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Land as a Differentiated Factor of Production: A Hedonic Model and Its Implications for Welfare Measurement

Raymond B. Palmquist

The hedonic methodology can be traced back to Court (1939) and received considerable application beginning in the 1960s. However, it was not until 1974 that a theoretical model that could serve as a basis for the empirical techniques was developed by Rosen.[1] That model considers the interaction of consumers of a differentiated product and the producers of that product. Rosen's theoretical model has proven extremely useful in the ensuing years and is cited in almost all works in the hedonic field. The model has also been used to develop welfare measures for amenities using hedonic techniques (see Bartik 1988, and Palmquist 1988). While most of the applications of the Rosen model have been concerned with a differentiated consumer product as is appropriate, there are also important issues involving differentiated factors of production, particularly land. There has been some interesting empirical work in this area (e.g., Downing 1973, or Chicoine 1981), but such work has had to proceed without a detailed model. Without such a model, specification questions arise and careful welfare measurement is not possible. The purpose of this paper is to develop a model of the derived demand for a differentiated factor of production (agricultural land) and to develop welfare measurement techniques that can be applied to various land and agricultural policy questions.

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EQUILIBRIUM LAND PRICES AND INDIVIDUAL BEHAVIOR

While it is common to treat land as a homogeneous factor of production, each parcel of land actually has a large number of characteristics that will vary between tracts. These characteristics include characteristics that cannot be changed by the owner of the land and others that can be changed in response to market information. The owner cannot reasonably change the soil type or structure, the topsoil depth (although the rate of change in that depth can be influenced), the erosivity of the soil (although the amount of erosion can be affected), major topographic features or terrain, or climate including rainfall, temperature, and sunshine. Other features can be changed such as drainage, terracing, changing the pH or fertility, irrigation of the land, erosion control such as grass waterways or tillage techniques, and building structures on the land. The price for which the land rents[2] depends on the land's characteristics. This relationship can be represented by a hedonic equation

$$R = R(z_1, \ldots, z_n), \qquad [1]$$

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[1] An alternative theoretical model was independently developed at the same time by Freeman (1974). While both models have been used since then, the Rosen (1974) article is more widely cited.

[2] The model is developed in terms of rental prices for land, rather than sales or asset prices. In empirical work there may be better data available on sales contracts rather than rental contracts, in which case the empirical specification must be modified to account for anticipated future changes in the characteristics and uses of the land (see Palmquist and Danielson forthcoming).

where R is the rental price of the parcel and $z = (z_1, \ldots, z_n)$ is a vector of the n characteristics of the farmland. This function need not be linear,[3] since many of the characteristics cannot be sold independently.

An individual demander of the services of the land (a farmer) is unable to influence the equilibrium price schedule in equation [1], although the price the farmer pays will depend on the characteristics of the chosen parcel. Similarly, a supplier of land services (a landlord) cannot influence the equilibrium price schedule, but the landlord can change the rental price earned by his parcel if the characteristics can be changed. Equation [1] is determined by the interactions of all demanders and suppliers of land in a particular market. A farmer who operates on his own land can be considered implicitly to rent the land from himself and has the option of renting to someone else.

On the demand side are individuals who wish to use the land as an input to their production of agricultural crops. The multiple-output, multiple-input farm production function can be written implicitly as,

$$g(x, z, \alpha) = 0, \qquad [2]$$

where x represents the vector of net outputs ($x_i > 0$ implies x_i is an output, whereas $x_i < 0$ implies x_i is an input) exclusive of land, z is the vector of characteristics of land as before, and α is a vector of farmer characteristics that influence their productive ability. The elements of α represent differential skills in growing particular crops or in farming under particular conditions.

Farmers maximize profits, but to concentrate on their willingness to pay for the use of particular parcels of land, let us consider their variable profits[4] on a parcel of land. These profits are the difference between the value of outputs and the value of non-land inputs. Maximizing these profits on a particular parcel of land yields the following problem,

$$\max_x \pi^{DV} = \sum_{j=1}^{m} p_j x_j \text{ subject to } g(x, z, \alpha) = 0,$$
$$\pi^{DV} \geq 0, \qquad [3]$$

where π^{DV} is the "variable" profits of this demander of land and the p_j are elements of a vector p of prices of outputs and non-land inputs. This maximization problem can be solved for output supply and non-land input demand functions, $x = x(p, z, \alpha)$. These can be substituted back into equation [3] to yield the variable profit function,

$$\pi^{*DV} = \pi^{*DV}(p, z, \alpha) = \sum_{j=1}^{m} p_j x_j(p, z, \alpha). \qquad [4]$$

