market.

One of the advantages of this welfare measure is that it requires relatively little information. To use this measure, a researcher would simply need an estimate of the hedonic price function and details of the level of the environmental attribute at affected properties before and after the improvement.

Of course, the assumptions made in deriving Equation (26) were very restrictive. In what follows, we shall present three more measures of landlord welfare change that successively relax these assumptions.

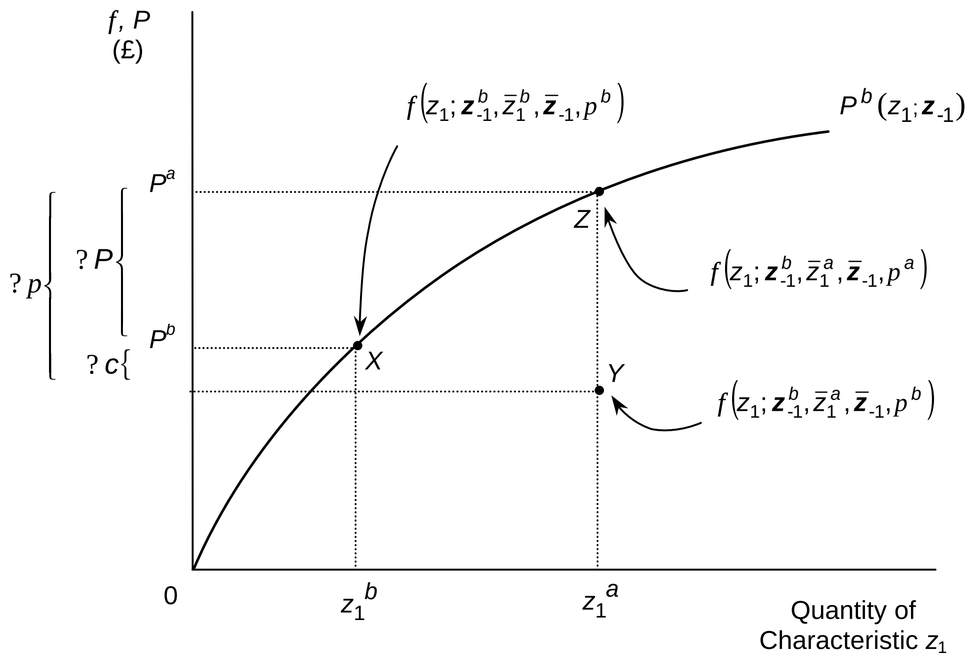
First, consider the situation where the level of the environmental attribute z_1 influences the landlords' costs. In other words, let us relax Assumption 4. Examples of environmental improvements that might result in concomitant cost savings include;

- a reduction in air pollution which reduces the necessity to clean or repaint the property
- a reduction in crime which reduces the need for repairs caused by vandalism

This case is depicted in Figure 15. Again the environmental improvement has only a local impact (Assumption 1), the level of the attribute is entirely determined by exogenous factors (Assumption 2) and the landlord persists in supplying other property attributes at the same level after the improvement (Assumption 3).

Before the improvement, the landlord chooses to locate at point *X*. Here the landlord supplies a property with the exogenously determined level of environmental quality z_1^b and chosen levels of other property attributes given by the vector $\mathbf{z}_{-1}^b$. At this combination of attributes the landlord maximises profits by charging a rent P^b of which p^b is profit.

Figure 15: Landlord welfare change for a localised change in an exogenously determined environmental attribute when costs change



Following an environmental improvement, the level of z_1 is increased to z_1^a at no cost to the landlord. Further according to Assumption 3, the landlord continues to provide other property attributes at the same levels, that is, $\mathbf{z}_{-1}^b$. However, by relaxing Assumption 4, we allow for the possibility that the environmental improvement may reduce the cost of providing the other housing attributes at these levels.

Indeed, following the environmental improvement the landlord could locate at point *Y*. Here, the landlord could charge a lower price yet, as a result of cost savings, achieve the same level of profits as previous to the environmental improvement. The vertical distance between *X* and *Y* measures the cost savings brought about by the environmental improvement.

Of course the landlord will not locate at *Y*. Instead, he will maximise his profits by locating at point *Z*. Here the landlord charges a rent P^a of which p^a is profit.

The environmental improvement increases the landlord's profits from p^b to p^a. Again, this increase can be measured as the vertical distance between the offer curves, *YZ*. Notice that allowing for cost changes expands our measure of the welfare gains for landlords. Not only does the landlord enjoy an increase in rent, ΔP, but also experiences a reduction in costs Δc.

