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Factor Price Risk and the Diffusion of Conservation Technology: Evidence from the Water Industry

Georgina Moreno
Department of Economics
Scripps College

David Sunding
Department of Agricultural and Resource Economics
University of California, Berkeley

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Abstract

The paper examines the influence of factor price risk on factor-use efficiency through the adoption of conservation technology. The effect of a mean-preserving increase in factor price risk on optimal input-use efficiency is shown to be conditional on the own-price elasticity of factor use evaluated at the initial equilibrium. The conceptual analysis indicates that that there may be a discrepancy between the aggregate and firm-level effects of price risk on efficiency. Theoretical results are tested and confirmed using a unique data set from the water industry.

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I. Introduction

In recent years, technology diffusion has become a main theme of environmental economics. This interest stems from the demonstrated ability of new technologies to ameliorate the conflict between environmental quality and economic activity. Indeed, some have argued that the successful diffusion of new technologies is among the most important factors leading to the success of environmental policies and improvement in environmental quality (Kneese and Schultz (1978); Jaffe, Newell and Stavins (2001)).

Conservation technologies are prime examples of technology that benefits the environment. These technologies typically entail a fixed up-front investment, in return for which they produce some desired output with a lower level of resource use. Examples abound, and include electricity-conserving appliances, fuel-efficient cars and water-saving irrigation technologies.[1]

Economic models of technology diffusion have established the principle that prices have a large effect on the adoption decision (see the survey article by Sunding and Zilberman (2001)), and conservation technology is no exception to this rule. In particular, it has been well established that the diffusion of conservation technology is stimulated by an increase in factor prices. A recent study by Pizer et al. (2001) examined the highly polluting oil refining, plastics, pulp and paper, and steel industries and found that increases in energy prices increased the likelihood of adopting conservation technologies. Rose and Joskow (1990) demonstrated that fuel price increases had a positive and significant effect on the diffusion of a fuel-saving technology in the electricity

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[1] Conservation technologies are not the only type of technology that benefits the environment. Pollution-reducing technologies lower the amount of effluent produced per unit of output. These technologies are not considered in this paper.

industry. Similarly, Boyd and Karlson (1993) showed that the diffusion of an energy-saving technology used in the U.S. steel industry was positively related to the price of fuel.

While the effect of input price on adoption is fairly clear, the influence of changes in factor price *risk* on long-run efficiency is not well understood. This omission in the literature is significant, and somewhat surprising, since price volatility is quite evident in resource markets and economists have speculated that price risk may play an important role in determining input-use efficiency. Consider, for example, the survey article by Jaffe, Newell and Stavins (2001). While the authors agree that price risk influences the diffusion of conservation technology, their discussion of the impact of price risk is couched mainly in terms of Dixit-Pindyck "irreversibility" effects. They observe that price risk affects a firm's hurdle rate and thus the *timing* of investment in conservation technology. There is undoubtedly merit in this argument, and empirical studies have confirmed, consistent with the option value hypothesis, that adoption is more likely to occur in periods where input price is high (see, for example, Carey and Zilberman (2001)). What has not been studied in detail is the more basic question of how price risk affects the relative long-run returns from conventional and conservation technology. In particular, it is not clear whether an increase in price risk makes the conservation technology makes the conservation technology less or more attractive.

We pursue the question of how factor price risk influences the diffusion of conservation technology by developing a conceptual model of long run input-use efficiency. This framework is consistent with the seminal approach of Hausman (1979) that views technology adoption as embedded in a two-stage process of input demand. In the first stage, an input-use technology is selected, thereby fixing the input-output ratio. In the second stage, agents choose the level of output, which implies a level of factor utilization.

