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Air Quality and View Degradations due to Copper Mining and Milling: Preliminary Analysis and Cost Estimates for Green Valley, Arizona

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Green Valley, Arizona is a retirement community located near major open-pit copper mines. Mining and milling activities create dust, which degrades air quality, and mine dumps and tailings banks, which degrade the viewscape. Although the tailings banks are highly visible, this study found that consumer surplus lost from dust-polluted air is more than twice that from degradation of viewscape. Consumer surplus lost from both air quality and viewscape degradation is estimated to be between \$116,000,000 and \$169,000,000. These preliminary estimates are based upon two studies: hedonic property values, and a contingent valuation survey of willingness to pay.

KEY WORDS: Mining environmental costs; copper's environment cost; Green Valley; environmental valuation; mining's social cost.

INTRODUCTION

Green Valley, Arizona, a retirement community located 25 miles south of Tucson, Arizona, has a population of about 21,000 (1992). Unlike other retirement communities in Arizona, such as Sun City; Green Valley is located near major open pit copper mines (Cyprus Sierrita and Pima). Clearly, infrastructure that serves the mining complex also provides conveniences to Green Valley residents, and the mines provide employment to surrounding communities and to some residents of Green Valley. On the other hand, activities associated with mining and milling create environmental externalities that affect Green Valley residents. Among these externalities are airborne dust, especially when conditions are dry and windy, and the visibility of unsightly mine dumps and tailings banks. Noise and dust problems appear to be most serious near the Duval mine road, which crosses the northern part of Green Valley.

The banks of the tailings ponds, which are high in order to improve dust control, diminish the quality of the view, hereafter referred to as viewscape, for nearby residents. As the tailings banks are located on the west side of Green Valley, they detract from the scenic values of the landscape and sunsets. For those who are located on the west side of Green Valley, near the mine complex, the viewscape is principally of tailings banks. On the other hand, those living in the eastern and southern parts of Green Valley are farther from the mine and are near Madena Canyon and more than ten golf courses. Thus, the impact of mining on viewscape varies considerably across the Green Valley community.

The objective of this study is to make initial or preliminary estimates of the cost to the Green Valley community of the degradation of viewscape and air quality caused by the copper mining and milling activities (Kim, 1994). This study is not a benefit-cost analysis of mining, because it does not estimate the benefits

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of mining to the Green Valley community. The neglect of benefits should not be construed to imply that those benefits are inconsequential or that the environmental costs outweigh the benefits, only that they are not measured in this study.

CONCEPTUAL FRAMEWORK

Simply stated, the cost to Green Valley residents of the proximate copper mining activities is taken to be the consumer surplus lost, the consumer deficit, occasioned by the degraded states of environmental amenities, which in this study are restricted to viewscape and air quality . To illustrate the concept, consider one environmental amenity and let q be its level. Let $f(q)$ be the inverse demand function for the amenity and let q_0 and q_1, $q_0 > q_1$, be levels of the amenity in its natural and degraded states, respectively. Then, the cost of degradation of the amenity to level q_1 is the consumer deficit of this state:

$$cs = \int_{q_1}^{q_0} f(q)\, dq$$

Application of this approach requires an estimate of $f(q)$ and the identification of the relevant states, q_0 and q_1. As these environmental amenities are not traded goods, estimation of $f(q)$ requires approaches that differ from those for market goods. This study uses two different approaches for the estimation of $f(q)$: hedonic property values, and willingness to pay contingent valuation (CVA).

The first approach, hedonic property values, uses real estate transactions to estimate a hedonic price equation for the characteristics of properties, including environmental state, q. With this approach, $f(q)$ for the estimation of consumer surplus, is the marginal implicit price equation for the amenity, which is the partial derivative of the hedonic price equation with respect to q.

The second approach uses a survey of residents in the affected community to determine their willingness to pay for various improved states of the environmental amenity. From these survey responses, a willingness to pay (wtp) equation is estimated. With this approach, $f(q)$ is the marginal willingness to pay function, which is the first derivative of the wtp equation with respect to q.

LIMITATIONS AND ADVANTAGES OF THIS STUDY

Although this study estimates lost consumer surplus by two very different methods (hedonic and contingent valuation), this is not a methodological study *per se*. Other investigations (Rosen, 1975; Kanemoto, 1988) already have shown that the methods often produce very different estimates, for they are based upon different procedures and assumptions. The existence of controversy about methodology suggests that there is value to estimating consumer deficit by both methods, for differences in the two estimates indicate uncertainty about the true loss of consumer surplus.