Accordingly, this broader welfare measure can be calculated as;

$$\Delta p = \Delta P + \Delta c = \left(\begin{array}{c} \left[P^b\left(z_1^a, \mathbf{z}_{-1}^b\right) - P^b\left(z_1^b, \mathbf{z}_{-1}^b\right)\right] \\ + \left[c\left(z_1^b, \mathbf{z}_{-1}^b; \bar{z}_1^b, \bar{\mathbf{z}}_{-1}\right) - c\left(z_1^a, \mathbf{z}_{-1}^b; \bar{z}_1^a, \bar{\mathbf{z}}_{-1}\right)\right] \end{array} \right) \tag{27}$$

Since, this measure continues to assume that there are no adjustments in the hedonic property market the welfare change is only experienced by landlords owning properties in the affected area. Using this measure, the total welfare impact of the environmental improvement is given by;

$$W_L = \sum_{l \in H_1} \left(\begin{array}{c} \left[P^b\left(z_{1l}^a, \mathbf{z}_{-1l}^b\right) - P^b\left(z_{1l}^b, \mathbf{z}_{-1l}^b\right)\right] \\ + \left[c\left(z_{1l}^b, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^b, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^a, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^a, \bar{\mathbf{z}}_{-1l}\right)\right] \end{array} \right) \tag{28}$$

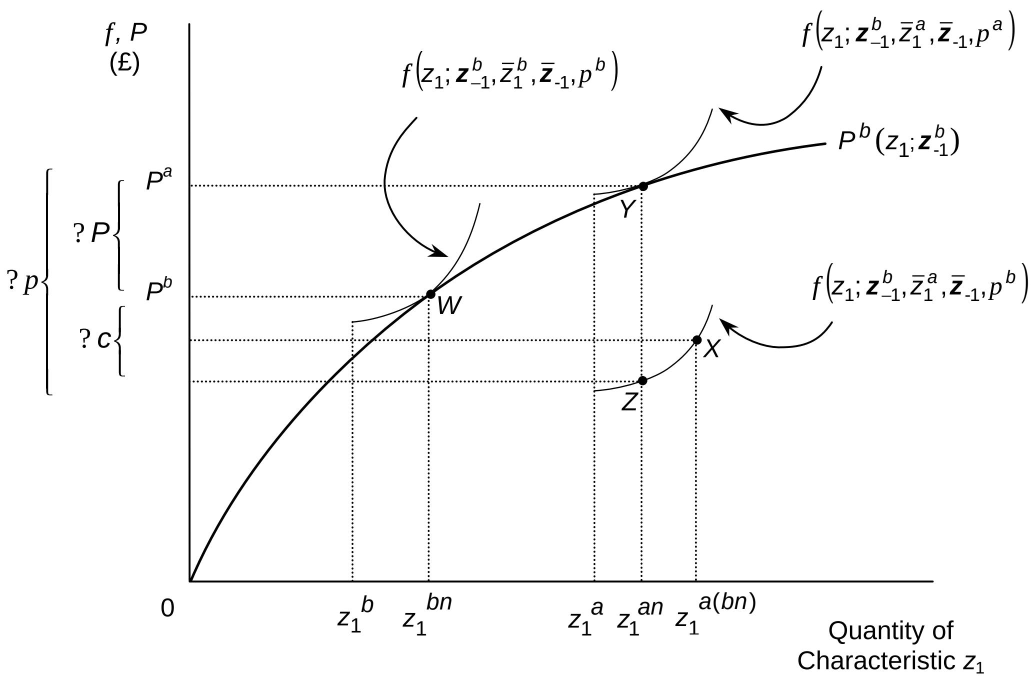
Notice that this measure of welfare change is informationally more exacting since it demands that the researcher has knowledge of the landlords cost function.

The two welfare measures that we have developed so far, have both assumed that landlords are not able to influence the level of environmental quality of their properties. Whilst this may be true in the short-term, we have already cited counter examples. For instance, a landlord can change a property's exposure to noise pollution by installing double-glazing.

Our next task, therefore, is to relax Assumption 2 and consider the situation where the level of environmental quality is not entirely determined by exogenous factors. For now, however, we maintain Assumption 3. That is, following an environmental improvement, we allow landlords to alter the level of environmental quality of their properties but not alter the levels of other property attributes. Compared with the last two scenarios, this is more indicative of a landlord's medium to long term response to changes in property market conditions.

The pattern of responses is fairly complex and is laid out in Figure 16. In the first instance the landlord is faced by the hedonic price function $P^b(\cdot)$ and the exogenously determined level of the environmental attribute z_1^b. To illustrate let us assume that z_1 is the level of crime in the area. Faced with these two restrictions, the landlord maximises profits by investing in private goods that expand the level of attribute z_1 to z_1^{bn}. Here the superscript *n* indicates the *new* level of the property attribute once the investments have been undertaken. For instance the landlord could further reduce the risk of crime by installing a burglar alarm monitored by a private security company. Following these investments, the landlord achieves point *W* where the rental value of the property is P^b and the landlord earns a profit of p^b.

