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Cost-Responsiveness of Conservation Practice Adoption: A Revealed Preference Approach

Erik Lichtenberg

While there is current interest in reorienting agricultural policy toward environmental and resource conservation goals, relatively little is known about the influence of cost on conservation adoption decisions or about how farmers combine multiple practices into an overall conservation package. Using farmer survey data combined with information on standard unit installation costs, this study estimates latent demand models for seven on-farm conservation practices. All of the practices exhibit downward-sloping demand. Topographical variations in adoption conform to expectations. The estimation results suggest that cost sharing should have substantial effects on the adoption of several practices, and indicate strong complementarity among others.

Key words: conservation technology adoption, cost-sharing, Environmental Quality Incentives Program (EQIP), green payments, soil conservation, water quality protection

Introduction

The Farm Security and Rural Investment Act of 2002 authorized a substantial expansion of federal cost sharing—increasing funding for the Environmental Quality Incentives Program (EQIP) from $200 million annually to $1.3 billion annually by 2007, and introducing a new Conservation Security Program that expands eligibility for cost sharing and other subsidies to a wider variety of farming practices and farm operations. One notable feature of the 2002 Farm Security and Rural Investment Act is a heightened emphasis on subsidies to promote conservation on working farmland. This shift toward funding conservation on working farmland has been undertaken in the absence of much information about how farmers respond to such subsidies.

There is a sizable empirical literature on farmers' use of soil conservation practices (Ervin and Ervin, 1982; Rahm and Huffman, 1984; Saliba and Bromley, 1986; Gould, Saupe, and Klemme, 1989; Norris and Batie, 1987; Lynne, Shonkwiler, and Rola, 1988; Featherstone and Goodwin, 1993; Feather and Amacher, 1994; Weaver, 1996; Lohr and Park, 1995; Cooper and Keim, 1996; Cooper, 1997, 2003; Soule, Tegene, and Wiebe, 2000; Wu and Babcock, 1998; Khanna, 2001). Most are behavioral studies that examine the influence of factors such as farmer characteristics (human capital, attitudes toward risk, preferences for environmental quality), natural features of the farm which influence erodability (e.g., topography), and attributes of the farm operation (tenure status

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farm size, off-farm labor), and do not consider the influence of prices or costs. As a result, these studies provide little guidance on how to set cost-sharing rates to achieve desired adoption of soil-conserving, runoff-reducing practices.

A few recent studies have attempted to estimate cost responsiveness of farmers' adoption of soil-conserving and/or runoff-reducing practices using stated preference data. Studies by Lohr and Park (1995); Cooper and Keim (1996); and Cooper (2003) used survey data to estimate growers' willingness to accept incentive payments to adopt farm management practices believed to improve environmental quality. Each of these studies examines farmers' stated willingness to accept a government subsidy of a given size and how much acreage they would plan to enroll given a positive participation decision. All three found that participation increased as the size of the incentive payment increased, indicating standard downward-sloping demand. By design, none of the studies considered the possibility that farmers might use any of these practices without receiving a subsidy payment. Cooper and Keim (1996) and Cooper (2003) explicitly dropped from their sample all farmers currently using each practice from the adoption model for that practice. Subsequently, Cooper (1997, 2003) attempted to incorporate the unsubsidized use of these practices by retaining in the sample data on farmers currently using each practice from the survey data developed by Cooper and Keim. Those farmers currently using each practice were assumed to state they would use that practice with an incentive payment of zero (an assumption which likely understates cost responsiveness, since those finding it profitable to use a given practice would be willing to pay a positive amount for the right to do so).

The aforementioned studies find a significant degree of cost responsiveness, suggesting that subsidies for conservation on working farmland are likely to result in substantial increases in the use of such practices. However, stated preferences are not always good predictors of actual behavior, making it desirable to validate the results of these studies using revealed preference data. This paper conducts such a revealed preference study using data from a survey of Maryland farmers. An unusual feature of the Maryland situation is a state cost-sharing program offering fixed reimbursement rates that can be interpreted as unit costs of installing these technologies. These unit costs vary across counties because of differences in the availability of machinery, topography, soil types, and wages for off-farm labor. They vary across individual farmers because farmers receiving cost sharing face a lower, subsidized unit cost. The availability of these data permits the use of a revealed preference approach to estimate actual, rather than stated, demand from observed adoption of environmentally benign farming practices.

These data also permit the use of a dual approach to study patterns of complementarity and substitution between conservation technologies in addition to the cost responsiveness of adoption. Adoption of multiple soil and water conservation practices is common in Maryland because topography and soils frequently vary substantially within farms and because farmers usually diversify crop and livestock production. This variability tends to lead farmers to use many different combinations of practices. For example, the farmers in this sample used 75 of the 128 possible combinations of the seven practices investigated here. Many were quite idiosyncratic (only about seven combinations were used by 10% or more). While several other studies have investigated joint adoption of multiple conservation practices (Dorfman, 1996; Khanna, 2001; Wu and Babcock, 1998; Amacher and Feather, 1997), computational difficulties limited them to consideration of two or three practices. Simulated maximum-likelihood methods allow estimation of joint adoption of larger numbers of conservation practices; for example, Cooper (2003) estimates a multinomial probit model of the adoption of five such practices. However, these methods are econometrically complicated. Moreover, they may not work well when adoption frequencies are low because integrals calculated using Monte Carlo simulation may not converge.

The dual revealed preference approach utilized here offers an attractive alternative due to its computational simplicity. The applicability of a dual approach is often limited by data availability, however, since most cost-sharing programs lack fixed reimbursement rates that vary cross-sectionally (or intertemporally) enough to serve as proxies for unit installation costs. The dual approach also may not be usable in stated preference studies like that of Cooper (2003) where bid offers are collinear by design.