The estimates made in this study should be considered "preliminary" for several reasons. One of these is that sample sizes are small; for example, the hedonic housing model is estimated on only 20 real estate transactions, and the contingent valuation model on a survey of 40 respondents. These estimates are preliminary for another reason: The contingent valuation survey was not field tested. In fact, by virtue of its sample size, that survey is like a field test. Although small in number, the 20 real estate transactions represent the total transactions during a period of 4 months, for Green Valley, like most communities near active mines is small (roughly 3700 detached single family units—see discussion in subsequent section "Estimates"). An advantage of this short time period is that it increases the likelihood that the real estate market was in equilibrium during the real estate transactions, a requirement for estimating hedonic price models by single-equation methods.

Green Valley presents some advantages for investigating the loss of consumer surplus due to degradation of air quality and viewscape due to mining and milling. Many mining communities that are located near active mines are small populations whose members are associated either directly or indirectly with the mine complex. Dependence of residents upon the mining activity would complicate the estimation of consumer loss due to degradation of environmental amenities by mining and milling. But, Green Valley, being primarily a population of retired persons adjacent to an active mine, presents requisite conditions without the complications due to dependence.

HEDONIC PRICE EQUATION FOR PROPERTY CHARACTERISTICS

Basic Concepts

The foundation of the hedonic approach is the concept that when a market for a complex good (having many characteristics) is at equilibrium and all consumers have identical incomes, the characteristics of the purchased goods (real estate in this study) reveal consumer preferences for the characteristics (Freeman, 1974, 1979; Lucas, 1975; Harrison and Rubinfeld, 1978; Brookshire and others, 1982; Schulze and others, 1981; Brookshire and others, 1985). For example, when purchasing a property (house on a lot), the consumer is considered to be purchasing a set of property characteristics that are consistent with his order preferences for:

H = a vector of m house characteristics, such as square feet, number of rooms, etc.
N = a vector of k neighborhood characteristics, e.g., proximity to school, work, etc.
Q = a vector of n environmental characteristics, e.g., view air quality, etc.

Thus, given that the market for properties is in equilibrium and that all consumers have the same income, the regression of sale prices of properties on property characteristics produces an estimate of the hedonic price equation for the characteristics of properties. For a linear hedonic price model:

$$P = a_0 + a_1h_1 + \cdots + a_nh_n + b_1n_1 + \cdots + b_kn_k + c_1q_1 + \cdots + c_nq_n$$

where,

a_i, b_j, c_l are the coefficients of h_i, n_j, and q_l, respectively, $i = , \ldots, m$; $j = 1, \ldots, k$; $l = 1, \ldots, n$;
a_0 is the estimated intercept (constant);
P sale price of property.

The partial derivative of P with respect to, say, q_l is the marginal implicit price (mip) for the environmental amenity q_l. When all individuals have identical income and utility functions, the marginal implicit price function is itself the demand function (Freeman, 1985), which was represented by $f(q)$ in the foregoing comments on consumer surplus:

$$\text{mip} = c_2 \rightarrow f(q_2)$$

Thus, when the hedonic price equation is linear, as in the above, the marginal implicit price is constant. Of course, when the hedonic price equation is nonlinear, the marginal implicit price for an environmental amenity may vary with the magnitude of the amenity or other variables in the equation, depending upon the mathematical form of the model.

Adaptation to this Study

Environmental Proxies

This study employs two proxies for the environmental amenities of viewscape and clean air. Map distance from tailings banks, D, is used as a proxy for clean air, meaning freedom from mine and tailings bank dust. Orientation of house, DD, is used as a proxy for viewscape, with $DD = 2.71828$ when the backyard faces the tailings banks, and $DD = 1$, otherwise. These values for DD are specified so that their logarithms are 1 and 0 in the estimated log–log hedonic and willingness to pay equations.

Neighborhood Characteristics

Green Valley is known as a retirement community; consequently, neighborhood characteristics, such as proximity to schools and to work, are *a priori* much less important than for a standard community. With regard to other characteristics, such as ethnicity and age of household, the assumption was made that the community also is relatively homogenous; consequently, data were not collected for these neighborhood variables. Although this assumption seems reasonable, it was not tested; accordingly, it is acknowledged that at least in principle, the exclusion of these characteristics could impart parameter bias.

House Characteristics

Data on Green Valley real estate transactions were obtained for the 4-month period from July 1, 1993 to October 26, 1993 (Kim, 1994) from the area Multi-Listing Services (MLS). Since Green Valley is a small community, only 20 properties were sold during this 4-month period, according to Multi-Listing Services. Of course, this small sample could have been increased by extending the time period for real estate transactions, but only at increased risk of violating the assumption that the real estate market is in equilibrium during that period.