Figure 16: Landlord welfare change for a localised change in environmental attribute



Now let us consider a public programme that leads to an increase in the exogenously supplied level of z_1 from z_1^b to z_1^a. In our example, the level of criminal activity in the area falls. For the sake of argument, imagine that the landlord did not adjust to this change. In our example, the landlord might continue to employ the private security firm despite the fact that crime risks in the area have fallen. Following the change the landlord's property would boast a level of environmental quality given by $z_1^{a(bn)}$ where the superscript $a(bn)$ indicates that this is the level of provision *after* the change but whilst maintaining the *new* level of property investments undertaken *before* the change.

Thus if the landlord wished to maintain the same level of profit as previous to the change, he would end up at point *X* which lies on the new offer curve providing the original level of profit, p^b.

Notice that, as in the previous scenario, the increased environmental quality has resulted in immediate reductions in the costs of providing other housing attributes. Indeed, the vertical distance between *W* and *X* measures the cost savings brought about by the environmental improvement.

Of course *X* is by no means the landlord's optimal location. Indeed, given $P^b(\cdot)$ and the exogenously determined level of the environmental attribute z_1^a, the landlord would be best advised to increase the rent on the property and consider the potential benefits of changing the property's level of environmental quality.

In Figure 16 the best the landlord could do would be to relocate to point *Y*. Here, the level of the environmental attribute z_1 has been altered to z_1^{an} and the landlord maximises profits at p^a by charging a rental of P^a. Continuing our example, in response to the fall in crime in the area, the landlord may decide to increase the rent on the property whilst terminating his employment of the private security company.

Once again, the increase in the landlord's profits will be the vertical distance between *Y* and the point on the equivalent offer curve delivering the original level of profits, point *Z*. In Figure 16, therefore, the increase in the landlord's profits is the distance *ZY*.

Again this increase in profits can be decomposed into a change of price and a change in costs according to;

$$\Delta p = \Delta P + \Delta c = \begin{pmatrix} \left[P^b\left(z_1^{an}, \mathbf{z}_{-1}^b\right) - P^b\left(z_1^{bn}, \mathbf{z}_{-1}^b\right)\right] \\ + \left[c\left(z_1^{bn}, \mathbf{z}_{-1}^b; \bar{z}_1^b, \bar{\mathbf{z}}_{-1}\right) - c\left(z_1^{an}, \mathbf{z}_{-1}^b; \bar{z}_1^a, \bar{\mathbf{z}}_{-1}\right)\right] \end{pmatrix} \tag{29}$$

This measure is broader than those that were discussed previously, because it allows for landlords to adjust the levels of environmental quality after the exogenous change. Since we are still dealing with a localised environmental improvement, this broader measure will still only be defined for properties in the affected area. The total welfare change is given by

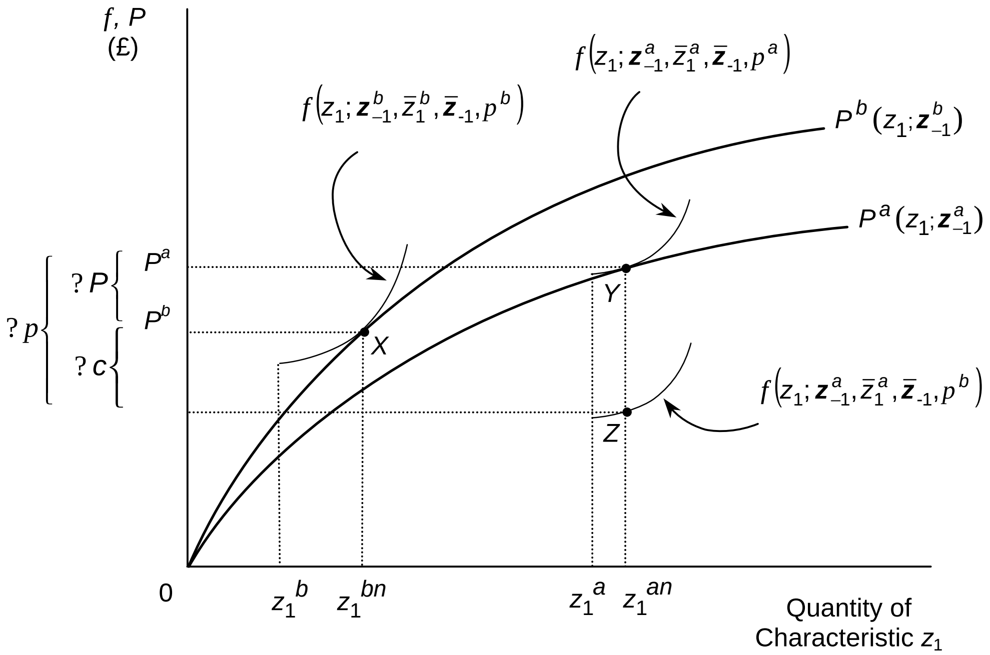
$$W_L = \sum_{l \in H_1} \begin{pmatrix} \left[P^b\left(z_{1l}^{an}, \mathbf{z}_{-1l}^b\right) - P^b\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^b\right)\right] \\ + \left[c\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^b, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^{an}, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^a, \bar{\mathbf{z}}_{-1l}\right)\right] \end{pmatrix} \tag{30}$$

ii. Landlord welfare changes from a non-localised environmental improvement

The final welfare measure we discuss relaxes all four assumptions simultaneously. This scenario, therefore, includes situations where the environmental improvement is substantial enough to result in a shift in the hedonic price function. Further, unlike the measure described by Equation (30), we allow for the fact that the landlord may decide to change the levels of provision of all the housing attributes as a result of the environmental improvement and subsequent shift in the hedonic price function. This case is depicted in Figure 17.