A Latent Demand Model of Conservation Practice Adoption

Our data, like those of most adoption studies, contain discrete indicators of whether or not farmers used given soil-conserving, runoff-reducing practices. In principle, though, farmers' decisions about the use of such practices are continuous rather than discrete, even when only discrete indicators are observed. In other words, farmers typically determine how much acreage to cultivate using conservation tillage, how many acres to plant to cover crops or filter strips, how many linear feet of terraces or diversions to install, etc., even though survey data often contain information only on whether or not a farmer uses each practice. Thus, in this study, the underlying adoption decision is modeled conceptually in terms of a continuous derived demand giving the extent to which each practice is used as a function of its unit cost, the unit costs of related practices, and similar factors. The continuous derived demand is then used to specify a latent demand model to be applied to discrete adoption data.

Assume land and credit markets function well enough that farmers are free to choose to install and maintain conservation practices in order to maximize the value of their land. Let $\mathbf{y}_t = (y_{1t}, \ldots, y_{Jt})$ be a vector of outputs produced at time t; $\mathbf{x}_t = (x_{1t}, \ldots, x_{Mt})$ be a vector of inputs used at time t to produce output (and to maintain conservation practices and other capital investments as necessary); $\mathbf{z} = (z_1, \ldots, z_N)$ be a vector of conservation practices installed; $\mathbf{s}_t$ denote a vector of land productivity factors at time t that includes soil stock, land quality, and similar items; and $\mathbf{k} = (k_1, \ldots, k_R)$ be a vector of fixed factors, including human capital, non-soil natural capital, and produced capital. The technology available to each firm is expressed by the set $\Omega = \{(\mathbf{y}_t, \mathbf{x}_t, \mathbf{s}_t, \mathbf{z}, \mathbf{k})\colon (\mathbf{x}_t, \mathbf{s}_t, \mathbf{z}, \mathbf{k})$ can produce $\mathbf{y}_t\}$. Let $\mathbf{p}_t$, $\mathbf{w}_t$, and $\mathbf{c}$ be the respective price vectors corresponding to $\mathbf{y}_t$, $\mathbf{x}_t$, and $\mathbf{z}$, and let r_t be the interest rate at time t. Then

$$(1)\qquad V(\mathbf{p}, \mathbf{w}, s_0, \mathbf{k}, T, r, \mathbf{z}) = \max_{\mathbf{y}_t, \mathbf{x}_t} \int_0^T \left\{ \sum_j p_{jt} y_{jt} - \sum_m w_{mt} x_{mt} \right\} e^{-r_t t}\, dt - \sum_n c_n z_n + R(s_T, \mathbf{k}, \mathbf{z}) e^{-r_T T}$$

$$\text{s.t.: } (\mathbf{y}_t, \mathbf{x}_t, \mathbf{s}_t, \mathbf{z}, \mathbf{k}) \in \Omega,$$

$$\dot{\mathbf{s}}_t = g(\mathbf{x}_t, \mathbf{k}, \mathbf{z})$$

denotes the value of the farm's land, which equals the present value of the rent generated over the farmer's operating horizon T plus the value of the land at the end of the operating horizon given the terminal level of land productivity, the farm's fixed factors, and the conservation practices installed, $R(s_T, \mathbf{k}, \mathbf{z})$.

Demand for installing the N conservation practices is defined implicitly by the first-order conditions:

$$\text{(2)} \qquad \frac{\partial V(\mathbf{p}, \mathbf{w}, s_0, \mathbf{k}, r, T, \mathbf{z})}{\partial z_n} - c_n + e^{-r_T T} \frac{\partial R(s_T, \mathbf{k}, \mathbf{z})}{\partial z_n} = 0, \quad n = 1, \ldots, N.$$

If these installation demands are linear in parameters, they can be written as:

$$\text{(3)} \qquad z_n = \sum_i \beta_{ni} \mathbf{W}_i + u_n, \quad n = 1, \ldots, N,$$

where β_n is a vector of parameters and $\mathbf{W}$ is a vector of independent variables. Assume that u_n has a mean of zero and a variance σ_n^2, and that the data contain only indicators I_n, taking on a value of one if z_n is positive ($I_n = 1$ if $z_n > 0$) and zero otherwise ($I_n = 0$ if $z_n \leq 0$). In this case, the probability that a farmer reports using practice n is

$$\Pr\{I_n = 1\} = \Pr\{z_n > 0\} = \Pr\left\{ \sum_i \frac{\beta_{ni}}{\sigma_n} \mathbf{W}_i > 0 \right\}.$$

If u_n is distributed normally, the parameters of the demand function can thus be estimated up to the normalizing constant σ_n using probit.

Interrelatedness in adoption is characterized by jointness in demand, which can be investigated simply by examining the cross-price coefficients of conservation practices. A negative cross-price coefficient indicates two technologies are complements, a positive cross-price coefficient indicates substitutes, and a cross-price coefficient not significantly different from zero suggests that adoption decisions for two technologies are unrelated.

Data

The empirical study combines data from a telephone survey of 592 Maryland farmers conducted in 1995, with county-level price data obtained from two sources: the *1992 Census of Agriculture* (U.S. Department of Commerce, 1994) and the Maryland Agricultural Cost-Share Program (1995). As noted above, the use of multiple soil-conserving, runoff-reducing practices is widespread among Maryland farmers. For example, the data from the telephone survey indicate that in 1995, three-quarters of Maryland farmers used one or more of these practices, while the median number of practices used per farm was four. Farmers use multiple practices in part because variations in topography and soils, both across and within fields on a farm, create problems which are best addressed by different technologies.[1] Diversification of output also motivates the use of multiple practices. Most Maryland farmers raise several different crops, and many produce both crops and livestock.