Besides the selling price, other data obtained from MLS included the following: living room size, number of bathrooms, number of bedrooms, age of house, time on market, financing arrangements, listing price, type of air conditioning, type of dining room, guest room, and capacity of garage. Data on income of those who purchased houses were not available. Because of the small sample size (20) and collinearity among some of the variables, some variables were eliminated; for example, square footage of living area is highly correlated with number of bedrooms, number of bathrooms, and capacity of garage. The following variables were retained for the hedonic price equation:

P = sales price of house
SQ = square footage of living area of the house
TP = type of payment to purchase the house:
= cash payment $\rightarrow TP = 2.71828$;
= otherwise $\rightarrow TP = 1.0$
Y = year when house was built

The values specified for TP, as with DD, are such that their natural logarithms are 1 and 0.

The Estimated Hedonic Price Equation

The hedonic price model for this study relates selling price, P, of a property to house characteristics SQ, TP, Y, and the proxies for clean air, D (map distance of house from tailings bank), and viewscape, DD (orientation of house):

$$P = f(SQ, TP, Y, D, DD)$$

To permit greater flexibility in the relationship of D to P, an additional variable, X, was created as a nonlinear transformation of D and added to the set of possible explanatory variables, including D:

$$X = 1.05 - (0.9947)^D$$

The selection between D, $\ln(D)$, X, or $\ln(X)$ was based upon statistical analysis. The transformation D to X services the reasonable notion that eventually increasing distance from tailings bank provides little appreciable increase in property value. Thus, X, the transformed proxy for clean air, increases with distance but at a decreasing rate, becoming asymptotic to 1.05, and for $D = 0$, X has as its minimum a value of about 0.05. The parameters of the transformation were estimated by iterative conditional regression of $\ln X = \ln(k - P) = \ln(b)\, D$, where P is the sale price of the house: Given a specified value of K and the data on P and D, constrained regression (intercept = 0) was used to estimate $\ln(b)$. Various values of K were selected, seeking that value of K and the associated estimate of $\ln(b)$ that best fit the data on P, giving $K = 1.049942779$ and $b = 0.9947$.

Various forms of f, including linear, semi-log, and log–log, were estimated in search of that equation that best fits the data in the sense that it had the highest adjusted R^2 and coefficients of all included variables were statistically significant at the 5% level. Estimated linear equations with D or X were distinctly inferior to the log–log models, but estimated linear-log models also fit the data well ($R^2 = 0.929$ for equations with $\ln(D)$ or $\ln(X)$). The t statistics for the coefficients of $\ln(D)$ and $\ln(X)$ in the log–log equations are slightly larger, however, than those for the linear-log equations: 2.52 and 2.33 for coefficients of $\ln X$ and $\ln D$, respectively, for the log–log equations, compared to 2.20 and 2.24 for the linear-log equations. Of the various forms for f that were examined, the one selected for the hedonic price model employs X instead of D and is log–log, i.e., it depicts a linear relationship between the logarithm of price and the logarithms of the explanatory variables:

$$\begin{aligned}\ln(P) = {} & \underset{(-5.760)}{-531.232} + \underset{(5.079)}{0.8239}\ln(SQ) \\ & + \underset{(5.794)}{70.707}\ln(Y) + \underset{(2.516)}{0.2872}\ln(X) \\ & - \underset{(-2.255)}{0.2253}\ln(DD) + \underset{(3.170)}{0.3117}\ln(TP)\end{aligned}$$

$$R^2 = 0.934$$

The numerical values in parentheses beneath the estimated parameters are t-statistics. Given the assumption of independence of the explanatory variables, all estimated coefficients are statistically significant at the 5% level. Generally, the estimated hedonic price equation shows that property values decline with increased dust and with a viewscape that includes the tailings banks.

A second log–log model, one using $\ln(D)$, was estimated to examine the sensitivity of the selected model to using $\ln(X)$ instead of $\ln(D)$. The estimated hedonic model with $\ln(D)$ is very similar in all regards to the selected model except that the coefficient of $\ln(D)$ differs numerically from that of $\ln(X)$ because of the different numerical values generated by the transformation of D to X;

$$\begin{aligned}\ln(P) = {} & -538.402 + \underset{(5.683)}{71.573}\ln(Y) \\ & + \underset{(5.085)}{0.840}\ln(SQ) + \underset{(2.987)}{0.302}\ln(TP)\end{aligned}$$

$$- 0.145 \ln(D) - 0.226 \ln(DD)$$
$$(-2.327) \qquad (2.211)$$

$$R^2 = 0.931$$

Statistically, there is little basis for preference of one log–log equation over the other. Even for *DD* and *D* (or *X*), the statistical properties of the coefficients are similar: *t* values for the coefficients of ln(*DD*) in both equations are nearly identical (2.26 and 2.21), and the *t* value for the coefficient of ln(*X*) in the selected (first) model is only slightly larger than that for ln(*D*) in the second estimated model (2.52 compared to 2.33).

