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Agent Heterogeneity in Adoption of Anaerobic Digestion Technology: Integrating Economic, Diffusion and Behavioral Innovation Theory

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ABSTRACT

Anaerobic digestion technology addresses environmental issues of waste disposal and greenhouse gas emission reduction. This paper examines attitudes toward adoption of this conservation technology on dairy farms. To specify an appropriate dependent variable without a large number of adopters, an ordered probit model is constructed. The empirical analysis uses data from a 2006 survey of Northwest dairy farms. Aggregate variables are constructed based on behavioral economics and conservation adoption literature. Variables include private and social costs, social motives, capacity, innovation receptivity, and opportunity costs, most of which are found to be highly related to the decision to seriously consider adoption.

Keywords: adoption, anaerobic digestion, behavioral economics, conservation, dairy, environment, meta-utility, Northwest

JEL Classification Codes: Q55, Q53, Q54

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I. INTRODUCTION

Urban expansion, threats to native salmon populations, higher energy prices, increasing concern over global warming, and the resulting increase in regulatory pressures are encouraging dairy farmers in the Pacific Northwest to consider adopting new technologies for waste management. One technology of national interest for confined animal waste streams is anaerobic digestion. However, early adopters of anaerobic digestion technology experienced a high rate of failure because of technical problems and financial difficulties. As a result, there has been little adoption of digestion technology for dairy applications in the United States. Renewed interest has been spurred by increased attention to the need for alternative fuels, a surge of public subsidies, and the availability of private funding.

This paper focuses on the nature, or the "character," of those who might adopt such technology. Its primary contribution is to demonstrate that a broader, behavioral model can provide a better theoretical and empirical model of technological innovation than that derived from standard economic elements alone. These elements are framed by some traditional models in other social sciences, but are also informed by recent developments in the areas of neuroeconomics and behavioral economics – notably the dual-motive or meta-utility theory. Other novel aspects of the paper are the aggregation of primary variables into more informative aggregate index variables and the integration of revealed preferences (adoption) and stated preferences (considering adoption) through a common categorical dependent variable.

Digestion systems for dairies capture methane produced from the biological degradation of manure waste. Digestion technology optimizes the environment for naturally occurring microorganisms that degrade biomass and create methane via methanogenesis. Anaerobic digestion (AD) is an integrated sustainable conservation technology that contributes to water, climate, and air environmental goals.[1]

AD is used to mitigate water quality issues by reducing the levels of chemical and biological oxygen demand in discharged agricultural waste (e.g., Martin 2005). The digestion process reduces the quantity of harmful pathogens that occur in untreated manure and which can pose health risks to humans and animals when mismanaged in proximity to food production and water recreation (e.g., Pell 1997; Martin 2005).

AD reduces greenhouse gas emissions through the capture and combustion of methane that would otherwise be released. This is significant because manure waste management accounts for more than 25% of all agricultural emissions of methane (U.S. EPA 2007). Burning the captured methane reduces the net greenhouse potential of the gas by emitting only water and carbon dioxide. Methane is a much stronger greenhouse gas than carbon dioxide; releasing one ton of methane has the same greenhouse potential as the release of 23 tons of carbon dioxide (e.g., Ramaswamy 2001). The use of biological methane can also replace the use of fossil methane, "natural gas". Further, burning biogas reduces farm odor. Odor reduction is especially important for farms near urban areas that face complaints or potential legal action.

The captured methane is generally used as a fuel in modified combustion engines to produce electricity, which is sold or credited to local utilities. Other uses include powering farm equipment, local heating, and drying. Generating electricity from anaerobic digestion is net energy efficient (Lewis 1989). However, low electricity rates in the Pacific Northwest (PNW) and the lack of established markets for digestion co-products create uncertainty for investments in digestion technology.[2] Further, while utilities espouse support for renewable energy, farmers trying to sell power produced on the farm have viewed the utilities as obstacles. Perceived barriers include expensive connection, safety equipment, and feasibility studies, as well as reluctance of utilities to enter into contractual power purchasing agreements. Despite the hurdles, interest in digestion technology appears to be increasing among dairy farmers in the PNW.

The resurgence of attention to digestion technology raises the question of who might adopt this technology. In economics, the technology literature often focuses on financial feasibility and risk factors. However, there is a broader socioeconomic conservation adoption literature that accounts for the role of additional factors, including agent "innovation readiness" and sensitivity to stewardship, both factors of importance to the AD technology. In this study, concepts from the socioeconomic and behavioral economics literature are added to those from the conventional economic literature to guide construction and specification of an adoption model. The model is used to analyze the behavior, motives and intentions of AD technology adopters and potential adopters, with most of the data coming from potential adopters.

The organization of the paper will proceed as follows. The theoretical framework is introduced in Section II. Section III presents the data and their source. The empirical model is described in Section IV. Of particular interest are variables that represent social costs, stewardship, and diffusion typology. These variables are created based on theories and findings in the interdisciplinary conservation adoption literature, informed by recent developments in behavioral economics and neuroeconomics. Following the presentation of major findings in Section V, salient implications of the estimation are discussed in Section VI, including an evaluation of the stewardship motives and diffusion typology. Section VII concludes.

II. THEORETICAL FRAMEWORK

Technology adoption and innovation have been the subjects of scholars in many fields – including sociology, communication theory, social psychology, and economics. In the 1950s and 1960s, an influential theory about technology adoption emerged in sociology and communication theory. The canonical text for examining innovation through the patterns of the diffusion of information and adoption was Rogers' 1962 book (5^{th} ed, 2003). As described by Rogers, "diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system" (2003, pp. 35). He popularized the classic "S-curve" (logistic function) of adoption and the typology of adopters ranging from innovators to laggards (in current language – primary, secondary, tertiary, etc. adopters).[3] A key point is that differences in adoption are explained by differences in the "character" of the agents rather than by differences in the circumstances they face.

Another key concept from outside standard economics is the concept of "attitude." In social psychology attitude is a key determinant of behavioral intent. Attitude is the kind of mental process which economists have traditionally avoided. However, many scholars have applied the attitude concept to the study of adoption and adopters (e.g., Ajzen and Fishbein 1980). In contrast, economists tend to use an incentive-based analysis, generally focused on enterprise profits (Griliches 1957; Stoneman 2002).

One motive for reaching beyond standard economic assumptions is that, in general, economic approaches fail to explain behavioral heterogeneity in technology adoption. Since agents are treated as having the same motives, all agents in the same circumstances should adopt (or not) at the same time (risk attitudes being one important exception). Thus, strict economic models have difficulty explaining delayed (or non-) adoption of profitable practices or the adoption of unprofitable ones (Nowak 1987). In contrast, the idea that agents differ in the skills, motives, and attitudes that drive adoption is central in other social sciences approaches. In this paper we address two dimensions along which heterogeneous individual characteristics might influence adoption patterns: social motives for adoption and "innovation readiness" personality traits. Both can be viewed as attitudes or personality characteristics over which agents differ.

Attitude – Theory of Diverse Motivations

Consider an agent's decision to invest in a new technology where the available technology choices have features that may affect profits (and ultimately consumption) and features that may affect the environment. If we collapse all the features of the technologies into these two dimensions, we can represent the choice among technologies using a production possibility frontier (PPF). However, whereas a conventional PPF can be represented in one (positive) quadrant, all four quadrants must be used here because both environmental effects and profits can range from positive to negative (Chouinard et al. 2008). With waste management, the starting place is often negative in both monetary and environmental dimensions. This does not imply that overall farm operations are unprofitable, only that waste management is usually a costly sub-enterprise. In the environmental dimension, dairy manure has mixed effects ranging from the positive value of properly applied manure to negative spillovers on air and water quality. Figure 1 illustrates this case where the PPF peaks at a point where both net financial and environmental returns to the waste management sub-enterprise are negative. The diagram contains three illustrative "indifference curves" to be explained below. Algebraically, the PPF is

(1) $$(\pi, e) = F(v),$$

where π is profit (negative costs), e is net environmental impact, v is a vector of input quantities, and F is the 'menu' of potential technologies.

To explain heterogeneity of technology choice among potential adopters, we explore the characteristics of potential adopters. As noted, the economic approach tends to assume agents are essentially identical and should respond to the same situation in the same way – i.e., adopt (or not adopt) a technology at the same time. We now examine in more detail how agents (facing this same PPF) may differ in regard to *environmental sensitivity* and *innovation readiness*.