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[1] For example, critical area seeding reduces erosion, while winter cover crops may be used to control soil nitrogen during the off-season.

The sample for the telephone survey was drawn from the Maryland Agricultural Statistics Service (MASS) master list. Because of the large percentage of small, noncommercial farms in Maryland, the sample was stratified according to annual sales, with large operations oversampled and small ones undersampled. The sample respondents were stratified as follows: (*a*) between 2% and 5% of Maryland farm operators with annual sales under $100,000; (*b*) between 5% and 6% of Maryland farm operators with annual sales between $100,000 and $250,000; (*c*) 7% of Maryland farm operators with annual sales between $250,000 and $500,000; (*d*) 13% of Maryland farm operators with annual sales between $500,000 and $1,000,000; and (*e*) 23% of Maryland farm operators with annual sales of $1,000,000 or greater. MASS did not provide expansion factors; instead, weights were constructed from annual sales reported as categorical variables by respondents to correct for the stratification. The weight given to each stratum equaled the share of that stratum in the total Maryland farm population, as given in the *1992 Census of Agriculture*, divided by the share of the stratum in the sample. In cases where annual sales were not reported, they were predicted from known characteristics of the farm.

The survey contained information on farm operation, farm finance, farm topography, human capital of the farm operator, and use of 12 different soil and water conservation practices. Farm operation information included total land operated, owned, rented in, rented out; acreage of corn, soybean, small grains, hay, pasture, tobacco, vegetables, and other crops; and numbers of milk cows, other cattle, hogs, sheep, poultry, horses, and other livestock. Farm financial information included annual sales (recorded as a categorical variable), the percentages of sales derived from crops and livestock, and the percentage of income derived from farming. Topographical information included the percentages of land operated with slopes of 2%–8% and with slopes greater than 8%. Human capital indicators included age, education, and years spent managing a farm.

Farmers were asked whether they used each of 12 different types of conservation technologies: critical area seeding, filter strips, contour farming, stripcropping, cover crops, minimum or no tillage, grade stabilization, grass- or rock-lined waterways, terraces, diversions, ponds, and sediment troughs. Table 1 gives brief descriptions of the practices investigated here. Farmers were also asked whether they had ever received cost-sharing funds from the State of Maryland or U.S. Department of Agriculture for each type of conservation technology.

The Maryland Agricultural Cost-Share (MACS) Program reimburses farmers for up to 87.5% of the costs of establishing or installing an approved conservation practice. Participating farmers can submit detailed invoices to obtain reimbursement of actual costs incurred. In most cases, however, farmers submit documentation of the amount of the practice installed (e.g., acres of cover crops or linear feet of terracing), and repayment is calculated using a flat reimbursement rate adopted by the county in which their farm is located. The MACS Program uses these county flat reimbursement rates to estimate total costs of different practices. These flat reimbursement rates vary across counties mainly because of differences in the opportunity costs of labor and construction machinery, both of which are higher in counties closer to major urban centers (Washington, Baltimore) and, to a lesser degree, near ocean resort areas. They also vary because of differences in topography, soil type, and similar factors.

Flat reimbursement rates were available for seven practices (defined in table 1): critical area seeding, contour farming, stripcropping, cover crops, grassed or rock-lined

Table 1. Soil and Water Conservation Practices

Conservation Practice	Description
Critical Area Seeding	Planting grass, legumes, trees, or shrubs in small, isolated areas of excessive erosion in order to provide surface cover to stop raindrop splash and slow water flow.
Contour Farming	Farming sloping land in such a way that preparing land, planting, and cultivating are done on the contours in order to reduce erosion and control water.
Stripcropping	Growing crops in a systematic arrangement of strips or bands on the contour in order to reduce erosion and control water. The crops are arranged so that a strip of grass or close-growing crop is alternated with a strip of clean-tilled crop or fallow, or a strip of grass is alternated with a close-growing crop.
Cover Crops	A crop of close-growing legumes, or small grain grown primarily for seasonal protection and soil improvement in order to control erosion during periods when the major crops do not furnish adequate cover; add organic material to the soil; and improve infiltration, aeration, and tilth. It usually is grown for one year or less, except where there is permanent cover as in orchards.
Grass- or Rock-Lined Waterways	Grading natural drainage ways to form a smooth channel, then planting with grass or lining with rock in order to protect the drainage way from gully erosion and trap sediment running off a field.
Terraces	Breaking a long slope into a series of shorter, level sections in order to slow water runoff and channel it into a stable outlet.
Diversions	Structures built to divert part or all the water from a waterway or a stream into a different watercourse, and irrigation canal or ditch, or a water-spreading system or a channel constructed across the slope with a supporting ridge on the lower side. Used to divert excess water from one area for use or safe disposal in other areas.

waterways, terraces, and diversions. Costs of critical area seeding, contour farming, stripcropping, and cover crops, were expressed in terms of dollars per acre; costs of grassed or rock-lined waterways, terraces, and diversions were expressed in terms of dollars per linear foot. Each flat rate should represent 87.5% of the actual unit cost of its respective conservation practice. Farmers who did not receive cost sharing for a practice were assumed to face a unit cost equal to 1/0.875 times the relevant flat rate. Farmers who did receive cost sharing for a practice were assumed to face a unit cost equal to 0.125/0.875 times the relevant flat rate. Due to an oversight, cost-sharing information about critical area seeding was not included in the survey, so flat rates for critical area seeding were used unadjusted as the unit cost of this practice.