Although statistically the two estimated hedonic models are similar, they differ in their elasticities of *P* with regard to *D*. The distance elasticity (*E*) of price for the second estimated model is constant at 0.145, while for the selected estimated model it is a function of distance *D*, having small values for small *D* but approximating that of the second model for $D = 10$: For $D = 1, 2, 5$, and 10 miles, $E = 0.03, 0.05, 0.10$, and 0.14, respectively.

Subsequent to examining the economics implied by the selected hedonic model, in the following section, the selected hedonic property model is used to derive an inverse demand function for clean air and viewscape and to value consumer loss attributed to mining and milling.

Discussion About the Economics of the Hedonic Equation

Based on economic theory, signs of the coefficients are consistent with *a priori* expectations. For example, theory dictates that price of the property increases with square footage of living area and that newer homes command a higher price than older ones. Both of these expectations are realized in the estimated equation. Since *Y* is the year of construction, the newer homes are represented by larger values of *Y*; consequently, the logarithm of *Y* should have a positive coefficient. Everything else being equal, properties that are farther from the tailings banks are bothered less by dust; consequently, they should command higher prices than those near the banks. As *X* increases with distance *D*, albeit at a decreasing rate, the coefficient of the logarithm of *X* should be positive, as it is in the above equation. Everything else being equal, properties whose backyard face the tailings banks should command a lower price than those facing away from the banks. In southern Arizona, a significant amount of year-round domestic activity takes place out of doors. Since the logarithm of *DD* for those properties facing the banks is 1, and 0 for those facing away, the coefficient of the logarithm of *DD* should have a negative sign, as it does in the estimated equation. Finally, type of payment, *TP*, may reflect a mix of age and wealth. Older, retirement-age buyers may have trouble getting financing, so by necessity a greater proportion of purchases may be by cash payment. On the other hand, those property buyers able to pay cash probably have greater wealth than those that do finance, at least on average. Since the logarithm of *TP* is 1 for cash payment and 0 for financed purchase, it should have a positive sign, everything else being equal. This expectation also is realized in the estimated equation.

Marginal Implicit Price Functions for Air Quality and View

The marginal implicit price function for air quality is the partial derivative of *P* with respect to *D*:

$$\text{mip}(D) = 0.0015262e^{-531.231} [1.10578 - (0.928)^{D}]^{-0.7278} [Y^{70.71}SQ^{0.8239}TP^{0.3117}DD^{-0.2253}]$$

And, the marginal implicit price function for view is the partial derivative of *P* with respect to *DD*:

$$\text{mip}(DD) = -0.2253e^{-531.231} [1.10578 - (0.928)^{D}]^{0.2872} [DD^{-1.2253}Y^{70.71}SQ^{0.8239}TP^{0.3117}]$$

These marginal implicit price functions are downward sloping with regard to the levels of environmental amenities.

The Inverse Demand Functions for Air Quality and View

The computation of consumer surplus for an amenity requires the inverse demand function for that amenity. By invoking the assumption of homogenous income and preferences, the marginal implicit price functions will be used as inverse demand functions in a later section to compute consumer surplus (deficit).

A WILLINGNESS TO PAY EQUATION

Approach in General

This section describes the estimation of a willingness to pay (wtp) equation, meaning the willingness to pay for environmental amenities. The data that support the estimation of this equation were obtained by an open-ended contingent valuation survey. Basically, each individual of a sample of Green Valley residents was asked to respond to questions designed to elicit his/her willingness to pay for environmental amenities, which in this study are clean air and a natural viewscape (Kim, 1994). Contingent valuation has been used since the 1960s to value a variety of nonmarket, public goods such as air quality, drinking water, national parks, etc. (Davis, 1963; Hammack and Brown, 1974; Randall and others, 1974; Randall and Brookshire, 1978; Randall, 1992; Brookshire and Coursey, 1987; Cummings and others, 1986; Bohm, 1972). Some economists prefer contingent valuation on the grounds that it requires fewer assumptions than the hedonic price approach and can, when properly designed, provide a total valuation (Randall, 1992) which includes existence and option values as well as use value. On the other hand, contingent valuation is criticized by some because it is subjective, employs hypothetical questions, and presents opportunity for either the respondent or the elicitor (questioner) to introduce biases (Kim, 1994; Bishop and others, 1983; Diamond and Hausman, 1993).