If a farmer's rental costs for the land, $R(z)$, are subtracted from "variable" profits, one obtains π^{*D}, actual profits.[5]

The equilibrium rent schedule is the result of the bids of farmers for the use of the land and the offers of the landlords. A farmer's bid for a particular parcel of land will depend on the characteristics of that parcel, the prices of outputs and other inputs, the desired profit level π^D, and the farmer's production skills. The bid function, θ, is defined by

$$\theta(z, p, \pi^D, \alpha) = \pi^{*DV}(p, z, \alpha) - \pi^D. \qquad [5]$$

The partial derivative of the bid function with respect to a characteristic of the land is $\theta_{z_i} = \partial\pi^{DV}/\partial z_i \geq 0$, since the variable profit function is nondecreasing in fixed factors given typical assumptions about the production technology (Diewert 1978) and the z, desirable characteristics of land, enter in the same manner as fixed factors. The second partial derivative of the bid function with respect to a characteristic is $\theta_{z_i z_i} = \partial^2\pi^{DV}/\partial z_i^2 \leq 0$, since the variable profit

[3] There is no reason the hedonic equation cannot be linear. The functional form cannot be chosen on theoretical grounds. The possibility of restrictions on the functional form being available is discussed below.

[4] The use of the term "variable profits" should not be misinterpreted. Variable profit is normally revenue minus expenditure on variable factors. Here the characteristics of land are not fixed. However, land costs are not netted out of variable profits as the term is used here.

[5] If there are fixed factors, payments to those factors should also be subtracted from variable profits to calculate actual profits.

function is concave in fixed factors, again given the usual assumptions about the production technology (Diewert 1978). The partial derivative of θ with respect to p_j is equal to x_j by the envelope theorem, so it is positive for outputs and negative for inputs. The partial derivative of θ with respect to desired profits is -1, since higher profits require an offsetting reduction in the bid, ceteris paribus.

The bid function shows the payment a farmer would be willing to make for the use of any parcel of land, given a particular desired profit level. In equilibrium the increase in the bid of a farmer with a marginal increase in one of the characteristics of the land must equal the increase in the market rental price of land with a marginal increase in that characteristic. Otherwise the farmer could increase profits by using land with different characteristics. In addition to these marginal conditions, the farmer's total bid for a parcel must equal the rental price of the parcel.

To derive the market equilibrium rent schedule, we also must consider the behavior of landowners. For this purpose it is useful to separate the vector of characteristics, $z = (z_1, \ldots, z_n)$ into two sub-vectors, $\hat{z} = (z_1, \ldots, z_k)$ and $\tilde{z} = (z_{k+1}, \ldots, z_n)$, where the components of $\hat{z}$ are characteristics exogenous to the landowner and the components of $\tilde{z}$ are within his control. Examples of these two types of characteristics were given at the beginning of this section. The landowner seeks to maximize profits from renting the parcel of land by altering the characteristics within his control,

$$\max_{\tilde{z}} \pi^S = R(\hat{z}, \tilde{z}) - C(\hat{z}, \tilde{z}, r, \beta) \quad \text{subject to } \pi^S \geq 0, \quad [6]$$

where π^S represents the profits of the landowner, $R(\cdot)$ is the rental price schedule from equation [1], $C(\cdot)$ is a joint cost function with the usual properties, r is a vector of input prices, and β is a vector of technical parameters which may vary between landowners. The elements of β may include, for example, ownership of other parcels in the immediate area or availability of special credit opportunities. Equation [6] yields first-order conditions requiring that the marginal cost of the characteristics under the landowner's control be equal to the marginal characteristics price in the market.

An offer function, $\phi(\hat{z}, \tilde{z}, \pi^{S'}, r, \beta)$, representing the prices at which the landowner would make parcels available to the market, can be defined in a manner analogous to the bid function,

$$\phi(\hat{z}, \tilde{z}, \pi^{S'}, r, \beta) = \pi^{S'} + C(\hat{z}, \tilde{z}, r, \beta), \quad [7]$$

where $\pi^{S'}$ is the desired profit level. However, since some of the characteristics are beyond control of the landowner, he is limited in the amount of some of the characteristics he can offer. The partial derivative of the offer function with respect to an endogenous characteristic is non-negative, since it is equal to the marginal cost of that characteristic, and the second partial derivative is also non-negative, since it is equal to the slope of the marginal cost function at a profit-maximizing equilibrium. An increase in profits increases the offer price by an equal amount.