Our approach to the relationship between price risk and conservation technology adoption is also related to Abel's 1983 paper on optimal factor intensity. Abel considers a mean-variance model of the choice of optimal factor intensity and shows that, in general, a marginal increase in the variance of the factor price has an ambiguous effect on factor intensity. While our paper and Abel's are related in that they both use a two-stage framework, our conceptual model relies on a more general stochastic dominance approach instead of a change in variance in a two-moment model as considered by Abel. In particular, our conceptual analysis considers the case of a mean-preserving increase in factor price risk, which is perhaps the purest expression of an increase in risk. Economists have been aware for some time of the distinction between an increase in risk and an increase in variance. Although this notion is usually attributed to Rothschild and Stiglitz (1970), the same point was made by Borch (1969), and was appreciated decades earlier by some researchers outside economics (for example, Hardy et al. (1934)).

A main conclusion from our conceptual analysis is that a mean-preserving increase in price risk can increase or decrease the optimal level of factor-use efficiency. The direction of the change in efficiency relates to the short-run elasticity of input demand with respect to the input price. If factor utilization is elastic with respect to realizations of the input price, then an increase in risk increases optimal efficiency. If utilization is inelastic, then the opposite result holds.

Our conceptual model is then used to formulate an econometric test of the influence of price risk on factor use efficiency. We utilize a unique data set from the water industry comprised of observations on water use efficiency at the micro level for two groups of farms served by the same water utility. Membership in the groups is exogenously determined by historical water rights that are appurtenant to the land and not the owner. By design, these groups face prices with identical means but different levels of price risk. We estimate an ordered probit model of technology choice whose form is determined by the conceptual model. In particular, we estimate a model in which factor price risk is interacted with a measure of the elasticity of utilization. Results are consistent the main hypotheses, and highlight the importance of considering the impact of changes in price risk at an appropriate scale.

The paper is structured as follows. In Section II, we present the basic conceptual model. Section III lays out the main conceptual results concerning the effect of price risk on conservation technology adoption. Section IV presents the empirical model, data and estimation results. Concluding comments relating to policy implications, aggregate input-use efficiency and induced innovation are given in Section V.

II. The Model

Consider the input use problem of an individual agent such as a household or firm. Following Hausman (1979), we suppose that input use per period is the result of a two-stage decision process. In the first stage, the agent chooses the level of input use efficiency (measured by the input-output coefficient, a), by selecting among a continuum of possible technologies. Each possible technology is characterized by the pair $\{a, z\}$, where z is the annualized fixed cost of the technology. More efficient technologies require a larger outlay, and thus $z = z(a)$ with $z_a < 0$.[2]

In each period, the agent chooses an output level, x. The consumer's periodic input use is then $\bar{a}x$, where the bar denotes that the efficiency of input use is fixed by the prior choice of technology. The agent faces a stochastic input price, $p \in \left[\underline{p}, \overline{p}\right]$. The parameter p has a known distribution $F(p,\theta)$, where θ indexes risk and the corresponding density function is $f(p,\theta) = dF(p,\theta)$.

This model of input use and technology choice can be applied to a number of different energy and natural resource goods. For example, in the case of air conditioners, the activity level *x* is degree-hours cooled, *p* is the price of electricity, and *a* is the electricity requirement per unit of cooling. In the case of automobiles, *x* is the number of miles driven, *p* is the price of gasoline, and *a* is miles per gallon. In both cases, consumers decide input-use efficiency through their choice of technology based on their expectations about factor prices, and choose the level of factor use in each period based on the previous choice of input-use efficiency and the current factor price.

Now consider the conditions for short- and long-run optimization. In the short-run, the input-output ratio is fixed and the agent chooses the activity level to maximize welfare conditional on known prices. The agent's short-run optimization problem is given by

$$\max_x \; U = B(x) - pax - z(a)$$
$$s.t. \; a = \overline{a}$$

where $B(x)$ is the level of benefit derived from output level *x*, $B_x > 0$ and $B_{xx} < 0$.. The first order condition for this problem is

$$(1) \qquad B_x - p\overline{a} = 0 \;\; \forall p \,,$$

which implicitly defines the optimal level of output as a function of the input price and the prior choice of technology, or $x = x(p,\overline{a})$. From condition (1), we obtain the following comparative statics results:

$$x_a = \frac{p}{B_{xx}} < 0 \text{ and } x_p = \frac{a}{B_{xx}} < 0 \,.$$

[2] Subscripts denote derivatives.