Average prices received per unit of crop produced were included in the empirical models as measures of cross-sectional differences in expected output prices. Differences in local marketing opportunities in Maryland give rise to differences in average prices for farm commodities across counties; on the Eastern Shore, for example, poultry integrators typically pay a premium for corn and soybeans used in poultry feed. Dynamic duality results (see, e.g., Caputo, 1990) suggest that the coefficients of these output prices reflect the expected impact of these conservation practices on future crop productivity. Average crop prices were estimated for each county using data from the

1995 Maryland Agricultural Statistics (Maryland Department of Agriculture) by dividing the value of the crop (revenue received) by the amount of the crop produced. The price of small grains was calculated by dividing the sum of revenues for wheat, barley, rye, and oats by total production of these four crops. Tobacco is produced in only a few counties in Maryland. The price of tobacco in counties with no tobacco acreage was set to zero. The tobacco price variable thus gives the price of tobacco conditional on tobacco being grown. In other words, it is equivalent to an interaction term between the price of tobacco and a dummy variable equal to one if tobacco was grown in the county, and zero otherwise.

Model Specification and Estimation

As in the existing literature, demand for each practice is modeled here as a function of size of operation, the human capital of the farm operator, and topography. In addition, demand for each practice is modeled as a function of crop prices and the unit costs of soil-conserving, runoff-reducing practices.

Age and experience were used as indicators of human capital. It is widely believed that younger farmers are more willing to experiment with new technologies, and hence are more likely to adopt soil-conserving, runoff-reducing technologies. Also, older farmers are presumably closer to the end of their operating horizons, leaving less time to earn returns from new investments. (Although the contrary could occur, since a shorter time horizon could make farmers more willing to sacrifice short-term earnings for the sake of increasing the resale or rental value of their farmland, and thus more likely to invest in soil-conserving, runoff-reducing practices.) One would expect experience to lower the costs and increase the productivity of new practices, making farmers who had managed farms for a longer period more likely to invest in soil-conserving, runoff-reducing practices.

While education (years of schooling) was included in the survey, this item had an extremely high nonresponse rate: Including it in the empirical models resulted in the loss of 215 observations. Thus, education was omitted from the empirical model reported here. However, the results generated from the smaller sample obtained when education was included were virtually the same as those reported below.

Total acreage operated by the farmer was included as an indicator of size of operation. There are several reasons why farmers with larger operations might be expected to be more likely to adopt any given soil-conserving, runoff-reducing practice, including more varied topography, the ability to spread installation and/or equipment costs over a larger acreage, and greater diversification against risk.

Topography was measured as the share of land operated with moderate (2%–8%) and steep (over 8%) slopes. Farmers with larger shares of moderately and steeply sloped land would be expected to be more likely to use contour farming, stripcropping, grass- and rock-lined waterways, and terraces.

Three variables were included as measures of the opportunity cost of the farmer's time: the percentage of family income earned from farming, the presence of a dairy operation, and the presence of a poultry operation. Farmers with a greater dependence on off-farm income and those with dairy or poultry operations are hypothesized to have a greater opportunity cost of time, and thus be less likely to invest in soil-conserving, runoff-reducing practices.

The share of operated acreage rented in was included separately as an indicator of the strength of soil conservation incentives, since renters operating under short-term contracts are widely believed to have an incentive to overexploit soil [but see Allen and Lueck (1992) and Soule, Tegene, and Wiebe (2000) for discussions of soil conservation under different forms of rental contract].

As noted above, crop prices were included to obtain indirect measures of the expected crop productivity impacts of soil-conserving, runoff-reducing practices. Farmers facing higher crop prices should expect to earn more from investments that enhance future productivity (and earn less from investments that impair crop productivity in the short run in order to limit long-run productivity losses due to erosion and other forms of land degradation). Thus, a positive coefficient of a given crop price would be presumed to indicate that the practice enhances the productivity of a given crop. Similarly, a negative coefficient would be expected to indicate reductions in short-run crop productivity made attractive by longer-run protection of land quality.

The dual approach taken here simplifies estimation considerably. Estimation of a primal model of simultaneous adoption [as in Khanna (2001), or Dorfman (1996)] would require evaluation of a sevenfold integral. Alternatively, estimation of a polychotomous choice model [as in Wu and Babcock (1998), or Cooper (2003)] would require evaluation of 128 different possible combinations of these seven practices; the farmers in the sample used 75 of them. Compounding the difficulty of estimation, a substantial majority of those 75 combinations had only one or two users, and only about 10 of these 75 combinations were used by 50 or more of the farmers sampled. The dual model, in contrast, can be estimated using single probit models. Each of the seven latent demand models was estimated separately.[2] Observations were weighted in the manner described above. Thirty-nine observations were omitted due to missing values, leaving a sample size of 545. Table 2 presents (weighted) descriptive statistics of the variables included in the models.

Estimation Results

The models fit the data fairly well, as indicated by McFadden R^2 mainly ranging from 0.12 to 0.32. All seven practices had negative own-price coefficients that were significantly different from zero at a 1% significance level, indicating downward-sloping input demand curves, as expected (table 3).

As noted above, the cross-price coefficients of the demand models provide a means of examining interrelatedness among these technologies without requiring estimation of simultaneous discrete choice models. The signs of the cross-price coefficients which were significantly different from zero at a 5% significance level or better in at least one equation suggest that cover crops and critical area seeding tend to be used as complements for each other, and for grass- and rock-lined waterways and terraces. In three other cases (waterways in the contour farming and diversions models and stripcropping in the terraces model), cross-price coefficients were positive and significantly different from zero at a 10% significance level or better, suggesting (weakly at least) these practices may be substitutes.

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[2] Estimating each probit model separately ignores potential cross-equation correlation due to unobserved farmer-specific factors affecting choices among all seven conservation practices simultaneously. Estimation taking such cross-equation correlation into account would be more efficient than the single-equation approach taken here. However, the separate single-equation estimators are consistent, as are the estimators of the standard errors, because the marginal distributions of single random variables drawn from a multivariate normal distribution are themselves normal.