A landowner would maximize profits by equating the marginal offer prices for the characteristics under his control to marginal characteristics prices in the market. For characteristics beyond his control, the characteristic price and thereby his offer price would be completely demand-determined. The offer price for the exogenous characteristic would be equal to the market price, since at a lower offer price the landowner would forego profits and at a higher offer price the offer would not be accepted.

Thus, both farmers and landowners take the market price schedule as parametric, but that schedule is determined by the interactions of these two groups. The price schedule changes to eliminate excess demand or supply for parcels with each set of characteristics. If all farmers had identical productive capabilities, α, then the functional form of the hedonic price schedule necessarily would be concave in the characteristics because it would correspond to the common bid function. However, it is generally observed that farmers have skills in a particular set of crops or type of farming which indicates that the vector α differs between farmers. On the other hand, if all landowners had the same abilities to make improvements in the characteristics of their land (identical β-vectors), then the hedonic price schedule would have to be convex in $\tilde{z}$, although not necessarily in the exogenous characteristics. This possible restriction on the functional form of the price schedule should be considered.

The number of parcels available for farming is not fixed, since the land has alternative uses. The rental price of land with a given set of characteristics in these alternative uses fixes a lower limit on the rental price necessary to keep the land in farming. If the potential rental price of a parcel for agricultural use is below this limit, that parcel is taken out of agricultural use. On the other hand, if agricultural returns increase, rental prices in agriculture will rise and land may be bid away from other uses. The number of potential agricultural demanders of parcels also is not fixed. As land rental prices increase due to nonagricultural reasons, some farmers choose other occupations.

An important issue is how large an area is included within a single land market. Certainly, most agricultural crops are traded on national and international markets which would tend to integrate land markets throughout the nation. However, many crops are specialized to certain regions of the country. Most farmers (and, to a lesser extent, landowners when they are different individuals from the farmers) have fairly strong locational preferences. Finally, some farm programs and policies have regional differences. These factors tend to support the existence of regional land markets.

VALUING LAND IMPROVEMENTS

The model allows insights into the techniques necessary for measuring the value of changes in the characteristics of land. Such changes are a frequent result of public policies. The necessary techniques for such valuation differ greatly depending on the nature of the improvements. Improvements that affect only a few parcels in the market will have little effect on the equilibrium rent schedule, although the prices of the affected parcels may change significantly. However, some government policies toward land will have a significant impact on the equilibrium land rent schedule, and different techniques for welfare measurement are necessary.

When the equilibrium rent schedule is unaffected by the changes, only the landowners whose land is affected directly would be willing to pay for the improvement. The old price of the affected parcels would be below the price that the improved land could command after the improvement. The price would be bid up until it equalled the price of other land with the same characteristics. The owners of the improved land enjoy a capital gain due to this price increase. On the other hand, the farmers cannot be willing to pay for the improvement. The farmers who originally used the land that was improved might choose to relocate as the rental price on the land rose. Even if they did not choose to relocate, they could not be made better off by the improvements since previously they could have chosen land with these characteristics for the same price but did not choose to do so. The welfare changes of landowners and farmers on parcels that were not changed would be zero since the rental price schedule would be unchanged. Welfare measurement in this instance simply would require the estimation of the hedonic equation before the policy took effect, so that the affected landowners' capital gains could be estimated.

A major policy change might influence not only the rental prices of the affected parcels but also the equilibrium rental price schedule. When the price schedule changes because of the policy, the profits of the farmers may be changed as well as the rents of the landowners. If the welfare analysis is conducted after the policy change so the new hedonic price schedule is known, ex-