Denote the elasticity of input demand as $\varepsilon = x_p \, p/x$. For simplicity, we consider the case of constant elasticity with respect to the factor price (but not with respect to *a*, however); later, we relax this assumption and show that the main result is only slightly modified.

Now we turn to the long-run investment decision in which the agent chooses input-use technology to maximize expected utility. The long-run problem can be expressed as

$$\max_a \; EU = \int_{\underline{p}}^{\overline{p}} [B(x) - pax - z(a)] f(p, \theta) dp$$
$$s.t. \; x = x(p, a)$$

The first-order condition for the technology choice problem is

$$(2) \qquad \int_{\underline{p}}^{\overline{p}} [B_x x_a - pax_a - px] f(p, \theta) dp - z_a = 0$$

The first two terms in the integral cancel out by the short-run first-order condition (i.e., by the Envelope Theorem since $B_x - pa = 0 \; \forall p$). Thus, (2) simplifies to

$$(3) \qquad -\int_{\underline{p}}^{\overline{p}} px f(p, \theta) dp - z_a = 0$$

This optimality condition sets the expected marginal value of conservation, that is, the expected cost savings from increasing efficiency, equal to the marginal cost of a more efficient technology. We use this condition to evaluate the impact of an increase in factor price risk on the choice of technology.

III. Factor Price Risk and Technology Choice

We consider an increase in risk of the type described by Rothschild and Stiglitz (1970), namely a mean-preserving increase in risk.

Definition: An increase in factor price risk occurs when

i) $\int_{\underline{p}}^{p} F_\theta(p,\theta)dp \geq 0 \;\forall p$, and

ii) $\int_{\underline{p}}^{\overline{p}} F_\theta(p,\theta)dp = 0.$

It is now possible to show the following:

Proposition: If an increase in θ increases risk as defined, then

$\text{sgn}\left[da/d\theta\right] = \text{sgn}\left[|\varepsilon| - 1\right]$.

Proof: Totally differentiate (3) with respect to *a* and θ and rearrange as follows:

$$(4) \qquad \frac{da}{d\theta} = \frac{\int_{\underline{p}}^{\overline{p}} pxf_\theta(p,\theta)dp}{LRSOC}.$$

LRSOC is the second-order condition of the technology choice problem, and is negative. Thus,

$$(5) \qquad \text{sgn}\left[da/d\theta\right] = \text{sgn}\left[-\int_{\underline{p}}^{\overline{p}} pxf_\theta(p,\theta)dp\right].$$

Integrating the right-hand side by parts, we see that

$$(6) \qquad -\int_{\underline{p}}^{\overline{p}} pxf_\theta(p,\theta)dp = -\overline{p}x(\overline{p},a)F_\theta(\overline{p}) + \underline{p}x(\underline{p},a)F_\theta(\underline{p}) + \int_{\underline{p}}^{\overline{p}}\left[x + px_p\right]F_\theta(p,\theta)dp$$

The first two terms on the right-hand side equal zero since the supports of the factor price density are invariant. This leaves the expression

$$(7) \qquad -\int_{\underline{p}}^{\overline{p}} pxf_\theta(p,\theta)dp = \int_{\underline{p}}^{\overline{p}}\left[x + px_p\right]F_\theta(p,\theta)dp.$$

Integrate this equation by parts again to obtain

$$-\int_{\underline{p}}^{\overline{p}} pxf_\theta(p,\theta)dp = \left[x(\overline{p},a)+\overline{p}x_p(\overline{p},a)\right]\int_{\underline{p}}^{\overline{p}} F_\theta(p,\theta)dp$$

$$(8) \qquad -\left[x(\underline{p},a)+\underline{p}x_p(\underline{p},a)\right]\int_{\underline{p}}^{\underline{p}} F_\theta(p,\theta)dp +$$

$$-\int_{\underline{p}}^{\overline{p}}\left[\int_{\underline{p}}^{p} F_\theta(p,\theta)dp\right]\left[2x_p + px_{pp}\right]dp.$$