The landlord starts off with an exogenously determined level of environmental quality $\bar{z}_1^b$ and baseline levels of other property attributes given by the vector $\bar{\mathbf{z}}_{-1}$. In the first instance the landlord is faced by the hedonic price function $P^b(\cdot)$. In order to maximize profits the landlord wishes to move to point *X* by altering the environmental quality of the property to z_1^{bn} and the levels of other property attributes $\mathbf{z}_{-1}^b$. Here the landlord can charge a price of P^b and earns profits from the property of p^b.

Figure 17: Landlord welfare change for a non-localised change in an environmental attribute



Now a public programme results in an environmental improvement in the urban area. At the landlord's property this manifests itself as an increase in the exogenously determined level of environmental quality from $\bar{z}_1^b$ to $\bar{z}_1^a$. However, this is not a merely localised change. Indeed, the set of prices given by the old hedonic price function would no longer clear the market. Thus in response to the environmental improvement, the market adjusts, establishing equilibrium at the new hedonic price function given by $P^a(\cdot)$.

The landlord is faced by a number of simultaneous changes;

- environmental quality at their property increases
- as result of the environmental improvement the costs of providing different combinations of property attributes reduce
- the hedonic price function changes

In response the landlord will maximise profits by moving to point *Y* by altering the provision of environmental quality to z_1^{an} and the levels of other property attributes to $\mathbf{z}_{-1}^a$. Notice that we have allowed for the fact that it may be optimal to adjust the level of all housing attributes in response to the environmental improvement.

Following the same argument as that used previously, the relevant welfare measure is the vertical distance between the points marked *Z* and *Y*.

This measure is the landlords' equivalent to the Compensating Surplus measure defined for households. As with that measure, the landlord is allowed to respond optimally to the change in environmental quality and the shift in the hedonic price function. For this reason we label this comprehensive welfare measure the Compensating Profit (*CP*). In mathematical terms it is defined as;

$$CP = \Delta p = \Delta P + \Delta c = \begin{pmatrix} \left[P^a\left(z_1^{an}, \mathbf{z}_{-1}^a\right) - P^b\left(z_1^{bn}, \mathbf{z}_{-1}^b\right)\right] \\ + \left[c\left(z_1^{bn}, \mathbf{z}_{-1}^b; \bar{z}_1^b, \bar{\mathbf{z}}_{-1}\right) - c\left(z_1^{an}, \mathbf{z}_{-1}^a; \bar{z}_l^a, \bar{\mathbf{z}}_{-1}\right)\right] \end{pmatrix} \qquad (31)$$

If Δp is negative then the change in environmental quality reduces the welfare of the landlord. If Δp is positive then the change in environmental quality increases the welfare of the landlord.

Since all landlords are assumed to respond to the shift in the hedonic price function the total welfare benefits of the environmental improvement will include a measure for each of the *H* landlords in the urban area;

$$W_L = \sum_{l=1}^{H} CP_l = \sum_{l=1}^{H} \begin{pmatrix} \left[P^a\left(z_{1l}^{an}, \mathbf{z}_{-1l}^a\right) - P^b\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^b\right)\right] \\ + \left[c\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^b, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^{an}, \mathbf{z}_{-1l}^a; \bar{z}_{1l}^a, \bar{\mathbf{z}}_{-1l}\right)\right] \end{pmatrix} \qquad (32)$$

Notice that the informational requirements of the *CP* measure are extremely onerous. Not only must the researcher be able to predict how the hedonic price function will change in response to a non-localised change in environmental quality, but must also be able to predict the optimal response of each landlord to the change in market conditions.

Table 2 summarises the various measures of landlord welfare change described in this section.