First, consider environmental sensitivity. To incorporate a broader range of attitudes and beliefs, we combine the powerful formal decision logic of economics with insights from the recent literature in neuroscience and the heuristic decision models found traditionally in social psychology and more recently incorporated in behavioral economics. Important surveys of the literature include Camerer et al. (2005) and Sanfey et al. (2006). The theory we outline below draws from this literature following the basic framework established in the dual-motive or meta-economic models recently applied in conservation studies (e.g., Hayes and Lynn 2004; Kalinowski, Lynn, and Johnson 2006). Our development of the model includes visualization of the application in profit-environment space, inclusion of the diffusionist model, and identification and construction of aggregate variables to proxy the theoretical variables.[4]

We begin with the basic economic framework of optimizing behavior and utility/goal functions. By substituting a utility goal for a pure profit goal, the model is opened for expansion. For the profit- (or private-)motivated farmer, the goal or utility function can be written as:

(2) $$U^{pvt} = U^{pvt}(x_{\pi}) = U^{pvt}(\pi),$$

where x_{π} is a vector of goods purchased with profits, π.

The purely profit-maximizing goal function reduces to the profit function. In utility space, the farmer would have "indifference curves" represented by horizontal lines (I_1) in Figure 1. The highest profit permits the largest consumption of market goods and services. The farmer disregards effects on the environment unless they enter as private costs. Hence, without external controls, environmental outcomes are secondary effects of the agent's choice of the most profitable technology – a classic externality. Further, all farmers have the same indifference curve, I_1, in profit-environment space, regardless of their preferences over consumption goods. Therefore, if all farmers were purely profit maximizing (and had the same risk profiles and access to the same resources), they would all choose the same technology at essentially the same time (given an efficient capital market) represented by the peak of the PPF, point A.

With the utility function in (2), we can expand the agent's perspective to include direct well-being effects from non-market goods and services (amenities, disamenities), including environmental effects. For instance, the farmer could be concerned that run-off from manure waste spoils her favorite fishing stream or that odor spoils her backyard barbeques. The change from profit to a utility function has an implication for the heterogeneity of farmers' motives. Although the farmer's interest in the environment is still based on direct personal impacts, her choices can reflect differences in motives (utility) rather than simply differences in farm costs and returns. Specifically, the indifference curves for some farmers could now reflect a profit-environment trade-off as in indifference curve I_2 in Figure 1 and result in selection of point B:

(3) $U^{pvt} = U^{pvt}(\pi, e)$,

where *e* is an environmental effect based on the production of a vector of personally desirable non-market goods. Importantly, the slope of I_2 might vary among farmers:

While adding these egoistic environmental interests introduces agent heterogeneity over "environmental sensitivity," it does so in a rather trivial way – both in a theoretical and an empirical sense. A more interesting extension of the standard model can be had by bringing together (a) the economics literature critical of the simple "rational self-interest" model of human behavior and (b) recent work in neuroscience, biology and evolutionary psychology that has been introduced into economics under the rubrics of behavioral economics and neuroeconomics. These themes have been recently combined and applied to altruism generally and resource stewardship in particular through a dual-motive or meta-utility approach. The resulting model is similar to those found in Hayes and Lynne (2004), Chouinard et al. (2008), and Lynne (2006a).

Criticisms of the standard model of rational and self-interested "*homo economicus*" are extensive and arose virtually simultaneously with the model itself (e.g., Veblen 1898). For brevity and relevance, we focus on issues of altruism and moral/social values. Sen's (1977) article about “rational fools” is one of the most widely cited and respected of such criticisms. While he admits the usefulness of the formal, definitional model of rationality, Sen is highly critical of the *substantive* use of rational self interest. He argues that reducing human motives to a one-dimensional ordering grounded only in self interest ignores the real richness of human behavior. The resulting agent is a caricature, one who would act in socially and morally “foolish” ways. In particular, Sen argues that the morality of obligation and commitment is fundamentally different from utility and cannot be incorporated within the utility dimension.

Using these philosophical and conceptual arguments to motivate a search for an alternative approach, we turn to recent empirical findings in neuroscience, psychology and behavioral economics. For our purpose, there are two related main points – complexity of the decision-making process and pro-social behavior.

First, whereas formal economic models envision a unified optimizing decision process, empirical studies in psychology and experimental economics and laboratory studies in neuroscience and neuroeconomics reveal a more complex decision process. As Sanfey et al. (2006) note, “rather than thinking about human behavior as a being governed by a unitary, general purpose mechanism, it can often be better described in terms of the interaction – and sometimes competition – between different subsystems that might favor different alternatives for a given decision.” The brain is a highly interconnected system of systems (e.g., LeDoux 1996). The work on brain components is most dramatically rooted in the split brain research for which Roger Sperry (e.g., 1974) received the 1981 Nobel Prize. There is now also a large neuroscience literature on brain systems based on examination of localized brain activity via blood flow intensity (MRI studies) and on probing the firing of individual neurons (usually in simple organisms) (e.g., Sanfey et al. 2003; Spitzer et al. 2007). Meanwhile the behavioral economics and psychology literatures continue to reveal inconsistencies and heuristics in decision-making processes which suggest complicated, multiple-motive cognitive processes. One example is the "endowment effect" (or loss aversion) with different "utility scales" for gains and losses.

The second theme relevant to our work has to do with pro-social behavior. The existence of pro-social behavior and its roots in the brain have been established by a wide range of empirical studies in the behavioral sciences and in neuroscience (e.g., Levine 2006; Fehr and Fischbacher 2003). Illustrative work includes: (a) the discovery of oxytocin, the "trust hormone" (e.g., Kosfield et al. 2005), with studies showing it's level influences responses in the ultimatum game, (b) the willingness (in "ultimatum" and related trust games) to punish non-cooperators even at the agent's expense (e.g., Fehr and Fischbacher 2003; Sanfey et al. 2003; Spitzer et al. 2007), and (c) the discovery of "mirror neurons" that are stimulated when watching the behavior of other agents – presumably a neurological basis for empathy (e.g., Gallese and Goldman 1998).

To use these ideas in our theory, we draw on the recent work of behavioral economists who have integrated these streams of literature into a theory of multiple motives or meta-utility functions (e.g., Levine 2006; Cory 2006; Lynne 2006b). In this approach, the human brain is understood to contain multiple, interconnected motivational domains or utilities.[5]

The dual-motive models are partly built on MacLean's triune brain concept (e.g., Cory 2006) that emphasizes the existence of multiple complexes within the brain architecture. Scholars have developed a variety of models to represent how the pro-social components of behavior are woven into this triune brain architecture. For our purposes, we need not resolve the competing models dealing with this architecture but acknowledge two brain subsystems – a system effectuating egoistic behavior (mostly self-regarding motivation) and a system of pro-social or other-regarding motivation. The dual motives invoke different neural processes which are sometimes complementary and sometimes competitive, but are always interconnected and ultimately resolved. In empirical measurement of neural activity, they have different neural firing patterns, but the systems communicate, and they both connect to the higher, hedonic reward centers of the brain (Fehr and Camerer 2007).

The literature on multiple utilities or motivational domains has been explicitly applied to the topic of conservation behaviors. Lynne, with various co-authors, has conducted several studies centering on pro-social motives in conservation activities using a multi or meta-utility approach (e.g., Kalinowski, Lynn, and Johnson 2006; Hayes and Lynne 2004; Lynne 1995). Here, we introduce a multi-utility system in which there are two motivational domains. The two "utilities" are interconnected within a meta-utility or goal functional (function of functions):

(4) $$G = G\left(U^{pvt}(\cdot), U^{soc}(\cdot)\right)$$

$$U^{pvt} = U^{pvt}(\pi, e),$$

$$U^{soc} = U^{soc}(\pi, e),$$

where G is the overall meta-utility functional, and U^{soc} is the pro-social utility component.

The second utility function in equation (4) corresponds, roughly, to indifference curve I_3 illustrated in Figure 1. While the illustration in Figure 1 is useful, it is oversimplified. Since the egoistic and pro-social domains interact, each indifference surface may be conditional on values of the other. Mathematically, this takes the form of non-separability; that is, each domain's indifference curve can have different shapes and levels depending on the values in the other domain. Behaviorally, one can imagine making a pro-social choice which interacts with and enhances egoistic goals, or vice versa. For example, motives for buying a hybrid car might include transportation, appearance and features, environmental performance, and (green) social status, or any combination or interaction of these. In summary, while the complexity of the dual-motive system is difficult to represent on a two-dimensional graph, the functional $G(\cdot)$ allows for interaction between the two motivational domains and also for interaction between the individual arguments of each of the sub-equations.