The first two terms on the right-hand side of (8) vanish: the first by the definition of the mean-preserving increase in risk and the second by the invariance of $\underline{p}$. Thus, we are left with the following expression:

$$(9) \qquad -\int_{\underline{p}}^{\overline{p}} pxf_\theta(p,\theta)dp = -\int_{\underline{p}}^{\overline{p}} \Psi(p)\left[\frac{x}{p}\varepsilon(1+\varepsilon)\right]dp,$$

where $\Psi(p)=\int_{\underline{p}}^{p} F_\theta(p,\theta)dp \geq 0 \ \forall p$ and we use the fact that

$\left[2x_p + px_{pp}\right] = \frac{x}{p}\varepsilon(1+\varepsilon)$. It follows that

$$\operatorname{sgn}\left[\frac{da}{d\theta}\right] = \operatorname{sgn}\left[|\varepsilon|-1\right]$$

as claimed. ||

This proposition establishes that the impact on technology choice of an increase in risk depends on the elasticity of input use with respect to the factor price (more precisely, the elasticity of factor demand conditional on $a = a^*$).[3].

To gain some intuition for this result, first note that $MP = px$ is the marginal productivity of an increase in input-use efficiency, or a decrease in the input-output ratio. Accordingly, $MP_{pp} = \frac{x}{p}\varepsilon(1+\varepsilon)$ is the second derivative of the marginal productivity with respect to the input price. If this derivative is positive (i.e., if $|\varepsilon|>1$), then the marginal productivity of increasing the input-output ratio is convex in the input price, and a mean-preserving change in the factor price density increases the *expected* productivity of an improvement in input-use efficiency.[4] Conversely, if $|\varepsilon| < 1$, then MP is concave and the opposite holds.

It is worth noting that the proposition is unaffected by the assumption that the agent never "shuts down" (i.e., does not use any factor at all if the price is too high). In fact, there may exist a factor price $\hat{p}$ such that $x(p,a) = 0 \ \forall p \geq \hat{p}$. In this case, equation (6) becomes

$$\text{(6')} \quad -\int_{\underline{p}}^{\hat{p}} px f_{\theta}(p,\theta)dp = -\hat{p}x(\hat{p},a)F_{\theta}(\hat{p}) + \underline{p}x(\underline{p},a)F_{\theta}(\underline{p}) + \int_{\underline{p}}^{\hat{p}} \left[x + px_p\right] F_{\theta}(p,\theta)dp$$

The first term on the right-hand equals zero by the definition of $\hat{p}$. The second term equals zero since the supports of the density are invariant with respect to a change in risk. Thus, we are left with (7) as before (with the exception that the upper limit of integration is now $\hat{p}$). Then, (8) becomes

$$\text{(8')} \quad \begin{aligned} -\int_{\underline{p}}^{\hat{p}} px f_{\theta}(p,\theta)dp = &\left[x(\hat{p},a) + \hat{p}x_p(\hat{p},a)\right]\int_{\underline{p}}^{\hat{p}} F_{\theta}(p,\theta)dp \\ &-\left[x(\underline{p},a) + \underline{p}x_p(\underline{p},a)\right]\int_{\underline{p}}^{\underline{p}} F_{\theta}(p,\theta)dp + \\ &-\int_{\underline{p}}^{\hat{p}}\left[\int_{\underline{p}}^{p} F_{\theta}(p,\theta)dp\right]\left[2x_p + px_{pp}\right]dp. \end{aligned}$$

The first term on the right-hand side vanishes by the definition of $\hat{p}$ (i.e., since $x(\hat{p},a) + \hat{p}x_p(\hat{p},a) = x(\hat{p},a)\cdot(1+\varepsilon) = 0$ at $\hat{p}$), and the second term vanishes because $F(\underline{p},\theta) = 0$. Thus, we are left with (9) as before (again with the replacement of $\hat{p}$ for $\overline{p}$), and the proposition goes through.

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[3] A similar condition holds when the short-run elasticity is not constant. We discuss this point later in the text.
[4] This argument is essentially an expression of Jensen's Inequality.