Table 2: Measures of landlord welfare change

Welfare Measure	Description	Computation of Total Welfare Change for Landlords	Informational Requirements
Localised:			
Exogenous Attribute, no Cost Changes	• No shift in hedonic • Rent increase for improved properties	$W_L = \sum_{l \in H_1} P^b\left(z_{1l}^a, \mathbf{z}_{-1l}^b\right) - P^b\left(z_{1l}^b, \mathbf{z}_{-1l}^b\right)$	• Only affected landlords • Environmental quality before and after change • Original hedonic
Exogenous Attribute, with Cost Changes	• No shift in hedonic • Landlords in improved areas experience cost changes • Rent increase for improved properties	$W_L = \sum_{l \in H_1} \begin{pmatrix} P^b\left(z_{1l}^a, \mathbf{z}_{-1l}^b\right) - P^b\left(z_{1l}^b, \mathbf{z}_{-1l}^b\right) \\ + \left[c\left(z_{1l}^b, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^b, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^a, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^a, \bar{\mathbf{z}}_{-1l}\right)\right] \end{pmatrix}$	As previous, plus: • Changes in exogenous levels of other attributes • Landlord cost function
Any attribute	• No shift in hedonic • Landlords in improved areas experience cost changes • Landlords optimise level of provision of environmental quality attribute • Rent change for improved properties	$W_L = \sum_{l \in H_1} \begin{pmatrix} \left[P^b\left(z_{1l}^{an}, \mathbf{z}_{-1l}^b\right) - P^b\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^b\right)\right] \\ + \left[c\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^b, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^{an}, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^a, \bar{\mathbf{z}}_{-1l}\right)\right] \end{pmatrix}$	As previous, plus: • Landlords' choices of environmental quality attribute after improvement
Non-Localised:			
Compensating Profit	• Hedonic shifts • Landlords in improved areas experience cost changes • Landlords optimise property attributes • Rent change for all properties	$W_L = \sum_{l=1}^{H} \begin{pmatrix} P^a\left(z_{1l}^{an}, \mathbf{z}_{-1l}^a\right) - P^b\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^b\right) \\ + \left[c\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^b; \bar{z}_{1l}^b, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^{an}, \mathbf{z}_{-1l}^a; \bar{z}_{1l}^a, \bar{\mathbf{z}}_{-1l}\right)\right] \end{pmatrix}$	As previous, plus: • All landlords • Landlords' choices of all attributes after improvement • Hedonic before and after change

f. Combining Household and Landlord Welfare Measures

The total benefits to households and landlords resulting from an environmental improvement are found simply by adding W_H to W_L. Of course, this total welfare measure will depend on which assumptions are made and hence which of the formulas in Tables 1a and 1b are chosen to represent the households' and landlords' welfare changes.

Before discussing these measures further, we should note that such welfare estimates;

- measure the welfare benefits to both households and landlords for changes in environmental quality in their residential location
- ignore the benefits to visitors that travel by the improved area.
- ignore the benefits to those who work in the improved area[8].
- ignore the costs of causing the environmental improvement. For example, no account is taken of the costs to industry of reducing emissions or the cost to the tax payer of traffic calming schemes designed to reduce traffic noise.

In the simplest case, the environmental improvement is a localised phenomena that causes no change in the hedonic price function. If we assume that households incur no moving costs then they will relocated to a property offering the attributes of their original location prior to the improvement and experience no welfare change. Further, if we assume that landlords cannot affect the level of environmental quality at their properties, that the level of environmental quality does not influence the optimal level of provision of other attributes and that their costs of providing other property attributes are unaffected by the improvement, then the welfare gain for the landlords is simply the change in the rental price of their properties. The total welfare change is given by the sum of Equation (26) and the upper bound of Equation (19);

$$W_L + W_H = \sum_{l \in H_1} P^b\left(z_{1l}^a, \mathbf{z}_{-1l}^b\right) - P^b\left(z_{1l}^b, \mathbf{z}_{-1l}^b\right) + 0 \qquad (33)$$

In other words, under certain restrictive assumptions, the total welfare change can be measured as the change in price of affected properties. What is more, to calculate this measure requires only two pieces of information;

- the current hedonic price function.
- the level of environmental quality at each affected property following the environmental improvement.

For any one market, welfare changes as measured by Equation (33) should be relatively simple to estimate. Unfortunately, it is not possible to transfer such estimates to different property markets. Remember from Chapter 1 that the hedonic price function is

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[8] Of course, there is no reason why we shouldn't be able to measure the benefits to these individuals reflected in other hedonic markets such as the hedonic market for office space or the hedonic wage market.

determined by the unique conditions of supply and demand existing in a particular market. As a result, hedonic price functions will differ across property markets. A welfare measure calculated using the hedonic price function in one particular market would only be relevant to that market. It would make no sense to transfer such evaluations across different markets.