Kinds of Environmental Values

The value to an individual of simply *knowing* about an environmental amenity, such as a remote wilderness in Alaska, even though that individual may have no intentions of every going to Alaska, is defined as existence value. Option value is that value in excess of existence value that is assigned to the *possibility* (option) of going to Alaska to experience the wilderness (Randall, 1992).

Values of environmental amenities estimated in this study are *use* values, for consumer losses are based upon revealed preferences of property owners for environmental amenities. As the property owners currently reside in Green Valley, they are current users of environmental amenities. For them, existence and option values have no relevance, as they have exercised their options.

Possible Biases

The objective of the contingent valuation method is to elicit valuations which are close to those that would be revealed by an actual market (Pearce and Turner, 1990). Among the biases that can occur in the valuation of an environmental asset by contingent valuation methods are strategic bias, hypothetical bias, design bias, and operational bias (Davis and Turner, 1990).

Strategic bias occurs when a respondent thinks that the results of the survey might affect his/her welfare and by not telling the truth, he/she will secure a desired benefit. For example, if property owners believe that their stated willingness to pay for a hypothetical property farther from the mine could diminish their own real estate values, that belief could cause them to consistently understate valuations. To avoid strategic bias in the Green Valley contingent valuation survey, each respondent was assured by the interviewer that the results of the questionnaire would not be used for real estate valuation or for pricing policies, but for academic research.

Hypothetical bias occurs when responses are not conditioned on, or constrained by, losses that would be imposed by real markets. As the contingent valuation approach poses hypothetical circumstances, there are no actual consequences to a respondent's answers. Although respondents in the Green Valley survey may have been uncertain about elicited values, there is no *a priori* evidence that this uncertainty imparted a bias to value estimates.

Starting point bias occurs when maximum willingness to pay is influenced by the initial (starting point) value (price) provided by the elicitor. Starting point bias was not a concern in the Green Valley survey, because an open-ended survey was used, meaning that the respondent was not provided with a starting point. Instead, the respondent was asked to specify directly that price which he/she would be willing to pay.

Operational bias may occur when the operations employed to arrive at a price differ from those of the actual market, or when the operations involve conditions about which the respondent has little or no prior experience. Although Green Valley residents may not have been fully informed about how dust in the air varies with distance from the mine or how property values vary with dusty air, there is no indication that lack of knowledge imparted a bias to value estimates.

The Survey

In this study, willingness to pay is postulated to be a function of the same property and environmental characteristics used in the hedonic price equation, plus income. Data to support the estimation of the willingness to pay equation were obtained by direct personal interview using a five-page questionnaire plus a cover letter and map. The survey was conducted during April 30–May 10, 1994 on a randomly selected sample of 43 single-family house and townhouse residents of Green Valley, of which 40 respondents completed all questions.

Prior to posing willingness-to-pay questions, the respondents were asked for background information, such as their age, annual income, and characteristics of their property (house and lot). Property information included the year of purchase, the year the house was built, the size of the house, and its location and orientation. Then, respondents were asked to specify what they would be willing to pay for a property identical to their current property except in a specific location and with environmental amenities other than those that it currently possessed. Specifically, the willingness-to-pay questions posed are the following:

Suppose that your income were to increase by 25% and you are able to move to a house like the one that you now live in except that the house is farther away (or nearer to) the mine.

(a) Please indicate in the table how much you would be willing to pay for the house at different locations within Green Valley when the house (the front door) faces the mine.

(b) The same conditions as part (a) except that the house (front door) faces away from the mine. Please indicate willingness to pay, as you did in part (a).

The authors acknowledge that "best practice" would have asked for the *maximum* willingness to pay.

Care was taken in designing the questionnaire to ease the burden on the respondents. Location of property was described by five different ranges of distance from the copper mine in increments of 0.8 miles, and the map provided each respondent depicted these five distance zones. Each respondent answered ten hypothetical questions about his or her willingness to pay: combinations of five hypothetical locations and two orientations.

The Conceptual Model

Letting P be willingness to pay, the conceptual model of this study is that P is a function of size of living area, SQ, age of property, represented by Y, the year in which the house was built, dollars of annual income, I, distance from mine in miles, D, and orientation of house DD:

$$P = g(SQ, Y, I, D, DD)$$

where $DD = 2.71828$ when backyard faces tailings bank, and $DD = 1$, otherwise.

Estimated Willingness to Pay Equation

The regression model estimated as the willingness to pay equation is the following:

$$\begin{aligned} \ln(P) = &-199.741 + 0.11468 \ln(D) \\ &(-6.463) \qquad (6.330) \\ &- 0.0423 \ln(DD) + 0.21525 \ln(I) \\ &(-1.533) \qquad (9.183) \\ &- 0.664 \ln(SQ) + 26.854 \ln(Y) \\ &(11.895) \qquad (6.573) \end{aligned}$$

$$R^2 = 0.615$$

$$F = 117.95$$

Given the assumption that the explanatory variables are independent, all estimated parameters are statistically significant at the 5% level.