When the constant elasticity form is relaxed, the main result goes through with some modifications. In particular, note that

$$-\left(2x_p + px_{pp}\right) = -x_p\left(2 - x_a x_p B_{xxx}\right).$$

It follows that this expression is positive if $B_{xxx} < \frac{2ap}{\left[\varepsilon(p)x\right]^2}$, where $\varepsilon(p)$ is the elasticity of x evaluated at p. Thus, the principle that the effect of factor price risk on efficiency depends on the responsiveness of the activity level to the factor price remains unchanged. Further, when input use is highly responsive to the factor price (at least over some range of p), it is more likely that an increase in risk increases factor-use efficiency since it is less likely that the inequality above is satisfied.

Before turning to the empirical analysis, we should note that an examination of energy and natural resource markets shows that short-run elasticities of factor utilization can take on a wide range of values. Table 1 displays some estimated own-price elasticities of utilization. The estimated elasticity for residential water is near –0.5, while that for residential electricity is estimated to be roughly twice this figure. Accordingly, the conceptual model developed above implies that we should expect the effect of changes in price risk to vary among these markets.

IV. Empirical Analysis

In this section, we test the relationship between adoption of conservation technology and the magnitude of factor price risk. The statistical analysis is facilitated by our use of a unique data set from the water industry. This data set consists of observations on micro-level technology choice in an agricultural water district where farmers are divided into two groups (or "service areas"). Water rates in these service areas are designed such that mean water prices are identical, but prices fluctuate more in one area than in the other. That is, prices are characterized by the mean-preserving spread relationship examined in the last section. Membership in the two service areas is not by choice, but rather is determined by long-standing water rights that are appurtenant to the underlying farm rather than to its owner. Because of the water rights institutions that govern water allocation in the western United States, different price distributions are observed regularly for water users that are otherwise similarly situated (Burness and Quirk (1980)), making water a good candidate for study in this paper.

The data set consists of observations on water-use technologies at the field level. Having data at this level of disaggregation is critical since environmental conditions such as microclimate, landscape characteristics and soil quality (which also vary at the field level) are known to exert a large influence on the choice of irrigation technology (Green et al. (1997); Caswell and Zilberman (1985)).

One of our main goals in this empirical section is to test the relationship between the price responsiveness of factor use and the magnitude of price risk. Because the data set is at the field level, we are able to proxy the price responsiveness of water utilization by observing whether the field is dedicated to permanent crops such as trees and vines, or annual crops such as cotton and hay. If the field is planted with a permanent crop, then water use is relatively unresponsive to short-run fluctuations in the price of water. If, however, the farmer produces an annual crop where acreage (i.e., the fraction of the field that is actually planted) fluctuates based on the price, then water use has been shown to be very responsive to the periodic price of water (Sunding et al (2001)).

Empirical Model

In the case considered, there are three main types of water use technology available. In increasing order of efficiency, these are gravity, high-pressure and low-pressure technologies. Gravity technology includes traditional furrow and flood irrigation systems, high-pressure systems are sprinkler systems, and low-pressure technologies are variants of drip and "microsprinkler" irrigation systems in which water is applied precisely to a plant's root zone. Not surprisingly, gravity systems are the least expensive to design and install and drip systems are the most expensive, with high-pressure systems falling in between.[5]

Although technology choice is discrete, it is possible to order the choice by efficiency to reflect the ranked nature of the alternatives. Let T^* represent the unobserved input-output coefficient of a microunit and assume that it is a linear function of net benefits from investing in technology, that is,

$$T^* = x\beta + \varepsilon ,$$

where x is a matrix of the explanatory variables, β is a vector of coefficients and ε is the error term, which is assumed to have a standard normal distribution, $\Phi(\varepsilon)$. Let μ_1 and μ_2 represent the cut-off points in the distribution for each possible technology. Technology choice can then be defined in terms of T^* as follows:

$$T = \begin{cases} 0 & \text{if } T^* \le \mu_1 \\ 1 & \text{if } \mu_1 \le T^* \le \mu 2 \\ 2 & \text{if } T^* \ge \mu_2 \end{cases}$$

where $T = 0$ indicates gravity technology is observed, $T = 1$ indicates high pressure technology is observed, and $T = 2$ indicates low pressure technology is observed.