An interesting question concerns how the final decision must resolve the two motives in equation (4). Findings in neuroeconomics and the dual-motives framework show that the resolution need not be "rational" in the choice theory sense. At times, agents may be inconsistent (economically irrational) although their behavior may be "optimized" given their goals and situations.[6] At other times the motivational domains may be complementary, with the egoistic and pro-social rankings so similar that choice is clear, consistent, and tranquil. In effect, each agent harbors a microcosmic case of Arrow's impossibility theorem (Sen 1997).

In dual-motive theories, resolution of the motives generally occurs through some balancing of the two motives, e,g., tension reduction (Livnet and Pippenger 2006) or harmony achievement (Hayes and Lynne 2004). These are not "rational" choice rules, but they are procedures to find the "best set," as illustrated by Levine's (2006) neural net model of a heuristic process or Lynne's (2006b) executive brain which seeks "peace of mind" by balancing the satisfaction of both egoist and sharing motives.

While we do not need to know the exact mental processes by which motives are resolved and decisions made, it is important to acknowledge that, in choosing, the brain must recognize and integrate two (or more) motives to produce a choice which may not be formally rational but which is pragmatically rational. The concept of volitional pragmatism (Bromley 2004) may be a better way of characterizing this choice resolution than standard economic choice theory.[7] The general conceptual model outlined above will be implemented in the variable selection and empirical model specification discussed below.

Diffusion Theory

Returning to the puzzle about differences in rates of adoption under technically similar conditions, we now explore the ideas advanced by social scientists who hypothesize that different agents have different propensities to adopt (or not adopt) new things. Typically these differences are surmised to underpin a logistic function, or "S-curve" time-distribution of adoption rates. The classic logistic adoption curve of diffusion theory has been empirically confirmed in many marketing and technology adoption studies (Rogers 2003). However it remains something of a stylized fact in search of a definitive theory.[8]

What generates these differences in propensity to adopt? While it is clear that risk attitudes are a major component of adoption diffusion patterns, most diffusion theorists appeal to a larger complex of attitudes. Early adopters appear to be more comfortable with the very notion of change than later adopters: "Laggards" (5th stage adopters) prefer stability over change. This preference for the status quo is distinct from classic risk aversion. Hence, a more risky current technology may be preferred to a lower risk innovation. This preference may stem from differences in "loss aversion" and the magnitude of the endowment effect – components of prospect theory. It may reflect different types of learning patterns or different levels of self-confidence needed to implement a new enterprise.[9] In any case, it is thought to be a personality trait, not a characteristic of the technology itself.

In diffusion theory the role of information is critical. The stages in the diffusion of innovations come about through the interaction of information with personality types. In some versions of diffusion theory, innovation is essentially regarded as an "infection" of information. (The spread of diseases follows the same logistic curves as innovations do.) Again, this goes beyond the economists' notion that information is costly. In diffusion theories, there is heterogeneity in the agents' ability to deal with information. Some agents learn quickly and attend closely to the latest technical developments. Others may not quickly assimilate information nor trust unproven ideas or methods. Perhaps their cognitive skills are more concrete and they learn by watching and observing outcomes. In Bass's (1969) formulation of the diffusion theory, early adopters are *innovators*, later adopters are *imitators*. While pejorative (though less so than laggard), the latter term may describe a real (show me) personality trait.

We do not attempt to develop a new theoretical structure. We accept that the diffusion curve has been demonstrated empirically in many circumstances and that diffusion theory is widely held to be valid, at least descriptively. For the present model, diffusion theory generates hypotheses that agents will be heterogeneous with respect to innovation readiness or the "tendency to adopt," and that innovation readiness should correlate with the flow of information about the technology, thereby integrating the attitude and information dimensions discussed above. Early adopters are information users and researchers; later adopters pay less attention to technical information – they "wait and see" and eventually imitate the early adopters. The differences in innovation readiness or receptiveness among potential adopters will motivate the development of an operational measure based on information use patterns.

III. DATA

The data for the empirical study were collected in a survey of dairy farmers in Washington, Oregon, and Idaho during the spring of 2006. The survey process followed the basic "Dillman (2000) survey method" and included a primary mailing, a reminder postcard, and a second mailing to non-responders. The survey sampled 1,152 dairy operations, and 254 responses were received (22%). Of the total survey responses, 230 (20% of the initial sample) were usable before listwise deletion of observations containing missing values. The response rate was on the low end of previous response rates (13% - 63%) for non-production related dairy adoption surveys (Buttars, Young and Bailey 2006; Winsten, Parsons and Hanson 2000). Given the length and broad scope of the survey, the relatively low response rate was not surprising. Milk prices in the region were down at the time of the survey, which may have dampened the survey response rate as well (Northwest Dairy Association 2007).

Because of the high investment cost for anaerobic digestion technology, the survey was designed to oversample farms with herd sizes greater than 100 head.[10] The survey included questions regarding farm structure, investment, and socio-demographics. Table 1 presents definitions for the primary variables utilized in the model.

IV. EMPIRICAL MODEL

In this section, we identify the aggregate variables used in the empirical model and the statistical estimation procedure. The variables are derived from the theory above, standard economic theory, and the empirical conservation adoption literature. We develop aggregate proxies for the major conceptual variables and hypotheses about their expected signs.

Dependent Variable

Studying the adoption of digestion technology in the PNW poses a challenge because few farms currently operate digesters. Of 230 usable responses, only three indicated current digester use and four indicated digesters in planning or construction stages. By comparison, industry figures show five farms listed by AgSTAR as operating digesters in Washington, Oregon and Idaho (U.S. EPA 2006).[11] Given the statistically inadequate number of farmers with operating digesters, the survey was designed to examine farmer intentions and considerations as well as current operator behavior. The dependent variable (ADOPT) represents interest in AD adoption using a five-category Likert scale: 1 – not considering adoption, 2 and 3 – minor and some consideration to adoption, 4 – seriously considering adoption, 5 – actual adopter. Many economic adoption studies focus on "revealed behavior," using a binary variable in which categories 1-4 are lumped as non-adopters and contrasted with category 5, the adopters. Many social adoption studies focus only on the attitudes expressed by the respondents, irrespective of whether they adopt or not – what economists label stated preferences. The approach taken here combines these two approaches: that is, the analysis uses both stated and revealed preferences.

While the *estimation* uses observations on both revealed and stated preferences, the *analysis* emphasizes stated preferences because the data contained so few actual adopters. More specifically, we focus on the marginal effects and characteristics of category 4 – farmers seriously considering adoption. While this focus stems partly from data considerations, it is also consistent with our research objective since we are interested in those most likely to become actual adopters in the future. Furthermore, the assumption of some continuity of motivation from those considering adoption to those who have adopted is reinforced both by the diffusion of innovation literature and the theory of reasoned action put forth by Ajzen and Fishbein (1980).

The use of ordered probit is essential to this approach because ordered probit estimates effects for ordered categories regardless of the "distance" from one category to the next. It may be that the "distance" between successive categories from 1 through 4 is small, while the gap from 4 to 5 is huge, but in principle, this presents no statistical difficulties, as long as the ordering is not violated.[12] In the adoption literature, studies often address these "qualitative" differences by sorting agents, i.e., lumping types into different bins, before the statistics are done.

Explanatory Variables

Although we do not have data on all relevant variables suggested by the theory, we have sufficient information to create aggregate proxy variables. In this section we specify and justify the model to be estimated and then identify the relevant primary variables from the survey used to create each aggregate variable. We focus the investment problem on a few major determinants: the private costs of the project, the social (environmental) costs of the project, private motives and opportunity cost of the agent, social motives of the agent, the capacity of the agent to undertake the investment, and the attitudinal-knowledge state of the agent.[13]

The investment problem is motivated by the need to deal with the waste stream, which is a byproduct of dairy production. The costs and returns of a prospective investment concern direct and opportunity costs as well as any potential benefit streams stemming from the candidate technologies. Costs and returns can be divided along the private and social dimensions as in the theoretical production possibility frontier formulated in Figure 1, where private costs and benefits are denoted on the "π" axis and social costs and benefits on the "e" axis.

In a pure, abstract economy, adding a goal function to the specification of the cost and benefit streams would fully determine an investment model. Agents would choose from available waste management technologies based on the data and their utility functions, as in figure 1 with indifference curve I_1 based on profit maximization or curves I_2 or I_3 based on utility maximization (with alternative utility specifications). Resources could be reallocated to any investment opportunity in which the cost and benefit stream generated returns that passed the tests implied by the goal function.