Table 2. Descriptive Statistics of Maryland Conservation Practice Use Policy

Variable	Mean	Standard Deviation
Conservation Practices (Shares):		
Critical Area Seeding	0.1630	0.3656
Contour Farming	0.1507	0.3541
Stripcropping	0.2316	0.4175
Cover Crops	0.3435	0.4699
Waterways	0.2590	0.4336
Terraces	0.0590	0.2332
Diversions	0.1275	0.3301
Flat Reimbursement Rates for:		
Critical Area Seeding ($/acre)	575.25	247.33
Contour Farming ($/acre)	20.51	4.48
Stripcropping ($/acre)	22.04	3.79
Cover Crops ($/acre)	19.68	10.65
Waterways ($/linear foot)	2.51	0.96
Terraces ($/linear foot)	2.78	0.68
Diversions ($/linear foot)	2.72	1.00
Farm and Operator Characteristics:		
Age (years)	57.79	13.20
Experience (years)	31.23	19.17
Percentage of Family Income Obtained from Farming	40.99	43.62
Total Acres Operated	263.20	460.69
Percentage of Acreage Rented	25.83	36.60
Acres with Moderate Slope	104.36	215.64
Acres with Steep Slope	20.18	75.71
Output Prices:		
Corn ($/bushel)	1.65	0.29
Wheat ($/bushel)	3.00	0.19
Tobacco ($/pound)	0.25	0.55
Soybeans ($/bushel)	4.89	1.07
Hay ($/ton)	30.17	13.20
Dairy Operation (Yes = 1)	0.16	0.37
Poultry Operation (Yes = 1)	0.04	0.20

These estimated demand relationships seem sensible from a topographic perspective. The coefficients of the two topographical variables indicate that contour farming, stripcropping, and grass- and rock-lined waterways are used on both moderate and steep slopes, that terraces are used primarily on steep slopes, that diversions are used primarily on moderate slopes, and that the use of critical area seeding and cover crops is not sensitive to topography. Contour farming, stripcropping, waterways, terraces, and diversions perform similar functions: reducing sediment and nutrient flows on hillsides by controlling water flows (waterways, terraces, diversions, and, to some extent, stripcropping) and/or intercepting sediment (waterways, contour farming, stripcropping). In contrast, critical area seeding and cover crops appear to be used to supplement waterways and terraces as parts of a more comprehensive erosion- and runoff-control program (see table 1).

Table 3. Estimated Parameters of Conservation Practice Demands

Independent Variable	Critical Area Seeding	Contour Farming	Strip-cropping	Cover Crops	Waterways	Terraces	Diversions
Unit Cost of:							
Critical Area Seeding ($/acre)	-0.00138***	0.000128	-0.00051	-0.00072**	-0.00073**	0.000074	-0.00064
	(0.000417)	(0.000447)	(0.000381)	(0.000347)	(0.000368)	(0.000538)	(0.000473)
Contour Farming ($/acre)	0.0399*	-0.1050***	-0.0103	0.00740	0.0134	-0.00167	-0.00191
	(0.0212)	(0.0199)	(0.0178)	(0.0166)	(0.0183)	(0.0251)	(0.0200)
Stripcropping ($/acre)	-0.000913	-0.0202	-0.0661***	-0.0214	-0.0195	0.0720*	-0.0211
	(0.0196)	(0.0206)	(0.0182)	(0.0174)	(0.0187)	(0.0403)	(0.0205)
Cover Crops ($/acre)	-0.00058	-0.00801	0.00515	-0.0245***	-0.0235***	-0.0170	-0.00088
	(0.00841)	(0.00981)	(0.00807)	(0.00730)	(0.00816)	(0.0116)	(0.00921)
Waterways ($/linear foot)	-0.2278**	0.2216*	0.0790	-0.0894	-0.6148***	-0.0436	0.2005*
	(0.0923)	(0.1187)	(0.0891)	(0.0833)	(0.0947)	(0.1338)	(0.1206)
Terraces ($/linear foot)	-0.3324**	-0.1767	0.0200	-0.2420*	-0.1424	-0.9594***	-0.00800
	(0.1475)	(0.1597)	(0.1441)	(0.1387)	(0.1471)	(0.1985)	(0.1757)
Diversions ($/linear foot)	0.1183	-0.1573	-0.0757	0.00480	0.0914	0.00886	-0.8716***
	(0.0997)	(0.1071)	(0.0886)	(0.0863)	(0.0972)	(0.1387)	(0.1095)
Farm and Operator Characteristics:							
Age	-0.0118*	-0.0232***	-0.0139**	0.00407	-0.00906	-0.00553	-0.0105
	(0.00653)	(0.00783)	(0.00631)	(0.00562)	(0.00617)	(0.00950)	(0.00829)
Experience	-0.00203	0.00338	0.00556	-0.00194	-0.00224	-0.00042	0.00308
	(0.00463)	(0.00552)	(0.00437)	(0.00386)	(0.00437)	(0.00671)	(0.00589)
Percentage of Family Income Obtained from Farming	-0.00158	0.000501	0.00497***	0.00255	0.00346*	0.00304	0.00438*
	(0.00200)	(0.00237)	(0.00186)	(0.00172)	(0.00193)	(0.00285)	(0.00240)
Total Acres Operated	0.000310*	-0.00033	-0.00058**	0.000112	0.000118	0.000170	0.000072
	(0.000166)	(0.000258)	(0.000295)	(0.000160)	(0.000172)	(0.000231)	(0.000185)
Percentage of Acreage Rented	0.00225	-0.00531*	-0.000026	0.00277	-0.00129	-0.00472	-0.00283
	(0.00206)	(0.00274)	(0.00197)	(0.00182)	(0.00201)	(0.00343)	(0.00264)
Acres with Moderate Slope	0.000182	0.00238***	0.00155***	0.000056	0.000781*	0.000032	0.000600*
	(0.0003477)	(0.000483)	(0.000443)	(0.000313)	(0.000420)	(0.000439)	(0.000365)
Acres with Steep Slope	0.00149*	0.00410***	0.00393***	0.00103	0.00378***	0.00288***	0.00118
	(0.000863)	(0.00131)	(0.00120)	(0.000852)	(0.00136)	(0.00105)	(0.000884)

(continued . . .)