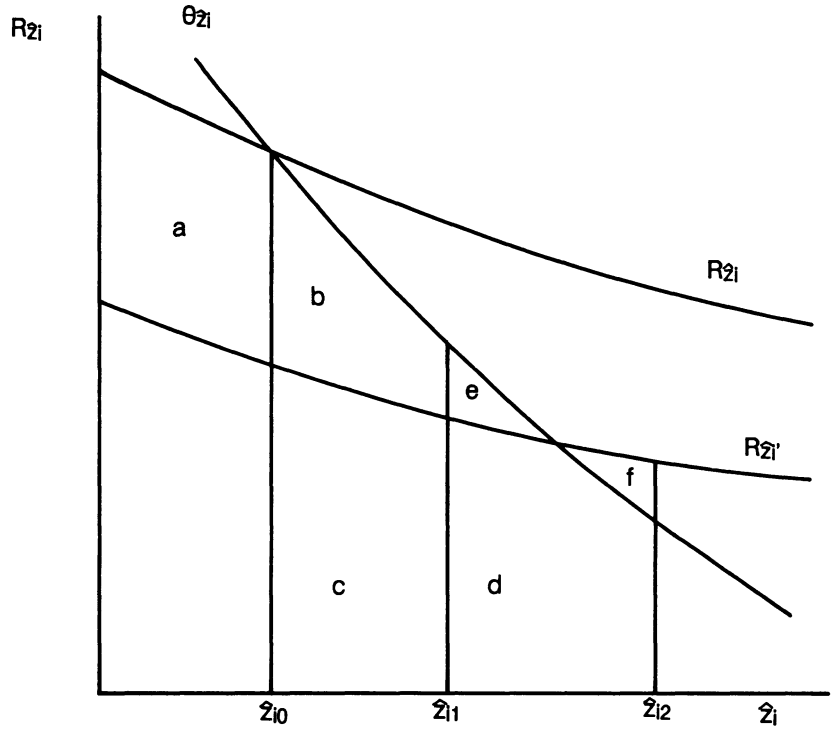

FIGURE 1

act measures are available by adapting the techniques developed in Palmquist (1988) to the profit functions developed here.

Before a policy is implemented, a forecast of the benefits is useful in deciding on the desirability of the policy.[6] An *ex ante* lower-bound on the benefits is always available, and in some cases the measure is exact. This measure can be derived from the variable profit function in equation [4]. That function represents profits before land rents are netted out, but the land characteristics are not truly fixed factors. Diewert (1974) has shown that the partial derivative of the variable profit function with respect to a fixed factor is the shadow price of that fixed factor. Thus, differentiating the variable profit function with respect to the characteristics of the land yields the inverse demands for these factors.[7] A farmer's total willingness to pay for a change in a characteristic of the land if the other characteristics cannot be altered could be obtained by integrating the inverse factor demand function between the original and the new level of the characteristic. The value measure derived from the inverse demands is exact if farmers do not adjust the quantities of any other land characteristics in response to the policy change. If they do change locations or the other characteristics of the current location change, then the measure is a lower-bound for the benefits of the policy, since the farmers only switch land if they can increase their profits by so doing.

Graphically, this type of welfare measurement can be shown in Figure 1. The

[6]Both Bartik (1988) and Palmquist (1988) consider *ex ante* welfare measurement in consumer hedonic models.

[7]In estimating these inverse factor demands, the econometric problems of identification and endogeneity in hedonic models must be considered. For example, see Bartik (1987), Epple (1987), and Palmquist (1984).

farmer's inverse demand for the characteristic is $\theta_{\hat{z}_i}$. The policy results in a shift in the equilibrium marginal rent schedule from $R_{\hat{z}_i}$ to $R'_{\hat{z}_i}$, and the farmer enjoys an increase in the quantity of the characteristic as well as a reduction in the rent schedule. Initially, assume that the level of the characteristic $\hat{z}_i$ increases from $\hat{z}_{i0}$ to $\hat{z}_{i1}$. If transactions costs prevent the farmer from relocating, then his welfare gain is *a* and *b*, area *a* because of the reduced rent on the original amount of the characteristic and area *b* because of the availability of the new units of the characteristic at prices below the farmer's marginal willingness to pay. The landlord, on the other hand, loses area *a* because of the reduced rent schedule but gains area *c* because of the higher level of the characteristic. The landlord's loss of area *a* cancels the farmer's gain of that area, so the net gain to the two individuals is area *b* plus area *c*. However, if the farmer relocates, then his gain is $a + b + e$. The change in the landlord's welfare is still $c - a$, so the net gain is $b + c + e$. Similarly, if the characteristic changes to $\hat{z}_{i2}$, then relocation also increases the welfare gain. With relocation the gain is $b + c + e + d + f$, whereas if relocation is not possible, the gain is reduced by area *f*. The welfare measure described provides a lower-bound on the gain even with relocation and is an exact measure if transactions costs prevent relocation or no relocation is desired after the change.

CONCLUSION

This paper has developed a model of a market for a differentiated factor of production. This consideration of the motivations underlying the hedonic price function in production can aid in developing an appropriate specification for such an equilibrium price schedule. More importantly, such a model provides a basis for the estimation of the derived demands for the characteristics of factors such as land. Techniques for welfare measurement when a policy affects a differentiated factor of production have also been considered.

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