[5] See Caswell (1983)) for a detailed description of irrigation technology used in California agriculture.

The cut-off points are estimated empirically. In particular, we estimate the following probabilities:

$$
(10) \quad
\begin{aligned}
\Pr(T = 0) &= \Phi(\mu_1 - \beta' x) \\
\Pr(T = 1) &= \Phi(\mu_2 - \beta' x) - \Phi(\mu_1 - \beta' x) \\
\Pr(T = 2) &= 1 - \Phi(\mu_2 - \beta' x)
\end{aligned}
$$

Equation (10) provides the structural model for the ordered probit estimation of the adoption of water-use technology. In the following sections we describe the data and estimation results.

Data

The data used in this analysis is a sample of 1,224 fields served by the Arvin-Edison Water Storage District, located 90 miles north of Los Angeles in California's Central Valley. The data set includes information on water-use technology, environmental conditions, the degree of water price risk and crop choice for a cross-section of 92,294 acres of land observed in 1993. The sample is balanced across available technologies: 44 percent of the fields use gravity irrigation, 21 percent use sprinkler and 35 percent use drip. Tables 1 and 2 provide summary statistics for the data set.

To control for the effect of landscape characteristics on the choice of irrigation technology, we included two environmental variables in our estimation: soil permeability and field slope. Soil permeability is measured in inches per hour and describes how fast the soil drains, or, conversely, how well it retains moisture. In our sample, soil permeability varies from 0.13 inches/hour to 13 inches/hour. Because pressurized irrigation systems can distribute water more evenly over time, these technologies are land-quality augmenting and improve the soil's water storage capacity relative to gravity systems. Thus, we expect soil permeability to have a positive effect on water-use efficiency.

Field slope describes the grade of the field. This variable is measured in percentage terms, where a higher percentage indicates a steeper slope. Slope varies from 0.5 percent to 10 percent in our sample. Since gravity irrigation technologies are difficult to implement on sloped fields, we would expect slope to have a positive effect on optimal efficiency.

The data set also includes the size of each field in acres. Field size can be used to control for scale economies in technology adoption. If there exist scale (dis)economies associated with adoption of efficient irrigation technologies, we would expect the probability of adoption to (decrease) increase with field size. The average field in our sample is 50.8 acres.

The water district in our sample has two service areas. As discussed earlier, water rates in Arvin-Edison are designed so that customers in these service areas face the same mean price of water, but are exposed to different levels of price risk (AEWSD (1982)).[6] Owing to the nature of water rights in the western United States, the degree of price risk is a characteristic of the field, and not of its owner. Accordingly, the degree of price risk is denoted as a binary variable (*Risk*), which is coded as 1 if the field is located in the high-risk service area.

As mentioned earlier, our data set includes information about the type of crop grown on each field. Both annual and permanent crops are evident in the sample: 78 percent of the fields are devoted to permanent crops while the remaining 22 percent are allocated to annual crops. Annual crops grown in Arvin-Edison include primarily lettuce, tomatoes, potatoes and carrots, and permanent crops include oranges, grapes, and tree fruits. Again, we are interested in crop choice

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[6] In 1964, the district established an integrated water management plan to mitigate the problem of ground water overdraft and the subsequent environmental damages from overdraft, such as water quality degradation, land subsidence, and eventual aquifer depletion. This plan divided the district into two service areas. The ``surface" service area consists of irrigators receiving supplies from imported project water through the district's distribution infrastructure. The ``ground water" service area continues to extract ground water from the underlying aquifer. In wet years, the district stores the excess imported supply in the underlying aquifer, creating a ``water bank" for the surface service area. In dry years, the banked water is withdrawn to meet the supply needs of the surface service area. This water banking has alleviated the ground water overdraft and allowed ground water irrigators to continue extracting ground water. The water banking facility also stabilized water prices for the surface service area

primarily as it relates to the effect of price risk on water-use efficiency. The conceptual model predicts that the effect of increasing price risk on the choice of technology depends on the magnitude of the elasticity of utilization. In particular, the model predicts that increasing factor price risk will increase the incentive to adopt efficient technology when the elasticity of utilization is high, and reduce it when the elasticity is low. Thus, risk is included in the model directly and interacted with the crop choice variable.