However, there are a number of financial and technical complications in addition to the theoretical complications discussion above. For instance, in the practical world, the capacity to invest is uneven. Differences in access to finance are frequently apparent. To these can be added differences in human capital. Finally, according to the diffusion models discussed above, we expect differences among respondents concerning "innovation readiness" – the propensity and ability to use knowledge.

In principle, these aggregate variables should fit into an operational model that, in reduced form, looks something like this:

$$(5) \qquad ADOPT = F(C^{pvt}, C^{soc}, K^{fin}, K^{hum}, K^{innov}, O^{alt}, O^{chg}; U^{pvt}, U^{soc}),$$

where C are the private (C^{pvt}) and social costs (C^{soc}); K are the investment capacity with respect to finance (K^{fin}), human capital (K^{hum}), and the innovative attitude or capacity to use information about new opportunities (K^{innov}); O are the opportunity costs of investment (O^{alt}) and planned changes (O^{chg}). These factors are conditioned on the existence of private (U^{pvt}) and environmental/pro-social (U^{soc}) motives/utility domains. Counting myriad possible interactions, this presents us with a large number of potential empirical variables and specifications. Although the functional structure of equation (5) is currently very general, the empirical model is specified in single-equation form which reflects an "equilibrium" solution of the PPF and indifference curves identified in the illustrations. The indifference curves and utility functions are not directly measurable, and the variables themselves are complex indices in which different empirical variables are aggregated to infer complicated latent variables.

In the following sub-sections, we specify corresponding aggregate proxy variables. In doing so, we note that in some cases, none of the variables from the survey exactly fit the *ex ante* requirements of the variable. In three cases, individual survey questions (herd size, proximity to urban areas, and planned farm expansion) are used to help create two of the proxy variables. To proxy the conceptual variables, we aggregate the primary empirical variables using an index approach. The World Bank's Human Development Index (HDI) is taken as a prototype index and we employ similar methods to construct our indices.[14] The HDI is constructed from three primary components (GDP/capita, education, health) by normalizing measures of these three social features to a 0-1 scale, setting 1 equal to the highest value and 0 equal to the lowest value.

For each primary variable, we subtracted the lowest value and divided by the difference between the largest and the smallest values to obtain a 0-1 index. These values were summed to obtain the aggregate proxy variable (or a subcategory). Subcategories were aggregated in the same way, and the aggregate variables were then scaled to a 0-1 index. Table 2 lists primary and aggregate variables organized by the categories noted in equation (5) and discussed below.

Private Costs

Private costs include two subcategories: costs directly proportional to the quantity of waste and costs reflecting "qualitative" or management intensity factors. The survey did not include a direct quantitative measure of manure load, so a proxy is required. Clearly, herd size (HERD) is an indicator, but it is inexact. For instance, cows that produce more milk typically produce more waste. Hence, milk production per cow (MILK/COW) is another indicator of waste load. Since both HERD and MILK/COW are expected to be positively correlated with waste load, both are hypothesized to positively influence the dependent variable, ADOPT. We construct the manure load proxy (MNRLOAD) by summing HERD and MILK/COW.

In addition to manure load, other factors are involved in waste management costs for a particular enterprise. Since the survey wasn't a financial survey, a proxy for other management costs was sought. One factor concerns the opportunities for using and/or disposing of the manure. When farmers have few acres to apply manure, they face greater costs finding disposal sites. While a farm acreage variable is often used in crop-related conservation adoption studies, it typically has a different rationale (for example, Upadhyay et al. 2003; Nowak 1987). In such studies, acreage is directly related to the target conservation practice (e.g., cropping patterns or tillage technology). In contrast, for dairy digesters, farm acreage has an indirect effect through costs, because a dairy with large acreage is not expected to need digestion technology as much as a farm with fewer acres and a similar herd size. To capture this effect a variable for the per-cow "pressure" on the land was calculated by dividing HERD by total acreage (ACRE).

Management intensity may also vary with the different waste collection systems that are used by different farms. In particular, farms with flush systems generate a greater volume of waste, and this increases both on-site storage needs and distribution volume. Some digester configurations provide benefits when recycling flush water and hence digester systems may be more attractive investments for those with flush waste management systems. Hence a flush system binary variable (FLUSH) is included in the model.

A final, general proxy for management intensity is the time spent managing manure

(MANAGE). We sum the variables MANAGE, HERD/ACRE and FLUSH to obtain an indicator of management intensity (MGMTLOAD).

In summary, private cost is focused on the direct costs of manure load and the general costs of manure management intensity.[15] The aggregate proxy variable, C^{pvt}, was obtained by summing MNRLOAD and MGMTLOAD sub-indices. Each component of the aggregate index is expected to have a positive causal impact on the dependent variable.[16] Consequently, this variable is expected to be fundamental and positively related to ADOPT.

Social Costs

Environmental costs are both central to this study and difficult to measure. Here, environmental effects have three faces.[17] First, where such effects create potential liability for the producer, they are internalized as part of the private costs structure. Consequently, the greater the potential environmental liability, the greater the dairy operator's profit motivation to deal with them.[18] Secondly, negative environmental effects are straightforwardly interpreted as social environmental costs. Finally, in this survey, some of the measures for environmental effects are also measures of social environmental attitudes. For instance, respondents' reported observations of "environmental problems" in air and water quality are almost certainly influenced by their environmental social sensitivity. That is, a person notices a problem more if s/he is predisposed to see it. Ideally, a survey would include direct measures of social impacts and attitudes and this would have helped us separate some of these effects.

Without explicit identification of environmental spillovers in our survey instrument, we use statistics to extract what information is available. The survey does provide a number of relevant responses. It includes two variables that measure perception of problems – the number of acres with perceived odor (ODOR) and water problems (WATER). Another relevant and available raw variable that is likely to be more "objective" is the size of the herd (HERD). Herd is a proxy for global environmental impacts because of the emissions of methane directly from cows, and it is another proxy for the potential magnitude of local spillover. Finally, the closer a dairy is to an urban area, the higher the probability of economic externalities (i.e., costly emissions); hence, we include URBAN as another component of social costs. They are summed to form the aggregate social cost proxy variable, C^{soc}.

We label this index *social cost* because it concerns the pure spillover aspects of the manure operations. Note again that social costs may lead to internalized private costs to the farmer so that some “environmental costs” are reflected in private management costs as discussed above. This can be literally the case where a farmer is held legally liable for damages. But farmers can also be concerned about potential liability or concerned about bad relations with neighbors. This is a good example of how the “dual motives” become entangled when one tries to sort them out empirically. This illustrates that these variables are neither theoretically nor empirically “pure” measures of own interests versus other interest. Specifically, this social cost variable responds to a mixture of social motives and indirect private motives; it is, by nature an “interaction term” in our theoretical equation, G(.). However, in practice, we consider it primarily an indicator of socially motivated costs under the assumption that most of the private concerns would be captured with other variables, including management intensity. It is hypothesized that C^{soc} will be positively related to ADOPT.

Capacity Variables

In the practical world, farmers can only undertake major investments if they have the wherewithal. For this study we identify two domains of traditional investment capacity – financial assets and human capital – as well as a knowledge-innovation readiness domain which is related to diffusion theory.

Gross income is frequently used to represent farm size, and by extension, financial capacity. However, using gross income confuses scale with financial capacity since operating costs are not deducted (Nowak 1987). Again, without ideal, specific data, we developed other proxies for financial assets. Two potential variables are the value of the dairy herd and the value of the farm land. Lacking farm-specific price data, we used state-level land and cow prices (USDA 2007a-b) to create proxies for herd value (herd size times the state cow price) and for land value (owned acres times state land price). A financial sub-index variable, ASSET, was calculated by summing these two variables. Because land prices are so much higher when land is in close proximity to urban areas, the percent of acreage within 5 miles of a town or subdivision (URBAN%) was added to ASSET to create the aggregate proxy variable K^{fin}.

While demographic variables such as education and age are almost always used in studies like this, they are often problematic.[19] Usually they are simply seen as "control" variables, although in some cases there is an attempted theoretical justification. Thus, adoption studies often use the age of the farmer as a proxy for planning horizon (e.g., Upadhyay et al. 2003; Rahelizatovo and Gillespie 2004). Higher education is often expected to broaden personal perspectives regarding the need for conservation and make agents more receptive to innovation – an elitist, but reasonable hypothesis (Upadhyay et al. 2003).