This equation differs from the hedonic price equation in that it contains income, I, and $\ln(D)$ instead of $\ln(X)$, where X is the nonlinear transform of D, as explained above. As indicated by its t-statistic, income is a very important factor in the willingness to pay equation. As income increases, so does the willingness to pay. The use of $\ln(D)$ instead of $\ln(X)$ is strictly a statistical result: it proved to have more explanatory power than $\ln(X)$ or X in the willingness to pay equation. The signs of the remaining coefficients of variables, other than I, conform with *a priori* expectations based upon economic theory—as explained above for the hedonic price equation.

The Marginal Willingness to Pay for Air Quality and View

The inverse demand function for air quality is the marginal willingness to pay (mwtp) function, which is the partial derivative of the wtp equation with respect to D:

$$\text{mwtp}(D) = 0.11468e^{-199.741}[D^{-0.88532} DD^{-0.0423}I^{0.21525}SQ^{0.6644} Y^{26.854}]$$

And, the marginal willingness to pay for better scenic view is the partial derivative of the willingness to pay equation with respect to orientation, DD:

$$\text{mwtp}(DD) = -0.0423e^{-199.741}[D^{0.11468} DD^{-1.0423}I^{0.21525}SQ^{0.6644} Y^{26.354}]$$

CONSUMER SURPLUS

Perspective

A previous section established the concept that the cost to Green Valley of degradation of air quality and viewscape is the lost consumer surplus. The computation of this consumer surplus requires inverse demand functions for the amenities. The estimation of these demand functions has been described in the foregoing sections. However, the use of these demand functions to compute consumer surplus for the Green Valley community requires that the community be described in terms of the variables of the demand functions. For example, how many properties are 1, 2, . . . , 5 miles from the tailings banks?

Approach in this Study

This study applies the inverse demand functions to the Green Valley community by first computing a weighted average consumer surplus for the community, CSbar, and then multiplying this weighted average by the relevant number of properties. This procedure is performed twice, first for the hedonic approach, using the marginal implicit price function, and again for the contingent valuation approach, using the marginal willingness to pay function.

Ideally, the weighted average consumer surplus would be based upon data for each Green Valley household. As such data were not available for this study, the population of households was represented by the random sample of households used for the contingent valuation survey (Kim, 1994). Let $r(SQ, Y, TP, D, DD)$ describe the joint relative frequency for SQ, Y, TP, D, and DD in the random sample. These relative frequencies were used to weight the marginal implicit prices for environmental amenities, giving CSbar. Prior to constructing the joint relative frequencies, a correlation analysis was performed on the survey data, which revealed that all correlations were very weak except those of income, I, with SQ, Y. Since I is not a variable in the mip equation, the joint relative frequencies were computed as the product of the marginal relative frequencies. Conceptually,

$$r(SQ, Y, TP, D, DD) = r(SQ) \times r(Y) \times r(TP) \times r(D) \times r(DD)$$

The joint relative frequencies for the mwtp equation were computed so as to take into consideration the correlation (dependency) of I with SQ and Y. First, the joint relative frequencies $r(SQ, I)$ and $r(Y, I)$ were computed. Then the conditional relative frequencies for SQ and for Y, given I were computed:

$$r(SQ; I) = r(SQ, I)/r(I)$$

$$r(Y; I) = r(Y, I)/r(I)$$

Finally, the joint relative frequencies, $r(SQ, Y, TP, D, DD, I)$ were computed using the conditional and marginal relative frequencies:

$$r(SQ, Y, TP, D, DD, I) = r(SQ; I) \times r(Y; I) \times r(I) \times r(D) \times r(DD)$$

Reference Levels of Amenities

Computation of consumer deficit due to the degradation of an environmental amenity requires a specification of two reference levels, the natural level and the degraded level. In this study, the natural level for view is taken to be $DD = 1$ ($\ln(DD) = 0$), which implies that the backyard of the property does not face the tailings banks; accordingly, the degraded level is $DD = 2.71828$ ($\ln(DD) = 1$) for the backyard facing the tailings banks.

The natural level for air quality is taken to be $D = 5$ miles for the mwtp approach, or equivalently $D = 50$ cm of map distance for the mip approach. The logic here is that due to the rate of particle deposition over distance, properties that are 5 miles or more away from the mine and tailings banks are affected very little by dust.