Table 3. Continued

Independent Variable	Critical Area Seeding	Contour Farming	Strip-cropping	Cover Crops	Waterways	Terraces	Diversions
Output Prices:							
Corn ($/bushel)	-0.00678	0.4832	-0.1832	0.5475*	0.4760	-0.4916	-0.3841
	(0.3897)	(0.5150)	(0.3738)	(0.3306)	(0.3587)	(0.5430)	(0.5274)
Wheat ($/bushel)	2.3124***	-0.6870	-0.8106	-0.4500	0.2099	0.8042	0.1875
	(0.6052)	(0.6666)	(0.5701)	(0.5280)	(0.5956)	(1.0602)	(0.7317)
Tobacco ($/pound)	0.6565***	0.3217	0.5105***	1.0577***	0.9421***	0.3585	0.8073***
	(0.2135)	(0.2182)	(0.1978)	(0.1919)	(0.2015)	(0.3037)	(0.2267)
Soybeans ($/bushel)	-0.1698	-0.1123	0.1216	-0.0303	-0.0530	-0.0987	-0.1037
	(0.1214)	(0.1265)	(0.1045)	(0.0943)	(0.1129)	(0.2303)	(0.1396)
Hay ($/ton)	-0.00243	0.0117	-0.00086	0.0104	-0.00356	0.00743	0.00539
	(0.00701)	(0.00922)	(0.00791)	(0.00657)	(0.00683)	(0.00966)	(0.00794)
Dairy Operation	-0.1078	-0.2357	0.0460	0.1091	0.1330	0.1512	-0.0790
	(0.2191)	(0.2730)	(0.2010)	(0.1926)	(0.2060)	(0.2949)	(0.2660)
Poultry Operation	-0.5410*	-0.8201**	-0.1099	0.0875	-0.0888	0.0457	-0.8169**
	(0.2861)	(0.3824)	(0.2235)	(0.2067)	(0.2270)	(0.3532)	(0.3765)
Constant	-5.3292***	2.4511	3.3566**	1.2355	0.9844	-1.6088	1.9159
	(1.4455)	(1.6600)	(1.3853)	(1.2773)	(1.4650)	(2.6049)	(1.7911)
McFadden's R^2	0.1222	0.3077	0.1567	0.1622	0.2405	0.2348	0.3241
-2 log L	428.997	314.643	500.410	591.434	476.663	187.653	284.480
Percentage of correct predictions	74.9%	84.6%	75.0%	74.7%	79.0%	77.5%	83.2%

Notes: Single, double, and triple asterisks (*) denote statistically different from zero at a 10%, 5%, and 1% significance level, respectively. Standard errors are reported in parentheses.

It was argued earlier that the coefficients of crop prices should be indicative of the impacts of these soil-conserving, runoff-reducing practices on crop productivity. Interestingly, none of these practices seem to have any effect—positive or negative—on corn, soybeans, or hay, while only critical area seeding seems to have a positive effect on wheat productivity. In contrast, five of these seven practices (all but stripcropping and terraces) appear to have significant positive effects on tobacco productivity. It should be recalled that the tobacco price variable used is partly qualitative, since it equals zero in all counties where tobacco is not produced. Tobacco is grown exclusively in Southern Maryland, whose terrain is largely rolling hills and thus subject to erosion. Demand for erosion control is greater in this region than on the relatively flat Eastern Shore, where most of the state's crop acreage is located. Thus, the tobacco price coefficient may be reflecting topographical considerations. The tobacco price coefficient in the cover crop equation may also be due to concerns over tobacco quality, which is highly sensitive to excess nutrients. Cover crops remove residual nutrients during the off-season, giving growers greater control over soil nutrient levels during the tobacco growing season.

Implications for Cost-Sharing Programs

In agriculture, cost sharing of soil and water conservation technologies has been the main policy instrument used to address erosion problems and, more recently, agricultural nonpoint source pollution in the United States. It is offered under federal, state, and some joint federal-state programs, and has been especially prominent in efforts to tackle nutrient pollution problems in the Chesapeake Bay. Both the federal government and the State of Maryland provide cost-sharing funds for Maryland farmers. Federal programs provided an average of about \$1 million annually in cost-sharing funds for Maryland farmers. Overall, the Environmental Protection Agency estimates historic annual spending on cost-sharing agricultural and silvicultural best management practices in the Chesapeake Bay watershed at \$41–\$52 million. About 45% of the total is attributable to Maryland (Industrial Economics, Inc., 1998). Cost-sharing expenditures in Maryland will likely increase over the next five years. Specifically, the 2002 farm bill calls for a close to sixfold increase in annual spending on conservation incentive payments under the Environmental Quality Incentives Program nationwide by the year 2007, and introduces a new Conservation Security Program that authorizes expanding the use of cost sharing and other subsidies to a wider variety of practices and farm operations.[3]

The models derived here can be used to help improve the design and implementation of cost-sharing programs in two ways: (*a*) by identifying practices whose adoption is likely to be responsive to cost sharing, and practices for which cost sharing is likely to induce adoption of complementary practices, and (*b*) by identifying packages of complementary practices likely to need less cost sharing (thus avoiding unnecessary expenditure of funds). To investigate these prospects, we calculated the change in the probability of adoption of each practice due to a 1% change in its own unit cost or that of related practices. Let