Instead of this ad hoc approach, , we inquire whether age and education variables can be justified from within the framework of the theories used here. On reflection, one can employ a standard economic concept, human capital, a form of asset.

The human capital variable was created in two parts. The value of formal education was assessed at the 2005 U.S. mean earnings for each level of education (Baum and Ma 2007). The value of "on the job training" was measured as the 2006 U.S. predicted mean earnings from on-the-job training (experience) (Kitov 2005). Experience was proxied using a combination of age and years of experience managing the farm. The aggregate proxy variable (K^{hum}) was the sum.

Both financial and human capital assets are enabling rather than causal. An enterprise with greater assets can do more, **if it is otherwise motivated to do so**. Hence, this variable is expected to be positive or neutral, with the data showing whether it is relevant in this case.

Innovation Readiness

We label innovation readiness or receptivity in the empirical model as a capacity variable because it identifies the capacity to mentally entertain investment in new technology. Many conservation adoption studies include some elements of diffusion theory. It is included in this study as a key part of the underlying theory. Rogers' (2003) model of the five stages of adoption is used as a guide to create a variable that represents diffusion theory. Nearly all responses to our survey fall within the first three stages of adoption in his model:[20] *knowledge* (not considering adoption), *persuasion* (minor or some consideration), and *decision* (seriously considering adoption), where Rogers' label is in italics and the survey term is in parentheses. At the knowledge stage, information regarding digestion technology is likely spread primarily through trade journals and similar publications. As farmers cross into the persuasion stage, it is expected that the primary sources of information about the technology shift towards communication with other people in the dairy industry. A farmer in the persuasion stage is also likely to visit a digester in operation. Those who are considering making the decision are expected to use multiple sources of information and also seek expert advice on digestion technology.

The survey included a series of questions concerning respondents' sources of information pertaining to the categories above (communication with other farmers, trade publications, seeing a digester in operation, and communication with digestion experts), and it asked whether the respondent had researched digestion technology extensively. The innovation readiness variable, K^{innov}, was developed from these responses. Instead of using the index number procedures used for the other aggregate variables, this variable was created by regressing the dichotomous variable for *extensive research* on the information source variables and on the number of sources used. This approach converted a binomial variable into a continuous variable that better captures the diffusion typology. The regression results for this equation are reported in Table 3. Normalized predicted values for extensive research were used as the aggregate proxy variable (K^{innov}) which represents the respondent's stage of diffusion and potentially her receptivity to innovation. This variable is expected to be positively related to ADOPT.

Opportunity Costs

An important prediction of standard microeconomic theory is that investment decisions are made with recognition of the alternative possibilities. We develop two aggregate variables related to opportunity costs. One addresses opportunities for alternative investment and the other addresses operator plans for farm and/or personal status changes.

When farmers have prospects for developing their land for alternative uses, one would expect them to have less interest in large investments in waste management. The most relevant primary variable is the percent of land within 5 miles of a town or subdivision (URBAN%). For instance, Soule, Tegene, and Weibe (2000) used urban expansion to "account for the possibility that the farm might be converted to non-agricultural use in the near future" (p. 999). Other relevant primary variables include stated intent NOT to expand (NO-EXPAND) and farmers who work off the farm (OFF-FARM). An aggregate proxy variable for opportunity cost of alternative investment and work possibilities (O^{alt}) was constructed by summing these three variables. On balance, we expect this variable to be negatively related to ADOPT. While the urban proximity variable is used here because it relates to the opportunity cost of investing in a digester, it is also used (in different form) in the social cost index because proximity to urban areas implies greater exposure to liability from environmental spillovers; in these two cases its "pull" is opposite.

Three variables were also considered in development of the aggregate proxy variable for planned changes, O^{chg}. They include planned expansion of the dairy (EXPAND), planned retirement of the operator within 5 years (RETIRE), and a family member planning to continue farming (INHERIT). This proxy variable is generally expected to be positively related to ADOPT because both plans to expand and plans to retire and pass the farm to family members could result in higher likelihood of adopting AD technology. However, it is not unambiguous. For example, a farmer planning to retire and pass the farm to an upcoming generation might consider investing in an anaerobic digester in order to preserve the future viability of the farm; on the other hand, she may not want to burden the next generation with debt from such an investment, particularly if it turned out to be a bad investment. Hence, we do not have a clearly signed hypothesis about the relationship between O^{chg} and ADOPT.

Private Motives

According to the theoretical development above, we expect to distinguish two motives, though we also expect them to overlap and interact: self-interest (or self-regarding) motives and pro-social motives. We expect the self-interest or private motive to appear most directly and strongly in the concern about direct costs discussed above. Similarly, we expect the pro-social motive to appear most strongly in the direct consideration of environmental (social) costs (see discussion below). However, because the empirical model is estimated in a single-equation form, we can not statistically identify the structural role of conceptual variables specified in the theory section. Each empirical variable will reflect "equilibrium values" that mix elements of the PPF and the two utility domains. Analogous to estimating single-equation price functions rather than multiple-equation demand and supply systems, we are only able to obtain reduced-form estimates of the relationships. Moreover, the dual-motive theory makes clear that the true "structural model" is very complex, with multiple interactions among the components of the meta-utility function, G(·). For example, note the potential overlap in motive variables. There is no reason a highly profit-minded, commercial farmer might not also be altruistic or environmentally friendly. Still, other things equal, a more commercially-minded farmer will probably reflect a "profit motive" more than a less commercially-minded farmer, and vice versa.

Given these caveats, we attempted to probe motives more deeply by identifying variables that reflect as closely as possible the motive or utility components. Because the survey did not contain attitude scales over motives such as own interest, profit, altruism, and environmental sensitivity, we probed the existing data for variables to measure these latent motives.

As a proxy for the profit motive we constructed an index to identify the most "commercial-minded" farmers. As a first approximation, we treat size of operation and future plans as indicators of commercial orientation. Variables such as herd size, owned acreage, gross income, milk production (all correlated, of course), and plans for expansion suggest themselves. However, these variables are also related to other factors including the size of the manure problem (part of private costs), available financial assets (part of financial capacity), and planned changes (part of opportunity costs). Given these complexities and the absence of an exact variable for profit orientation, we constructed a proxy aggregate proxy variable for profit motives, U^{pvt}. This index was constructed from the primary variables of owned acreage (ACREOWN), milk production (MILK), and planning to expand (EXPAND).

While owned acreage is a size variable, it is only a loose indicator of enterprise size for dairy farms; more acreage is neither a necessary nor sufficient condition for a larger dairy. However, land is a commercial asset and we hypothesize that a commercially oriented farmer is likely to own more land, and vice versa. Use of the owned land variable is somewhat similar (but of opposite direction) to the use of rented acres in many conservation studies, under the hypothesis that the agent is less motivated to conserve and use rented acres efficiently.[21] The second factor, milk production, was chosen for similar reasons – that higher milk output is related to commercial orientation. Finally, the third factor, an expansion plan, was chosen since an operator seeking to expand dairy operations is likely to have strong commercial motives.

A difficulty in specifying the profit-motive variable is there are no *a priori* grounds for suggesting whether "profit-minded" farmers should be pre-disposed towards adopting AD technology. We are not measuring pure profit motive – which certainly should be "positive," but profit motive as it affects predispositions toward anaerobic digesters. We do not know how profitable AD technology would be relative to the farmer's choice set. Note the contrast with environmentally sensitivity. AD technology is clearly "green," but it is not unambiguously profitable. Hence, environmental sensitivity should be positively related to consideration of adoption of AD, but the profit motive is ambiguous as to hypothesized sign for adoption of AD. Simply stated, a farmer would be negatively disposed to AD technology on the profit dimension if a more profitable technology were available. We include the "profit motive" variable without strong expectations about sign.

Social Motives

The survey provides a number of variables relating to the farmer's social/environmental sensitivity and motives. Two sets of questions concerned the farmer's perception of the potential environmental benefits of digester technology to the farm itself (ENVBEN-P) and to the dairy industry as a whole (ENVBEN-S). Two others focused on how much water quality impact (WATERIMP) and air quality impact (AIRIMP) of digester technology would influence their decision to adopt. Another question indicated whether there were neighboring farms with whom the farmer might pursue a joint venture in investing in digester technology (VENTURE). Each of these variables indicates a concern with environmental effects and how the digester might help the farmer manage these effects. We constructed an index for these variables which seem to indicate environmental concerns. While this variable could reflect mixed private and pro-social motives (as expected for the dual-motive model), the emphasis on the environment leads us to interpret it as a more socially-oriented motive variable. Thus, ENVIRO is hypothesized to be positively related to ADOPT. Environmental motives will also be revealed in the perceived social cost variable, but we expect that the environmental/social motive variable will have an unambiguous sign, in contrast to the profit motive variable.