Of course, Equation (33) is by no means a comprehensive measure of the welfare change associated with a localised change in environmental quality. Indeed, by relaxing some of the assumptions underlying Equation (33) we could expand our measure of the welfare gain. For example, we might wish to allow for the fact that households face transaction costs when moving properties, that landlords might wish to optimally adapt the level of environmental quality at their properties and that changes in environmental quality might affect the costs of providing other property attributes. In this case our welfare measure would be the sum Equation (30) and the lower bound of Equation (19);

$$W_L + W_H = \sum_{l \in H_1} \begin{pmatrix} \left[P^b\left(z_{1l}^{an}, \mathbf{z}_{-1l}^{b}\right) - P^b\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^{b}\right)\right] \\ + \left[c\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^{b}; \bar{z}_{1l}^{b}, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^{an}, \mathbf{z}_{-1l}^{b}; \bar{z}_{1l}^{a}, \bar{\mathbf{z}}_{-1l}\right)\right] \end{pmatrix} - \sum_{h \in H_1} tc_h \qquad (34)$$

Of course, this may be a more comprehensive measure of the welfare change brought about by the environmental improvement, but it is also considerably harder for a researcher to estimate. Compared to Equation (33) the researcher would now need to estimate the moving costs for each household affected by the environmental change, the landlords' cost function and the adaptations made by landlords to the environmental quality attribute following the improvement. Indeed, attempting to estimate Equation (33) prior to a change in environmental quality is almost an impossible task.

In the extreme, we could relax all assumptions and allow for changes in environmental quality that are non-localised and precipitate alterations in the hedonic price function. Ignoring transaction costs, this measure would be derived by adding Equation (32) to Equation (23);

$$\begin{aligned} TSB &= \sum_{l} CP_l + \sum_{h} CS_h \\ &= \sum_{l=1}^{H} \begin{pmatrix} \left[P^a\left(z_{1l}^{an}, \mathbf{z}_{-1l}^{a}\right) - P^b\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^{b}\right)\right] \\ + \left[c\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^{b}; \bar{z}_{1l}^{b}, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^{an}, \mathbf{z}_{-1l}^{a}; \bar{z}_{1l}^{a}, \bar{\mathbf{z}}_{-1l}\right)\right] \end{pmatrix} \\ &\quad + \sum_{h=1}^{H} \begin{pmatrix} q\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}; u_{1h}\right) - q\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right) \\ - \left[P^a\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}\right) - P^b\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}\right)\right] \end{pmatrix} \end{aligned} \qquad (35)$$

This would give us our most comprehensive measure of the welfare change[9] and hence is labelled the *Total Social Benefits* (*TSB*) of the of the change in environmental quality. Notice that this measure is summed over all households and landlords in the urban area even those not originally located in the improved area. This is important since the latter group may be affected by subsequent changes in the hedonic market.

Further, and most importantly with regards to the present discussion, the measure is almost impossible to calculate. To assess Equation (35) researchers would require detailed knowledge of how the equilibrium hedonic price function would be affected by changes in environmental quality and how households' and landlords' choices would respond to both changes in environmental quality and changes in the hedonic price schedule. As discussed previously, the complexity of the hedonic market equilibrium precludes analytical solutions to this problem. As such, Equation (35) is of little use to practitioners attempting to measure the benefits derived from a program designed to change environmental quality in an urban area.

g. A Quantifiable Lower Bound

Since the informational requirements for measuring *TSB* are prohibitive, economists have looked to define a simpler measure that might lend itself to estimation in the real world. It turns out that one such measure is the sum of *QCS* measures presented in the previous discussion (Equation 21). All that is required to calculate this measure is knowledge of the bid function of households in the affected area, details of their current residential choices and information on the level of environmental change experienced by each household. The great advantage of using this measure is that estimates of welfare changes can be made without knowledge of how households, landlords and the hedonic price function react to a change in environmental quality.

Encouragingly, Bartik (1988) has given a theoretical justification for choosing to measure the welfare changes resulting from a change in environmental quality as the sum of households' *QCS*. He shows that the sum of *QCS* across all affected households provides a lower bound estimate of the *TSB*. That is, if we calculate the sum of *QCS* resulting from a change in environmental quality, we will be calculating a figure that whilst not reflecting the full benefits of the change will provide a lower estimate of these benefits.

Bartik's intuitive proof involves partitioning the welfare changes affecting households and landlords into a series of three stages. Whilst these stages help in the analysis of welfare changes they are not meant to represent a realistic sequence of events. The three stage decomposition is presented in Table 3.

In the *first stage*, some or all of the residential locations in the urban area experience an improvement in environmental quality. At this stage, we assume that neither landlords, nor households nor the hedonic market adjust in response to this change. Thus the household stays in the same property, the landlord does not increase the rent nor adjust

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[9] Though remember this formula is based on the less comprehensive *CS* measure that does not allow for the adjustments in residential location in response to changes in income.

the property's attributes and the hedonic price function does not change from its previous form.

- Since households cannot move property, the benefit to households will be simply their WTP for the environmental improvement at their original location. This is the *QCS* measure presented in Figure 11 and Equation (20).
- Since landlords cannot change rents or adjust the attributes of their properties, they will only be affected by the change in environmental quality if it affects their costs. Since we assume they make no changes to their properties at this stage, the measure of cost savings is that given by the vertical distance between *W* and *X* in Figure 16.

In the *second stage*, the hedonic price function shifts to its final form but we still constrain households and landlords to their original location and supply choices. Since households and landlords remain in the same location the change in rent associated with the shift in the hedonic price function acts to simply transfer money from one to the other. Indeed, whatever the pattern of rent changes in the second stage, there is no overall welfare effect.