Estimated Weighted Average Consumer Surplus

Air Quality

Hedonic Approach. For convenience, the calculation of CSbar by the hedonic approach is described by the following equation using calculus notation. Note, however, actual computation of CSbar was performed using the numerical values of the computed relative frequencies and the computed values of the mip equation. Conceptually:

$$\text{CSbar} = \int_Y \int_{SQ} \int_{TP} \int_{DD} \text{mip}(Y, SQ, TP, DD; D = 50)\; r(Y, SQ, TP, DD)\, dt\, dSQ\, dTP\, dDD - \int_Y \int_{SQ} \int_{TP} \int_{DD} \int_D \text{mip}(Y, SQ, TP, DO, D)\; r(Y, SQ, TP, DO, D) dY\, dSQ\, dTP\, dDD\, dD$$

CSbar = $18,058.73, or approximately $18,000

Contingent Valuation Approach. Similarly, in concept, the CSbar by the contingent valuation approach was estimated as follows:

$$\text{CSbar} = \int_Y \int_{SQ} \int_I \int_{DD} \text{mwtp}(Y, SQ, I, DD; D = 5)\; r(Y, SQ, I, DD) dy\, dSQ\, dI\, dDD - \int_Y \int_{SQ} \int_I \int_{DD} \int_D \text{mwtp}(Y, SQ, I, DD, D)\; r(Y, SQ, I, DD, D)\, dY\, dSQ\, dI\, dDD\, dD$$

Csbar = $7,914.37, or approximately $8000

Thus, the weighted average consumer deficit due to the mine and tailings bank dust as estimated by the hedonic approach is approximately twice that estimated by contingent valuation.

Viewscape

The negative consumer surplus due to the loss of natural view was estimated in a way that is similar to that described for air quality, except that the variable *DD* in the mip and mwtp equations was fixed at *DD* = 1. Accordingly, the weighted average consumer deficit by the two methods was:

Hedonic Approach. CSbar = $7,747.35, or approximately $7700.

Contingent Valuation Approach. CSbar = $2,193.26, or approximately $2200.

The loss of consumer surplus estimated by the hedonic approach to be due to the visibility of the mine dumps and tailings banks is over 3 times that estimated by contingent valuation willingness to pay.

Cost of Dust Greater than Cost of Degraded View

While the foregoing reveals that the two methods give quite different results, both methods show that the cost to Green Valley of dust-polluted air far exceeds that due to degradation of view due to the mine dumps and tailings banks:

Dust pollution:	$8000–$18,000
View degradation:	$2200–$7700

Discussion on Differences in Results of Surveys

Other studies have found significant differences in valuations by indirect (hedonic or travel cost) methods and contingent valuations. While such differences are common, explanations for the differences vary considerably. The indirect approach, e.g., hedonic, has been criticized as leading to overestimation of consumer surplus because of necessary strong assumptions, such as market equilibrium (Rosen, 1975). Moreover, direct use of the marginal implicit price equation to estimate consumer surplus requires the further assumption of homogeneity in income and preference. Kanemoto's (1988) investigation suggests that hedonic estimates are an upper bound estimate.

Contingent valuation, on the other hand, has been criticized because of the hypothetical nature of the questions and the fact that actual behavior is not observed (Cummings and others, 1986; Mitchell and Carson, 1989; Diamond and Hausman, 1993). Bishop and others (1983) found that when compared to travel-cost results (another indirect method), contingent valuation willingness to pay appeared to underestimate values. Brookshire and others (1985) found that average rent differential equals or exceeds the average marginal willingness to pay, based upon contingent valuation survey.

A Resolution of Consumer Surplus Estimates for Green Valley

Given the results of other investigations and comparative studies, a reasonable conclusion would be that the actual consumer surplus lies somewhere between the estimates by the hedonic and contingent willingness to pay estimates. In support of that conclusion, it was found during the survey that according to several respondents, real estate agents in Green Valley ask approximately $5000 more for a house with a good view (Kim, 1994).

This value is very close to the average of the estimates by the hedonic and contingent valuation approaches, $4450. Given the above general conclusion and this specific reference, perhaps it is reasonable to assume that the loss of consumer surplus due to dust pollution approximately $13,000, the average of estimates by the hedonic and contingent valuation approaches.

Assuming that the impacts of air quality and viewscape are independent, an assumption that is supported by the lack of significant correlation of *D* with *DD* in the survey data, the average combined consumer deficit from current environmental conditions is estimated to be $18,000.

COST TO THE GREEN VALLEY COMMUNITY

Perspective

Estimation of cost to Green Valley of the degradation of air quality and viewscape requires an estimate of the number of properties that are to be multiplied by the weighted average consumer deficit. Just what that number should be in the sense of giving the best estimate of social cost is somewhat uncertain. Should it include all housing units, just single family units, or only detached single family units? Although loss of environmental amenities affects individuals of all housing units, the effects may not be equal.