Statistical Procedures

The empirical model was estimated as a linear-in-parameters form. However, treating the dependent variable ADOPT as a continuous variable in an ordinary least squares regression would produce biased and inconsistent results. The bias and inconsistency occurs because the true interval spacing between the categories of ADOPT is unknown. The preferred procedure, and the one used for this analysis, was ordered probit regression which allows for uneven interval spacing.[22]

We used the aggregate proxy variables as our explanatory variables. They could cumulatively reflect an underlying latent variable while each variable in the subset only imperfectly measured an aspect of the latent variable. In some cases, one proxy variable could capture the key latent variable of interest. In other cases, several variables reasonably captured the basic dimensions of the underlying entity. The advantage of using aggregate proxy variables over latent factors is that they can be directly interpreted. However, care must be taken when interpreting the marginal effects of such variables because a particular empirical measure may be a proxy for a dimension of the latent entity rather than truly representing itself.

V. RESULTS

We report estimates for three models: (a) a model that is linear in all nine aggregate index variables, (b) an expanded model that adds an interaction term between private and social motives, and (c) a restricted model that excludes three variables judged to be statistically inconsequential to willingness to adopt AD technology. In all cases, the use of an ordered probit renders the estimated marginal changes nonlinear in parameters, so they must be calculated with respect to particular levels of the dependent variable. We report marginal changes only for the restricted model, but comment on the marginal changes for the expanded model.

Parameter estimates are reported for each of the three models in Table 4. Three variables (private costs, social/environmental costs, and innovation receptivity) were statistically significant at the 10% or higher levels in all models. Social motives were also significant in the linear model, and planned changes and motive interaction (i.e., the multiple of private motives and social motives) were significant in both the expanded and restricted models. In addition, private motives were significant in the restricted model.

With the exception of private and social motives and motive interaction, parameter estimates varied little among the three models, suggesting a fairy stable model. The estimated parameter sign on each significant variable, other than private motives, was consistent with expectations, and the negative sign on private motives was offset by the positive sign on motive interaction. Although insignificant in each model, the sign on alternative investments was also consistent with expectations. It was retained in the restricted model because its removal affected the magnitudes of other parameters and substantially lowered the Pseudo R^2 value.[23] The expanded model and the restricted model both had higher log likelihood values and Pseudo R^2 values than the linear model, so we judge the addition of motive interaction to be important in explaining willingness to adopt AD technology.

Interpreting marginal effects in the ordered probit model requires separate examination for each category of interest of the dependent variable, ADOPT. The category for those seriously considering adoption is the most informative for assessing the impact of important adopter characteristics.[24] Therefore, discussion of the results focuses on the marginal effects calculated as $\partial \Pr[ADOPT = 4] / \partial x_i$, where x_i is an explanatory variable. These effects allow for meaningful interpretation by examining the impact of a unit change in each variable on the predicted probability of adoption for those seriously considering adoption.

The value of x_i used in the partial differentiation also requires careful attention. If x_i is set equal to the sample mean, the value may not represent an actual farm type because the sample is skewed with regard to herd size. To address this issue, we chose two representative farm sizes. Mean values of farms with herd sizes between 300 and 599 head and mean values of farms with herd sizes between 600 to 1,999 head were used. This grouping imposes a truncation by excluding the 98 smallest and 21 largest farms from the representative farm mean calculations. Two means were used because smallest farms were assumed to be the least likely group to adopt, and largest farms had widely varying incomes, herd sizes, and acreages that would skew the mean calculation. By splitting the sample into two groups and imposing a truncation, the possibility of a few farms dominating and skewing the mean calculations was eliminated.

Consequently, two sets of marginal effects are reported for comparison in order to reflect the two size categories, designated as small (*X*small) and large (*X*large) herds. Both are based on parameter estimates from the restricted model. The mean values used for x_i for small and large herds are reported in the first two columns of Table 5. The marginal effects for both herds calculated subject to no planned expansion or retirement (i.e., with the planned changes variable set to zero) are reported in columns three and four. In columns five and six, the planned changes variable is set to one, and marginal effects are calculated for small and large herds looking to expand herd size, retire within five years, and have family members plan to farm.

For the linear variables, the sign of each marginal effect in all four farm situations was the same as the estimated parameter sign. For private motives, the marginal effect was determined by both the private motives and motive interaction parameters and was negative and very small in each case. The marginal effect of social motives was determined by the motive interaction parameter and had the same sign. Four marginal effects were statistically significant for both herds with no changes planned and for small herds with changes planned. Five were significant for large herds with changes planned.

Since farmers with planned changes were considerably more likely to consider adoption, the magnitudes of the marginal effects of individual variables are discussed here only for such dairies. With all other covariates constant at their small or large herd means, the largest difference in individual variables altered the predicted probability of seriously considering adoption by the following amounts for small and large herds, respectively: private costs (36.4% and 40.6%), social costs (30.3% and 33.7%), innovation receptivity (11.7% and 13.1%), alternative investments (-13.7% and -15.3%), planned changes (15.3% and 17.0%), private motives (-0.7 and -0.1), and social motives (24.5% and 38.7%). Thus, private costs, social costs, and social motives had the largest impacts (each in the 25-41% range) on serious consideration of adoption. Innovation readiness, alternative investments, and planned changes had moderate impacts (each in the 12-17 absolute% range). Although both the private motives and motive interaction variables were significant, their opposite signs basically cancelled out any impact of private motives on the conditional marginal effect estimate for private motives.

The estimated impacts based on the expanded model were almost identical to those based on the restricted model. Only the estimated impacts of social motives differed by more than 1% from those based on the restricted model, and they were all lower (up to 10% lower) than those based on the restricted model. In contrast to the large impacts implied by all variables except private motives in the restricted model, each of the remaining variables in the full model had less than a 2% impact on the probability of seriously considering adoption.

The importance of planning for changes is evident in the change in overall probability of seriously considering adoption (not reported in the table). The probability that the farmer is seriously considering adoption, conditional on no planned changes, is 5.9% for the small herd and 11.1% for the large herd. With planned changes, the predicted probability of seriously considering adoption increases by 11.6% for the small herd and 15.2% for the large herd.

VI. DISCUSSION AND POLICY IMPLICATIONS

This study has built on previous conservation adoption studies by considering diverse motivations from the behavioral economics, social psychology, and neuroeconomics literatures and attitudinal-knowledge status of the decision maker from the diffusion literature, in addition to the standard economic concepts. Rather than using a large number of highly collinear, primary variables, aggregate variables were created to proxy private and social costs of the project as well as private and social motives, opportunity costs, capacity, and knowledge typology of the decision maker. Two capacity variables were found to be unimportant in explaining the decision to seriously consider adoption of digester technology. Private and social costs, private and social motives, one opportunity cost variable, and knowledge typology (motivated as an attitudinal capacity variable) proved to be important to the decision. Two of these variables warrant particular attention.

None of the variables used in the creation of social motives directly impacts adoption on its own. Yet, U^{soc} behaves in the manner expected for a variable capturing the latent effect of environmental stewardship on the decision to adopt. It is plausible that environmental stewardship can emerge from genuine altruism toward neighbors, future generations, or ecosystems. Alternatively, environmental stewardship may result from concern about what the neighbors might do through political processes or legal action. Interestingly, in the restricted model, pro-social motives only enter as a positive interaction with the egoistic motives, whereas private motives alone have an individual negative effect and a net zero effect due to the interaction term. This result can be interpreted quite consistently with the dual-motive theoretical models (especially recalling the speculation that private profit motive alone might have a negative sign, given the historic pessimism over the profitability of anaerobic digesters). These results suggest that pure profit-seeking implies little interest in anaerobic digestion – and a sacrifice in the "utility" to be gained by the pro-social action. On the other hand, when the profit and other motives are brought together, the net effect is to "quiet" the negative profit-based motives and enhance the environmental, other-based motives. Hence, these results not only support the dual-motive theory, but suggest viewing many farmers as financially-realistic, environmentally-sensitive, dual-motive agents. In this relationship between private and social motives, we see the interdependencies found in the dual-motive theories, and we get a taste of agents "working out" their decisions by resolving the dual motives in a process similar to the prospective volition model described (for collective action) by Bromley (2004).