Notice, however, that though in stage 2 the aggregate welfare change across the whole urban area is zero, welfare changes for each individual household and landlord may be positive or negative depending on the particular pattern of rent changes. Landlords at unimproved sites, for example, will almost certainly experience some reduction in rent and hence profits.

In the *third stage*, households are allowed to move and landlords are allowed to change the attributes of their properties in response to the new hedonic price function. Since both households and landlords are allowed to respond optimally, they must, by definition, experience an increase in welfare. Households will move to the property that offers them the highest possible utility. This must be at least as beneficial as remaining in the original property since they could always opt not to move house. A similar story can be made for landlords' supply decisions. In effect, therefore, compared to stage 2, both households and landlords must witness an increase in welfare. Again this is not to say that every household and landlord experiences an increase in welfare over all three stages. Whilst households and landlords only benefit in stages 1 and 3, they may just as well lose benefit as gain benefit in the rent changes isolated in stage 2.

As shown in Table 3, summing all three stages for households results in the total welfare gains given by the sum of household *CS's* given in Equation (23). Similarly, summing all three stages results in the sum of landlords *CP*'s given in Equation (32). Thus the three stage decomposition, whilst not reflecting the simultaneous nature of responses to the change in environmental quality, accurately represents the overall change in welfare.

Table 3: A decomposition of the welfare effects of a change in environmental quality from Bartik (1988)

	Benefits at Various Stages		
	Households	Landlords	Net Efficiency Benefits
Stage 1: Amenity changes, no adjustment or rent change	$\sum_h \left[q\left(z_{1h}^{ao}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right) - q\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right)\right]$ Household WTP at original location: zero for unimproved sites, positive for improved sites	$\sum_l -\left[c\left(z_{1l}^{a(bn)}, \mathbf{z}_{-1l}^{b}; \bar{z}_{1l}^{a}, \bar{\mathbf{z}}_{-1l}\right) - c\left(z_{1l}^{bn}, \mathbf{z}_{-l1}^{b}; \bar{z}_{1l}^{b}, \bar{\mathbf{z}}_{-1l}\right)\right]$ Landlord cost savings: assumed non-negative for improved sites, zero for unimproved sites	Sum of all households' WTP plus all landlords' cost savings
Stage 2: Rent Change	$\sum_h -\left[P^a\left(z_{1h}^{ao}, \mathbf{z}_{-1h}^{bo}\right) - P^b\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}\right)\right]$ Rent change at both improved and unimproved sites	$\sum_l P^a\left(z_{1l}^{a(bn)}, \mathbf{z}_{-1l}^{b}\right) - P^b\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^{b}\right)$ Rent change at both improved and unimproved sites	Zero efficiency benefits; pecuniary transfer between households and landlords
Stage 3: Adjustment	$\sum_h q\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}; u_{1h}\right) - P^a\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}\right) - \left[q\left(z_{1h}^{ao}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right) - P^a\left(z_{1i}^{ao}, \mathbf{z}_{-1h}^{bo}\right)\right]$ Measure of household utility increase from adjustment, for households originally at both improved and unimproved sites	$\sum_l P^a\left(z_{1l}^{an}, \mathbf{z}_{-1l}^{a}\right) - c\left(z_{1l}^{an}, \mathbf{z}_{-1l}^{a}; \bar{z}_{1l}^{a}, \bar{\mathbf{z}}_{-1l}\right) - \left[P^a\left(z_{1l}^{a(bn)}, \mathbf{z}_{-1l}^{b}\right) - c\left(z_{1l}^{a(bn)}, \mathbf{z}_{-1l}^{b}; \bar{z}_{1l}^{a}, \bar{\mathbf{z}}_{-1l}\right)\right]$ Landlord profit increase from adjustment to new hedonic: applies to landlords at all sites	Net gain from adjustment must be non-negative for all
Sum of three stages	$\sum_h q\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}; u_{1h}\right) - q\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}; u_{1h}\right) - \left[P^a\left(z_{1h}^{an}, \mathbf{z}_{-1h}^{an}\right) - P^b\left(z_{1h}^{bo}, \mathbf{z}_{-1h}^{bo}\right)\right]$ Net household gain: sum over all households, Equation (23) in text	$\sum_h P^a\left(z_{1l}^{an}, \mathbf{z}_{-1l}^{a}\right) - c\left(z_{1l}^{an}, \mathbf{z}_{-1l}^{a}; \bar{z}_{1l}^{a}, \bar{\mathbf{z}}_{-1l}\right) - \left[P^b\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^{b}\right) - c\left(z_{1l}^{bn}, \mathbf{z}_{-1l}^{b}; \bar{z}_{1l}^{b}, \bar{\mathbf{z}}_{-1l}\right)\right]$ Net landlord gain, sum over all landlords, Equation (32) in text	Sum of 1st and 2nd columns is same as Equation (35)

The insight of Bartik's decomposition is to isolate all individual welfare losses as price changes in stage 2. Since price changes simply represent pecuniary transfers between agents in the property market, these losses must be offset by equivalent gains elsewhere. In other words when we are interested in the aggregate welfare change, we can ignore the losses incurred by certain landlords and households by netting these out as a price change.