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[3] The extent to which funds for these authorized increases in spending are actually appropriated remains to be seen.

$$F\left(\sum_i \frac{\beta_{ni}}{\sigma_n} W_{ij}\right)$$

denote the probability that farmer j's demand for practice n is positive, assumed to be standard normal. Then the (absolute) change in the probability of farmer j adopting practice n due to a 1% change in the unit cost of practice k is specified as:

$$\frac{\beta_{nk}}{\sigma_n} W_{kj} f\left(\sum_i \frac{\beta_{ni}}{\sigma_n} W_{ij}\right), \tag{4}$$

where $f(\cdot)$ is the density of $F(\cdot)$. We calculated these changes in the probability of adoption of each practice due to a 1% change in the unit cost of each practice for each farmer in the sample, and then averaged them over the sample using the weights described above. The (weighted sample) average changes in adoption probabilities are reported in table 4, along with associated standard errors calculated using the delta method.

As suggested by the values in table 4, the adoption of several practices appears quite responsive to cost sharing: A 1% increase in the own unit costs of waterways, stripcropping, and contour farming induce estimated reductions in the probability of adoption on the order of 0.3 to 0.4, while a 1% increase in the own unit costs of terraces and diversions should reduce the probability of adoption on the order of 0.2 to 0.3. The degree of complementarity between critical area seeding, cover crops, waterways, and terraces also seems substantial: A 1% increase in the price of related practices reduces adoption of critical area seeding and cover crops by about as much as a 1% increase in their respective own unit costs. The adoption of waterways also appears quite sensitive to the costs of critical area seeding and cover crops: 1% increases in the unit costs of these latter two practices reduce the probability of adopting waterways by about a third as much as a 1% increase in the unit cost of waterways. Finally, the values in table 4 suggest that the degree of substitutability between stripcropping and terraces may be quite substantial as well.

Waterways and critical area seeding have been priorities of federal cost sharing in Maryland, accounting for 29% and 17%, respectively, of federal cost-sharing expenditures in the state between 1987 and 1996 (Lichtenberg and Bastos, 1999). In contrast, cover crops have not been eligible for federal cost sharing since the mid-1980s (although their eligibility for state cost sharing was reinstated in the mid-1990s). The results of this analysis indicate that reinstituting federal cost sharing of cover crops could help expand the use of waterways and critical area seeding significantly. In addition, cover crops may be cheaper than alternative soil conservation technologies used in their stead. As a result, cost-sharing cover crops could help improve the efficacy of cost-share program implementation.

Based on the findings of this analysis, projects involving the combined use of critical area seeding, cover crops, and waterways are likely less costly—and thus need less cost sharing—than projects involving these technologies singly or in combination with other, unrelated technologies. As a result, they can be implemented at a lower cost share rate. In fact, those administering cost-sharing programs in Maryland may already be using knowledge about complementarities to keep cost-share spending down. The average rates at which cost sharing are actually allocated tend to be lower than the rates for which

Table 4. Changes in Adoption Probabilities Due to a 1% Increase in Conservation Practice Unit Cost

	Mean Change in the Probability of Adoption of:						
1% Increase in the Unit Cost of:	Critical Area Seeding	Contour Farming	Strip-cropping	Cover Crops	Waterways	Terraces	Diversions
Critical Area Seeding	-0.1678***	0.0121	-0.0738	-0.1275**	-0.1052**	0.0043	-0.0548
	(0.0458)	(0.0423)	(0.0533)	(0.0603)	(0.0510)	(0.0306)	(0.0381)
Contour Farming	0.1780**	-0.3209***	-0.0530	0.0463	0.0665	-0.0031	-0.0053
	(0.0887)	(0.0582)	(0.0854)	(0.0973)	(0.0848)	(0.0434)	(0.0521)
Stripcropping	-0.0092	-0.0691	-0.3673***	-0.1441	-0.1047	0.1475*	-0.0651
	(0.0883)	(0.0669)	(0.0948)	(0.1120)	(0.0960)	(0.0807)	(0.0598)
Cover Crops	-0.0024	-0.0262	0.0254	-0.1438***	-0.1053***	-0.0281	-0.0025
	(0.0329)	(0.0295)	(0.0373)	(0.0374)	(0.0316)	(0.0163)	(0.0243)
Waterways	-0.1173***	0.0879*	0.0513	-0.0686	-0.3649***	0.0091	0.0658*
	(0.0424)	(0.0459)	(0.0546)	(0.0596)	(0.0496)	(0.0253)	(0.0378)
Terraces	-0.1975***	-0.0778	0.0143	-0.2064*	-0.0973	-0.2159***	-0.0032
	(0.0813)	(0.0663)	(0.0984)	(0.1138)	(0.0953)	(0.0470)	(0.0651)
Diversions	0.0687	-0.0636	-0.0533	0.0040	0.0594	0.0020	-0.2840***
	(0.0568)	(0.0418)	(0.0598)	(0.0698)	(0.0613)	(0.0304)	(0.0382)

Notes: Single, double, and triple asterisks (*) denote statistically different from zero at a 10%, 5%, and 1% significance level, respectively. Standard errors are reported in parentheses.

projects are nominally eligible: The effective federal cost-share rate in Maryland averaged 40% between 1987 and 1996, compared to nominal rates of 50%–70%, while the effective state cost-share rate averaged about 70% during this period, compared to a nominal rate of 87.5% (Lichtenberg and Bastos, 1999).[4]

Conclusions

The existing empirical literature on farmers' use of soil-conserving, runoff-reducing farming practices, while sizable, contains relatively little information on the influence of cost on adoption decisions and on relatedness among farming practices, i.e., how farmers combine multiple practices into an overall conservation package. Such knowledge is important in light of current interest in reorienting agricultural policy toward environmental and resource conservation goals. This analysis uses farmer survey data combined with information on standard unit costs of installing seven soil-conserving, runoff-reducing practices obtained from a state cost-sharing program to estimate latent demand models for each of these seven practices. All seven exhibit downward-sloping demand. Topographical variations in adoption conform to expectations as well. The estimation results suggest that cost sharing should have substantial effects on the adoption of four practices. They also indicate strong complementarity among four others.