The diffusion/innovation readiness variable is based on a knowledge typology which places the diffusion process in a context with multiple communication channels and it incorporates these multiple channels into the specification of the stages of diffusion. This technique is a significant improvement over widely used single-channel simplifications of diffusion theory. The use of standard proxies for diffusion, such as knowledge of the problem or education, does not formally address the importance of multiple communication channels, nor does it show how the different channels are employed by the agents at various stages of diffusion. While the survey data used in this study were not fine-tuned to produce an explicit diffusion variable, the construction of the innovation readiness variable was a step towards incorporating a refined version of diffusion theory into socioeconomic adoption models.

Anaerobic digestion is an integrated sustainable conservation technology that contributes to climate, air, and water environmental goals. We have documented several conditions that substantially increase the estimated probability of dairies adopting the technology. However, it should be noted that the adoption of digestion technology could be inadvertently hindered by current public policy regarding alternative fuel development.

For example, at the time of the survey in May 2006, Northwest milk prices were only $11.30 per hundredweight (Northwest Dairy Association 2007). In 2007, the price of milk rose dramatically, but dairies were facing increasing financial pressures due to much higher corn prices (*ibid*). The rising demand for corn is putatively due to developments in the market for ethanol. This increasing demand for corn, currently subsidized by government programs, could drive up feed prices for dairy farmers over the long term. The rising demand for corn creates a negative pecuniary externality to dairy farmers which could result in a negative incentive for creation of energy through anaerobic digestion.

A related example is the incentive to burn wood byproducts to create energy. As wood mills install generation facilities powered by burning mill by-products, an important source of bedding becomes less available to dairy farms.

In both cases, one green energy technology could result in reduced adoption of another green energy technology. If dairy farmers face uncertainty with regard to feed and bedding price and availability, the adoption of digestion technology may become less appealing. These examples illustrate the complex interconnections in emerging bioenergy markets. Attention is required at the policy level to ensure that one industry does not bear undue cost as the nation endeavors to become cleaner and more sustainable.

VII. SUMMARY AND CONCLUSIONS

This study employed an ordered probit model to investigate the characteristics of dairy farmers who may consider adopting anaerobic digestion technology. The use of an ordinal scale for a dependent variable differs from typical adoption studies. By using this ordinal scale and the ordered probit procedure required to implement the model, this study combined stated and revealed preferences in one empirical model. By using stated preferences, a model was estimated to determine adoption behavior prior to widespread adoption. This expands on previous conservation adoption studies that examine only revealed preferences, and provides an empirical approach that can be used early in the diffusion process. In this study, we focus on results for those respondents seriously considering adopting because they are of particular research and policy interest.

The models used in this analysis were estimated from a data set of 230 Pacific Northwest dairy farms. Particular attention was given to the construction of variables that capture salient features of behavioral economics and conservation adoption literature in a small number of aggregate proxies. Of the variables for which clearly signed hypotheses were identified, all but one proved to be statistically significant and important to the decision to seriously consider adoption. They included private and social costs, private and social motives, one opportunity cost variable, and knowledge typology. This finding supports theories about two sources of agent heterogeneity: heterogeneous motives towards stewardship (from the social psychology and behavioral economics literatures) and heterogenous personal characteristics concerning knowledge states, innovation motives and communication channels (from the conservation adoption and diffusion theory literatures).

This study supports the application of behavioral economics and conservation adoption theory to describe which dairies are likely to adopt manure digester technology. It provides substantive support for the dual-motive, dual-interests, dual-utilities model. It supports past work showing that adoption decisions are influenced by economic and practical factors. Thus, the variables representing private costs were quite important as one would expect from traditional economic approaches. Hence, the study highlights the value of model integration rather than replacement. The use of a combined stated and revealed preference dependent variable along with the construction of indices representing key variables based on the dual-motive literature, and including diffusion typology and stewardship motivators, could prove valuable in future adoption studies, particularly studies about the process of adoption.

One implication of this study is that policies could affect heterogeneous agents in different ways. There has been a long practice of aiming certain programs at the "innovators." This study supports the idea that it may be beneficial for policy to target different types of agents. Regarding the diffusion process and the value of knowledge, it supports past studies suggesting that information can be critical for agents who are closer to an adoption decision.

Other implications stem from support for the dual-motive model of environmental sensitivity. For farm operators with the dual motives and practical outlook found in this study, the policies most likely to work are those that are financially feasible and that build a shared motivation to work together for the environment and the community. While the interaction between profit and environmental motives turned out to be complicated, it appears that the financial incentive variables alone had little effect on adoption, whereas the social motives were quite strong. One could argue that policy could be more effective by shifting away from pure financial incentives and working toward a shared motivation, or, perhaps even better, by better integrating financial incentives with shared motivation.

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TABLE 1

Definition of Primary Variables

Variable	Definition	Unit
ADOPT	Level of adoption consideration for digestion	Categorical, 1 to 5
HERD	Total herd size	Head
MILK/COW	Milk per cow	Cwt
MANAGE	Time spent managing manure, week	Categorical, 1 to 4
HERD/ACRE	Total herd/Total acreage	Continuous
FLUSH	Manure collected with flush system	%
ODOR	Acres with odor concern	Acre
WATER	Acres with water quality concern	Acre
URBAN	Acres within 5 miles of town	Acre
LANDVAL	Value of land owned	$
HERDVAL	Value of herd	$
URBAN%	% of land within 5 miles of town	%
EDVAL	Earning value of education	$
DOVAL	Earning value of experience	$
DIFFUSION	Predicted innovation receptivity	Index
NO-EXPAND	Expansion not planned	0, 1
OFF-FARM	Operator employed off farm	0, 1
EXPAND	Expansion planned	0, 1
RETIRE	Retirement planned in 5 years	0, 1
INHERIT	Family member will farm	0, 1
ACREOWN	Owned land	Acre
MILK	Milk produced	Lb
WATERIMP	Water quality important in decision making	0, 3, 8
AIRIMP	Air quality important in decision making	0, 3, 8
VENTURE	Interested in joint venture for AD investment	0, 1
ENVBEN-F	AD environmentally beneficial to farm	0, 1
ENVBEN-S	AD environmentally beneficial to society	0, 1, 2

TABLE 2

Aggregate Proxy Variables

Proxy (Index) Variable	Sub-Index	Primary Variables[a]
Private costs (C^{pvt})	MNRLOAD	HERD, MILK/COW
	MGMTLOAD	MANAGE, HERD/ACRE, FLUSH
Social/environmental costs (C^{soc})		ODOR, WATER, URBAN, HERD
Financial capacity (K^{fin})	ASSET	LANDVAL, HERDVAL
Human capital capacity (K^{hum})		EDVAL, DOVAL
Innovation readiness (K^{innov})		DIFFUSION
Alternative investments (O^{alt})		URBAN%, NO-EXPAND, OFF-FARM
Planned changes (O^{chg})		EXPAND, RETIRE, INHERIT
Private motives (U^{pvt})		ACREOWN, MILK, EXPAND
Social motives (U^{soc})		WATERIMP, AIRIMP, VENTURE, ENVBEN-F, ENVBEN-S

[a] See variable descriptions in Table 1. All variables were scaled to 0-1 before and after aggregation.

TABLE 3

Regression for Predicting K^{innov}

Independent Variable	Coefficient	Standard Error	t-statistic	p-value
INDUSTRY	0.0365	0.0351	1.0400	0.2990
PUBLICATIONS	0.0298	0.0314	0.9500	0.3440
OPERATION	0.0599	0.0359	1.6700	0.0970
EXPERT	0.2238	0.0366	6.1200	0.0000
ADJ-1	-0.0384	0.0279	-1.3700	0.1710
ADJ-2	-0.0364	0.0476	-0.7600	0.4450
ADJ-3	-0.1636	0.0601	-2.7200	0.0070
R^2 = 0.2614		Adj. R^2 = 0.2368		

[a] Values of 1 for these dichotomous variables have the following interpretations: K^{innov} – extensively researched digestion technology; INDUSTRY – discussed digestion technology with other farms or industry people; PUBLICATIONS – read about digestion technology in current trade journals and other publications; OPERATION – saw a digester in operation; EXPERT: digestion technology explained by an expert; ADJ-1,2,3 – number of "Yes" answers to INDUSTRY, PUBLICATIONS, OPERATION, and EXPERT.