Estimation Results

Table 3 presents the parameter estimates for the ordered probit model. As expected, the interaction term between risk and permanent crop production is significant, and the coefficients on the price risk and interaction terms are jointly significant.

This pattern of significance and sign conforms to the predictions of the conceptual model. When farmers produce both annual and permanent crops, the aggregate relationship between price risk and water-use efficiency is ambiguous (increasing risk leads some farmers to increase efficiency and others to decrease efficiency). This argument explains the insignificance of risk alone. The conceptual model does indicate that the influence of risk on efficiency is conditioned on the elasticity of utilization. This observation explains the significance and sign of the interaction term. Taken together, these results provide important confirmation of the theory developed earlier.

In Table 4, we consider how the probability of adopting each of the three types of technologies changes when factor price risk changes.[7] For fields devoted to annual crops, increasing price risk increases the probability of adopting drip irrigation by 5 percent. The effect on sprinkler technologies is negative but small. Looking at the results for fields in permanent crops,

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[7] Probability of adoption in Table 4 is computed for each service area/crop group at the mean of the landscape variables (50.7 acres, 2.9 inches/hour soil permeability, and 1.6 percent slope).

we find that an increase in factor price risk decreases the likelihood of adopting drip irrigation by nearly 12 percent. These results suggest that price risk has a large influence on optimal water-use efficiency.

The estimated coefficients for field size and slope are also significant.

To more easily interpret the ordered probit coefficients, consider the elasticity of the probability of adoption with respect to field size, permeability and slope. Average elasticities are given in Table 5 and are computed as follows. Let *j* index the technology, *n* denote the number of observations, and *x* denote explanatory variables. The average elasticity over all observations is

$$\bar{\eta}_{xj} = \frac{1}{n}\sum_{n=1}^{1,224}\eta_{xn} \ \ \forall j, x \ ,$$

where

$$\eta_{xn} = \frac{\partial \hat{\Pr}_{jn}}{\partial x_n}\frac{x_n}{\hat{\Pr}_{jn}}$$

and $\hat{\Pr}_{jn}$ is the predicted probability of choosing technology *j* for obervation *n*.

A one percent increase in field size decreases the probability of adopting gravity technologies by 15 percent, increases the probability of adopting high-pressure technologies by 1 percent, and increases the probability of adopting low pressure technologies by 13 percent. Field slope has a large effect on the probability of adoption. A one percent increase in slope decreases the probability of adopting gravity and high pressure technologies by 83 percent and 21 percent, and increases the probability of adoption low pressure technologies by 51 percent. Soil permeability has a smaller effect, and is statistically insignificant.[8].

[8] We investigated the exogeneity of crop choice to the model of irrigation technology selection. We could not reject the null hypothesis that crop choice is exogenous using a test of weak exogeneity (Smith and Blundell, 1993). Further, we explored whether there was a systematic relationship between crop choice and service area and found that service area is not significant in the crop choice model.

V. Discussion

This paper explores the impact of factor price risk on optimal factor-use efficiency. Since input use efficiency is often embodied in specific capital goods, it is important to consider efficiency in terms of the diffusion of conservation technologies. Toward this end, the paper first develops a conceptual model of the expected returns from conservation and conventional technologies in an effort to characterize optimal long-run efficiency. An increase in factor price risk is modeled generally using a particular notion of stochastic dominance – the mean-preserving spread. The main conclusion of the conceptual analysis is that the effect of factor price risk on efficiency is conditional on the elasticity of utilization. Accordingly, the influence of price risk on the diffusion of conservation technology should be expected to vary across industries.