As a result *TSB*, that is the total welfare change experienced by all households and landlords in the urban area, can be regarded as the sum of the four non-negative values defined in stages one and three. In words, these are;

1. WTP of households at improved locations to enjoy the change in environmental quality whilst staying in their original property ($\sum_{h \in H_1} QCS_h$)
2. cost savings for landlords at stage 1
3. household utility gains from relocation at stage 3
4. landlord profit gains from changes in supply at stage 3

Since all four values are non-negative, $\sum_{h \in H_1} QCS_h$ must also be a lower bound to *TSB*.

This is an extremely important insight since it gives us a good theoretical reason for using $\sum_{h \in H_1} QCS_h$ to measure the welfare change resulting from an environmental improvement. There are a number of reasons why this might be desirable.

- First, since the *QCS* measure does not require information on how the market price or agents in the market adjust to a change in market conditions, it can be calculated in advance of a public programme to improve environmental quality.
- Second, the *QCS* is a measure of household welfare change. Consequently using the sum of *QCS*s as a lower bound estimate of *TSB* removes the need to examine the supply side of the market. Researchers can ignore the considerable difficulties associated with estimating landlord cost and offer functions.
- Third, *QCS* is only defined for households in an affected area. As a result, the researcher only requires information on which households will be affected by the environmental improvement and the extent of improvement enjoyed by each.
- Finally, the *QCS* measure is based solely on underlying preferences for environmental quality as captured in the bid function. The measure is not particular to a specific property market. Indeed, if a researcher could derive the bid function from one market then this could be used to evaluate the *QCS* in another property market, provided the researcher was prepared to assume that preferences for environmental quality were stable across the two markets.

Clearly, using the sum of households' *QCS* as a lower bound approximation to the *TSB* makes it practical to carry out *ex-ante* assessments of the welfare gains from environmental improvements. Obviously, the accuracy of this approximation will depend on the size of the values taken by the other three elements of *TSB* isolated in Bartik's analysis. Certainly, the approximation will tend to be more accurate when the environmental change is less extensive as the benefits of household relocation and landlord change in supply will tend to be smaller.

h. Conclusions

This chapter has demonstrated how the benefits of an environmental improvement can be measured in the property market. The benefits captured in this market are those accruing to households and landlords of a particular residential location. The measures described here do not capture the benefits to visitors that travel by the improved area nor do they capture the benefits to those who work in the improved area.

In the simplest case, the environmental improvement is a localised phenomena that causes no change in the hedonic price function. If households can move freely and landlords do not enjoy cost savings and are constrained not to alter the supply of property attributes, then the welfare benefits of the improvement accrues to landlords as the *change in the rental price* of their properties (Equation 33).

This measure is easy to calculate for any property market for which the hedonic price function is known. Unfortunately, the fact that the measure is based on the unique hedonic price function of a particular market means that there is no theoretical substance to transferring such values across property markets.

Clearly, estimating the welfare change of an environmental improvement by the increase in prices of affected properties is to impose severe restrictions on the reactions of the economic agents in the market to the improvement. Indeed, a completely comprehensive measure of the welfare benefits of an environmental improvement is given by the *Total Social Benefits* (*TSB*) measure of Equation (35).

However, the *TSB* measure is little more than a theoretical construct. To estimate such a measure researchers would require detailed knowledge of how the equilibrium hedonic price function would be affected by changes in environmental quality and how households' and landlords' choices would respond to both changes in environmental quality and changes in the hedonic price schedule.

Unfortunately, hedonic market equilibria are too complex to derive satisfactory analytical solutions by which to predict such outcomes. Indeed, the *TSB* measure is almost impossible to calculate *ex-ante*, making it of little use to practitioners attempting to measure the potential benefits of a program seeking to change environmental quality in an urban area.

Nevertheless, in an important analysis, Bartik (1988) showed how a third measure the *QCS*, when summed over all households directly affected by the change in environmental quality, could always be taken as a lower bound to the *TSB*. There are a number of reasons why using the *QCS* measure might be desirable. In particular, the *QCS* measure is based solely on the household bid function. As a result, it is not necessary to consider the supply side of the market nor predict market conditions following environmental change. Further, the *QCS* measure is not particular to a specific property market. Indeed, if a researcher could derive the bid function from one market then, provided the researcher was prepared to assume that preferences for environmental quality were stable across the two markets, this could be used to evaluate the *QCS* in another property market.

In the next chapter, therefore, we investigate the possibilities for deriving estimates of the bid function from which the QCS measure of welfare change can be derived.