TABLE 4

Cumulative Model Parameter Estimates

	Linear Model			Expanded Model			Restricted Model		
Independent Variable	Parameter	Std Error		Parameter	Std Error		Parameter	Std Error	
Private costs (C^{pvt})	1.522974	.4840426	***	1.586158	.4862357	***	1.623541	.4803753	***
Social/environmental costs (C^{soc})	1.414856	.7592338	***	1.33139	.7639844	*	1.34877	.7526551	*
Financial capacity (K^{fin})	-.0075012	.7820349		.0778651	.7839733				
Human capital capacity (K^{hum})	-.0562295	.5188751		-.0076004	.52165				
Innovation readiness (K^{innov})	.5434375	.2643573	**	.5340705	.2645131	**	.5229972	.2636576	**
Alternative investments (O^{alt})	-.5948788	.8746803		-.648538	.8712916		-.6121199	.6882183	
Planned changes (O^{chg})	.580424	.3654003		.6510097	.3679509	*	.6816455	.3662505	*
Private motives (U^{pvt})	.1057235	1.174816		-2.096967	1.723539		-2.796638	1.229408	***
Social motives (U^{soc})	1.345302	.422677	***	.532341	.6254215				
Motive interaction ($U^{pvt}*U^{soc}$)				2.526754	1.448583	*	3.436802	.9743693	***
/cut1	1.270225	.6122972		.8289793	.6614124		.5585693	.459581	
/cut2	2.100623	.6183837		1.660735	.6665648		1.386303	.4630028	
/cut3	2.964039	.6312796		2.538452	.6758973		2.263344	.4753442	
/cut4	4.073563	.6643803		3.684358	.7019745		3.41454	.5190798	
Pseudo R^2	0.1368			.1418			.1405		
n	214			214			214		
Log likelihood	-262.2496			-260.7300			-261.1073		

Significance levels: * – 10%, ** – 5%, *** – 1%.

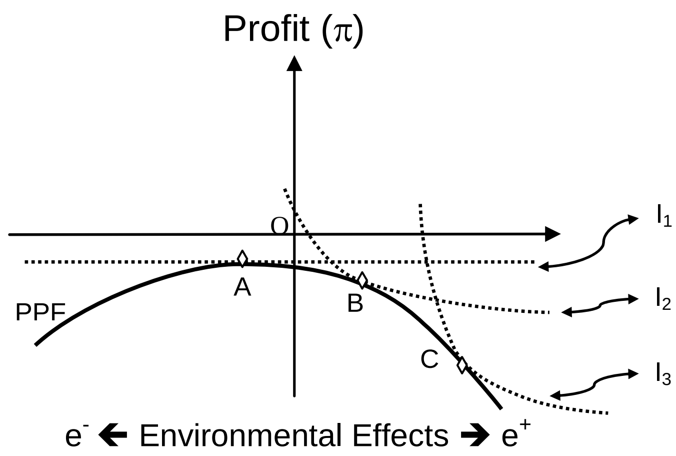
TABLE 5

Conditional Marginal Effect Estimates, Restricted Model

	Mean Values for Marginal Effects Calculations		Marginal Effects $\partial \Pr[CONSIDER = 4]/\partial x_i$			
			No Changes Planned		With Changes Planned	
Independent Variable	*X*small	*X*large	*X*small	*X*large	*X*small	*X*large
Private costs (C^{pvt})	0.383964	0.4931967	.183141**	.2827432***	.3642187***	.4059799***
Social/environmental costs (C^{soc})	0.129865	0.2518391	.1521459	.2348912	.3025777*	.3372711*
Innovation readiness (K^{innov})	0.283756	0.2682414	.0589959*	.0910811*	.1173271*	.1307798*
Alternative investments (O^{alt})	0.337626	0.3048286	-.0690492	-.106602	-.1373205	-.1530656
Planned changes (O^{chg})	0 or 1	0 or 1	.0768919***	.11871***	.1529176	.1704511*
Private motives (U^{pvt})	0.2356293	0.3341989	-.003311	-.000657	-.006585	-.000944
Social motives (U^{soc})	0.59701	0.6025282	.123201***	.269778***	.245019***	.387363***

* Indicates significance at a 10% level.

FIGURE 1. Profit-Environment Production Possibility Frontier



FOOTNOTES

[1] We will use the term anaerobic digestion to refer to the biological and technological processes involved. We will use anaerobic digester to refer to the equipment itself. Occasionally, we will use the acronym, AD, for either term.
[2] The Pacific Northwest encompasses Washington, Oregon and Idaho.
[3] The typology was initially developed by Bohlen and Beal (1957).
[4] The authors wish to thank an anonymous reviewer for inspiring several of our newer features, including the aggregate variable approach discussed below.
[5] A recent review detailing the interconnections among economics, psychology and neuroscience which comprise neuro-economics contained about 80 citations. They “challenge the core assumption in economics that behavior can be understood in terms of unitary evaluative and decision-making systems” (Sanfey et al. 2006).
[6] Although the formal mathematical algorithms of maximization require “rationality” in the technical sense (as laid out by the assumptions of choice theory), “optimization” can be obtained by non-rational heuristic processes – trial and error.
[7] In prospective volition, the action is worked out in an unfolding process of investigation and argumentation over both means and ends to find a feasible and “best” course of action. Bromley (2004) develops this notion in the context of collective action. We apply it here to the decision of the dual-motive individual. We are indebted to a reviewer for alerting us to the pragmatic/Bromley formulation.
[8] Many mechanisms are possible. For example, changes in quantity demanded with falling prices for new products could produce such curves, but the curves seem to persist even when price does not fall.
[9] For instance, Robert Cloninger identifies a number of personality traits which could affect differential rates of adoption readiness, including harm avoidance (anxiety-proneness versus risk-taking), novelty seeking (impulsiveness versus rigidity) and persistence (determination versus fickleness) (Levine 2006).
[10] The mean herd size for surveyed farms in the “less than $250,000” gross income category was 84 head, and the mean herd size for farms in the “$250,000 to $500,000” gross income category was 170 head. The high cost of digestion technology suggests that farms with less than $250,000 gross income would have a hard time financing a digester until an emerging technology proves economic for small farms.
[11] AgSTAR is a joint EPA-USDA program that promotes the use of biogas recovery systems (U.S. EPA 2006).
[12] Formally, the scale should also be single dimensional; we assume that the options can be laid out on a single scale from no probability of adoption to full adoption.
[13] We are indebted to an anonymous reviewer for suggesting this focus on fewer, informative variables.
[14] We explored a principal component/factor analysis approach to define proxy variables. The results were neither as intuitive nor as statistically informative as the index approach.
[15] In principle, there could be other factors in the cost structure, including any positive returns that are available from the co-products of managing waste. Some of this potential value is captured implicitly in the variables having to do with herd size relative to farm size (acreage), where spreading manure is likely to have benefits beyond simply disposing of waste. Also, we have no explicit variable measuring the relative riskiness of different technologies.

[16] Although the aggregate index is expected to have a causal impact, our statistical procedures only permit us to identify correlation between variables.
[17] A number of techniques are used in the conservation literature to gauge farm environmental problems. These techniques include indices and quantitative measurements of potential environmental detriment (Upadhyay et al. 2003; Taylor and Miller 1978; Nowak 1987; Ervin and Ervin 1982).
[18] We use liability in the economic sense of responsibility for damages rather than as a technical legal term.
[19] Again we are indebted to an anonymous reviewer whose comments on the standard control variable approach inspired our search for an alternative.
[20] In Roger's Innovation Decision Process theory, the diffusion process occurs over time through five stages (knowledge, persuasion, decision, implementation and confirmation) both within the individual and for the aggregate population. In the original Rogers terminology, the five agent types were labeled innovators, early adopters, early majority, late majority, and laggards.
[21] Land tenure is a staple in adoption studies (e.g., Rahelizatovo and Gillespie 2004; Upadhyay et al. 2003; Lynne, Shonkwiler, and Rola 1988). Soule et al. (2000) provide an in-depth analysis of how rental arrangements influence the adoption of conservation practices, primarily in crop-oriented studies.
[22] The spacing between categories for those seriously considering adoption and the actual adopters can be problematic if the actual adopters are conceptually different from non-adopters. That is, does the actual adoption category belong on the same scale with the other four categories. The use of a generalized ordered probit model was considered because it is more flexible with regard to model restrictions. However, estimation of an earlier model with the generalized model failed to converge, likely due to the small number of observations in category 5.
[23] Pseudo R2 = 1 - (constant-only log likelihood)/(full model log likelihood)
[24] The statistical results for category 5 were regarded as uninformative because of the small number of actual adopters.