The main hypothesis is tested using a unique data set concerning the adoption of water-saving technology. Water is an especially promising industry in which to test the theory developed here because the nature of water rights implies that there can be large, exogenous variations in water price risk among otherwise identical agents. Further, data on technology adoption are readily available (at least for agricultural water use), as are data on the relevant environmental conditions that have a marked effect on the relative productivity of various water-use technologies. Estimation of an ordered probit model produces results that are consistent with the conceptual model. In particular, estimation results are consistent with the main hypothesis that the impact of increasing price risk on input use efficiency depends on the magnitude of elasticity of utilization.

One of the main conclusions of economic research on technology diffusion is that the pattern of adoption over time is explained in large part by differences among potential adopters. This concept, which originates with the work of David (1969), has implications for our problem. In particular, if potential adopters of conservation technology are heterogeneous, then the impact of price risk on efficiency may be more pronounced at the firm or household level than at the aggregate level. If the input in question is a necessity to some and not to others, then price risk may encourage some users to adopt the conservation technology and others to adopt the conventional one. Thus, economists should consider carefully the impact of price volatility when predicting input-use efficiency.

The results of this paper also have important implications for public policy. The question of diffusion of conservation technology is only a matter of policy interest when adoption has external benefits. Thus, in situations where price volatility leads to adoption of less efficient input-use technologies, then it may be worthwhile to intervene in the market to stabilize prices. Price risk can be reduced by measures to expand storage capacity, reduce storage losses and improve the conveyance infrastructure. Whether these or similar measures are justified depends on a larger analysis of their costs, and also on a comparison of the welfare costs of stabilization to other policies such as an outright subsidy for adoption.

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Table 1:
Elasticities of Utilization for Selected Industries

Resource	*Estimated Elasticity*	*Source*
Residential Electricity	-1.11 to –0.78	Hasset and Metcalf (1999)
Residential Natural Gas	-2.3 to 0.0	Liu (1982)
Gasoline	-1.01 to –0.08	Dahl and Sterner (1991)
Residential Water	-0.64 to –0.46	Nieswadomy and Cobb (1993)

Table 2:
Summary Statistics for Continuous Variables

Variable	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
Permeability (inches/hour)	2.89	3.00	0.13	13.00
Slope (percent)	1.58	1.32	0.50	10.00
Field Size (acres)	50.78	52.66	1.00	490.00

Table 3:
Summary Statistics for Discrete Variables

Variable	*Observations*	*Percent of Sample*
Technology		
Gravity	534	43.63
High Pressure	261	21.32
Low Pressure	429	35.05
Crop Choice		
Permanent	960	78.43
Annual	264	21.57
Service Area		
Risk	639	52.21
No Risk	585	47.79
Sample Size	1,224	

Table 4:
Ordered Probit Estimation Results

Variable	*Estimated Coefficient*	*Standard Error*	*p-value*
Risk	0.130	0.134	0.333
Risk*Permanent	-0.511***	0.155	0.001
Permanent	0.194*	0.115	0.090
Field Size	0.003***	0.0007	0.000
Permeability	0.006	0.012	0.646
Slope	0.395***	0.0312	0.000
μ_1	0.565	0.114	-
μ_2	1.189	0.114	-
Test of joint significance of Risk and Risk*Permanent	$\chi^2(2) = 22.77$ **		
LRI (McFadden R^2)	0.10		
***: Significant at the 1% level. **: Significant at the 5% level. *: Significant at the 10% level.			

Table 5:
Adoption Effects for Annual and Permanent Crops

	Annual Crop			**Permanent Crop**		
	Predicted Probability			*Predicted Probability*		
Technology	No Risk	Risk	Change	No Risk	Risk	Change
Gravity	41.73	36.74	-4.98	36.33	49.14	12.81
High Pressure	24.34	24.46	0.12	24.45	23.49	-0.96
Low Pressure	33.93	38.79	4.86	39.22	27.37	-11.85

*: Change in adoption probability resulting from switch from low- to high-risk price distribution.

Table 6:
Average Elasticities for Field Characteristics

Technology	*Field Size*	*Soil Permeability*	*Slope*
Gravity	-14.6	-1.5	-82.0
High Pressure	-0.9	0.2	-21.8
Low Pressure	13.6	1.8	53.1