Another complicating issue is that the data employed for the estimation of the mwtp and mip functions were for detached single family units; consequently, the estimates of CSbar are strictly relevant only for detached single family units. Clearly, while multiplying CSbar by just the number of detached single family units is consistent, it must be a lower limit, for it ignores the impacts on all other housing units. On the other hand, multiplying CSbar by the total number of housing units will provide an overestimate, because nondetached units and multiple family units probably are affected less by viewscape than are the single family units. The actual social cost to Green Valley probably lies between the consumer values for these two extreme cases.

Preliminary Estimates

Initial Bounds

COLE (1994) shows a total of 9394 housing units during the 1993 year. Of these, 7514 were single-family units, including town houses and condominiums. Using the ratio of detached single-family units to total single-family units (0.49) obtained from Census (1990) data, the 7514 single-family units is estimated to include 3682 detached family units. Multiplication of the average total consumers deficit of $18,000 by 3682 and 9394 provides limiting values for the impact on Green Valley of environmental degradation due to copper mining:

$$\$66 \text{ million} < \text{Total Social Cost} < \$169 \text{ million}$$

Conceptually, these numerical estimates represent limiting values of the total present value of present and future benefits foregone by the Green Valley community due to the degradation of viewscape and air quality.

Restricted Bounds

The effects of air quality and viewscape degradation on multiple family units cannot credibly be estimated in this study because they were excluded from the data used to estimate the wtp and hedonic equations. Consequently, the 1880 multi-family units are purposefully excluded in the computation of the lower limit of a restricted bounds.

For a lower limit on a restricted bounds, assume that air quality degradation affects residents in all single- (detached and nondetached) family units equally. Multiplying $13,000 by the 7514 single family housing units gives approximately $97,682,000 as the negative consumer surplus of single family units due to degradation of air quality. Further, assume that degradation of viewscape affects primarily the detached single family units. Multiplying $5000 by 3682 gives approximately $18,000,000 as the negative consumer surplus of detached single family units due to degradation of viewscape by copper mining. Adding these two estimates together and rounding gives $116,000,000 as a conservative estimate of the combined consumer deficit for the Green Valley community due to degradation of air quality and viewscape by copper mining.

The actual consumer deficit is probably greater than $116 million because it ignores the negative consumer surplus of air quality for the multiple family units and the negative consumer surplus for viewscape for the detached single family units and multiple family units. Thus, the actual consumer deficit for air quality and viewscape for the Green Valley community probably lies within the interval:

$116,000,000–$169,000,000

CONCLUDING COMMENTS

A motorist passing by Green Valley is very much aware of the mine dumps and high tailings banks created by the Cyprus Sierrita and Pima mines. In spite of their visibility, the impact of the mine dumps and tailings banks on Green Valley is much less than the dust from the activities associated with the copper mining and milling. Estimates made in this study show that consumer surplus lost due to dust pollution of air is more than twice as large as that due to degradation of viewscape by mine dumps and tailings banks.

This study produced hedonic estimates of average consumer surplus lost by air quality and viewscape degradation that are between 2 and 3 times those made by willingness to pay contingent valuation. These differences may reflect some intangible influences: According to several respondents, estimates by the two approaches may have been closer if the contingent valuation survey had been conducted earlier, before the Green Valley Community Coordinating Council complained about dust from the mine complex (Kim, 1994). Since these complaints, the mining companies have made significant improvements in dust control. Moreover, the companies occasionally provide Green Valley residents with mine tours to provide visual information about the mining, milling, and dust control.

The different estimates of this study were resolved using an independent valuation of view by real estate agents, who suggest that the value of a good view in Green Valley is about $5000, which is very close to the mean of the hedonic and contingent valuation estimates. Assuming that the mean of the estimates for clean air is also appropriate, the average consumer surplus lost by dusty air is estimated to be $13,000. Thus, average consumer deficit due to degradation of both air quality and view is estimated to be $18,000. The number of housing units to which these estimates apply is uncertain; consequently, a preliminary estimate of the total consumer deficit for the Green Valley community due to air quality and viewscape degradation is estimated to be between $116 million and $169 million.

Although these costs (consumer surpluses lost) are large, it cannot be assumed that they exceed benefits to Green Valley and surrounding communities from copper mining. Besides direct and indirect employment benefits and tax revenues, benefits must include the building of a local high school, a recreation park, and some infrastructure. Comparison of the benefits of copper mining with environmental impacts is left to further research.

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