The applicability of these results to policy design is limited by the qualitative nature of the adoption measure. We observe only whether a farmer used any given practice. Consequently, the effect of changes in unit costs and other factors can be predicted only on the probability of adoption, and not on the amount of land served by different practices. These results cannot therefore be used directly in cost-benefit analysis since the environmental effects of using soil-conserving, runoff-reducing practices likely depend more on the spatial extent to which they are used than on the frequency with which they are used. The results can, however, be applied to the design and implementation of cost-sharing programs. They can be used to estimate the proportion of farmers who will adopt any given set of practices in response to specific cost-sharing rates [as Cooper and Keim (1996) and Cooper (2003) have done using estimates derived from stated preference data]. These findings should also be useful in improving targeting of cost-sharing funds by identifying the degree to which cost-sharing one practice can render adoption of a related practice more likely, thereby presumably increasing the cost-effectiveness of government spending in conservation programs.

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References

Allen, D., and D. Lueck. "Contract Choice in Modern Agriculture: Cash Rent versus Cropshare." *J. Law and Econ.* 35(1992):397–426.

Amacher, G. S., and P. M. Feather. "Testing Producer Perceptions of Jointly Beneficial Best Management Practices for Improved Water Quality." *Appl. Econ.* 29(1997):153–159.

Caputo, M. "Comparative Dynamics via Envelope Methods in Variational Calculus." *Rev. Econ. Stud.* 57(1990):689–697.

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[4] Payment caps and other limitations may also account for this discrepancy.

Cooper, J. C. "Combining Actual and Contingent Behavior Data to Model Farmer Adoption of Water Quality Protection Practices." *J. Agr. and Resour. Econ.* 22(1997):30–43.

———. "A Joint Framework for Analysis of Agri-Environmental Payment Programs." *Amer. J. Agr. Econ.* 85(2003):976–987.

Cooper, J. C., and R. W. Keim. "Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices." *Amer. J. Agr. Econ.* 78(1996):54–64.

Dorfman, J. "Modeling Multiple Adoption Decisions in a Joint Framework." *Amer. J. Agr. Econ.* 78(1996):547–557.

Ervin, C. A., and D. E. Ervin. "Factors Affecting the Use of Soil Conservation Practices: Hypotheses, Evidence, and Implications." *Land Econ.* 58(1982):277–292.

Feather, P. M., and G. S. Amacher. "Role of Information in the Adoption of Best Management Practices for Water Quality Improvement." *Agr. Econ.* 11(1994):159–170.

Featherstone, A. M., and B. K. Goodwin. "Factors Influencing Farmers' Decision to Invest in Long-Term Conservation Improvements." *Land Econ.* 69(1993):67–81.

Gould, B. W., W. E. Saupe, and R. M. Klemme. "Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion." *Land Econ.* 65(1989):167–182.

Industrial Economics, Inc. "The Costs of Water Pollution Control in the Chesapeake Bay Drainage Basin." Report prepared for the U.S. Environmental Protection Agency, Office of Water, Policy, and Resource Management, Washington, DC, September 1998.

Khanna, M. "Sequential Adoption of Site-Specific Technologies and Its Implications for Nitrogen Productivity: A Double Selectivity Model." *Amer. J. Agr. Econ.* 83(2001):35–51.

Lichtenberg, E., and G. S. Bastos. "Cost-Sharing Soil and Water Conservation in Maryland." *Economic Viewpoints* 3(Spring 1999). Dept. of Agr. and Resour. Econ., University of Maryland, College Park.

Lohr, L., and T. A. Park. "Utility-Consistent Discrete-Continuous Choices in Soil Conservation." *Land Econ.* 71(1995):474–490.

Lynne, G. D., J. S. Shonkwiler, and L. R. Rola. "Attitudes and Farmer Conservation Behavior." *Amer. J. Agr. Econ.* 70(1988):12–19.

Maryland Agricultural Cost-Share Program. "FY 1996 Flat Rate Schedule." Maryland Department of Agriculture, Annapolis, MD, September 1995.

Maryland Department of Agriculture. *Maryland Agricultural Statistics, Summary for 1995.* Annapolis, MD, 1995.

Norris, P. E., and S. S. Batie. "Virginia Farmers' Soil Conservation Decisions: An Application of Tobit Analysis." *S. J. Agr. Econ.* 19(1987):79–90.

Rahm, M. R., and W. E. Huffman. "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables." *Amer. J. Agr. Econ.* 66(1984):405–413.

Saliba, B. C., and D. W. Bromley. "Soil Management Decisions—How They Should Be Compared and What Factors Influence Them." *N. Cent. J. Agr. Econ.* 8(1986):305–317.

Soule, M. J., A. Tegene, and K. D. Wiebe. "Land Tenure and the Adoption of Conservation Practices." *Amer. J. Agr. Econ.* 82(2000):993–1005.

U.S. Department of Commerce. *1992 Census of Agriculture.* Bureau of the Census, Economic and Statistics Administration, Washington, DC, September 1994.

Weaver, R. D. "Prosocial Behavior: Private Contributions to Agriculture's Impact on the Environment." *Land Econ.* 72(1996):231–247.

Wu, J.-J., and B. A. Babcock. "The Choice of Tillage, Rotation, and Soil Testing Practices: Economic and Environmental Implications." *Amer. J. Agr. Econ.* 80(1998):494–511.