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THEORY OF PRUDENT FARM HOUSEHOLDS AND AGRICULTURAL INSURANCE

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Abstract

A farm household is prudent, in the sense that savings is used to hedge against future contigencies. This paper shows that a precautionary saving impinges in a non-trivial fashion on the extent to how much to produce. An expected utility-maximizing, prudent farm household may find it optimal to produce either more, less or the same level of output as that which maximizes expected utility of terminal wealth or profits. The conditions for such behavior show that risk aversion is not sufficient for a prudent farm household to reduce output under risk. The conditions that put restrictions on the measures of prudence as well as the magnitudes of wealth and direct effects provide a characterization of the level of output. However, if market insurance is available at actuarially fair rate, a complete insurance is still optimal for prudent farm households. Prudent behavior may explain low participation rates for public programs to reduce farm income variation.

Key Words: Prudence, precautionary saving, income risk, farm household, agricultural insurance, and agricultural policy.

Theory of Prudent Farm Households and Agricultural Insurance

The fact that saving provides insurance for future contingencies was recognized by Marshall (1920) and this phenomena has been examined by Leland (1968) who calls it "precautionary saving", Kimball (1991) who calls it "prudence", and Deaton (1991) who defines it "buffer saving."[1] In society it is widely believed that farmers face more income risk than other groups, so idea of precautionary savings is intuitively appealing in an agricultural setting. Rational farm households realize that their well-being depends on their ability to obtain consumption good. For them, returns from farming constitute an important proportion of the household's income available for consumption and other purposes. When this return is risky, the ultimate concern of the farm households is not the risky return itself but the effects of this risky return on the households' consumption.[2] Since future farming income is uncertain, it is optimal for farm households to save more than they would if their expected future income were known with certainty. Risky farm incomes will lead to changes in consumption of farm households only if saving are not used to offset income fluctuations. If farmers are able to save and dissave in response to fluctuating income, then risky income may have no serious consequences for the well-being of farm households. If so, there is only a limited role for subsidized stabilization policies in risky agricultural markets even in the absence of complete markets.

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[1]The theory of precautionary savings has recently been extended to study aggregate consumption behavior and appeared to have more power than the certainty equivalent permanent income model in explaining empirical puzzles of aggregate consumption behavior in the United States (e.g. Zeldes 1986, Deaton 1992, Carroll 1993, 1994).

[2]Potential effects of instability, risk or uncertainty on farmer's consumption is one of long-standing issues in agricultural economics. Girao *et. al.* (1974) were possibly among the first to empirically examine the effects of instability on farmer's consumption using Minnesota farm level data. Newbery and Stiglitz (1981) noted the potential importance of defining agricultural risk in terms of consumption rather than more conventional measures such as profit or terminal wealth. Roe and Graham-Tomasi (1986) examined the role of yield risk in farmer's consumption and production decisions in a systematic way. Finkelshtain and Chalfant (1991) showed that Sandmo's result regarding a risk averse firm's response to price risk may no long hold when producers consume a significant share of their own output.

While the importance of precautionary saving in agriculture can be hardly overemphasized, it is surprising that it has received so little attention in developed economies and has attracted only slightly more in developing economies. Gardner (1981) speculates that uncertainty could be one of the major reasons why farm households in the United States accumulate substantial wealth over time. With regards to precautionary savings, he notes "An elementary way to cope with instability is to save money when income is temporally high, and then dissave it when income is low." Several empirical investigations related to precautionary savings have recently been completed. Paxson (1992) finds that marginal propensities to save out of transitory income are quite high in Thailand farm households and concludes that farmers use savings to smooth consumption in response to unexpected shocks to income. Rosenzweig and Wolpin (1993) investigated the sale and purchase of bullocks on Indian farmer to smooth consumption, numerically simulating a theoretical model with an explicit dynamic optimization problem. Other related studies include the work of Morduch (1993) and Saha and Stroud (1994), both using Indian farm level data. The former shows that the ability to borrow to smooth consumption is critical in determining the adoption of risky new hybrids, while the latter found significant effects of price risk on consumption, production, and labor supply.

Though agricultural economists traditionally acknowledge the role of risk in farmer's production decisions, the theoretical basis for the presumed link between precautionary savings and output has not been fully explored. To fill this gap in the literature, one must take explicit account of precautionary savings in modeling farmers' production decisions. Based on a simple recognition that farm income is both stochastic and endogenous, the interaction between income risk, precautionary saving, and the production decision of the farm household is investigated. By doing so, a dynamic model is needed since saving is inherently intertemporal. To allow for mathematical tractability, while retaining the essence of decision makin, a two-period model is used to analyze intertemporal consumption, saving, and production decisions of a farm household with a stochastic farm income.[3] Analytical efforts are focused on whether and in what manner do prudent farm households adjust supply in response to a shift in income risk. As agricultural insurance is usually available to farmers in developed economies, how prudent farm household would respond to the presence of agricultural insurance is also investigated.

The Model

Consider the model of price-taking behavior applied to farm households which own and operate a farm. For them, the returns from the farm operation constitute an important portion of the household's income for consumption and other purposes. Farm income is endogenous and, more importantly, stochastic. The farm household, facing income uncertainty, is assumed to be *prudent*, in the sense that they have a precautionary motive for saving. This is the central assumption adopted in this paper. Unlike a conventional farm household model, a limited number of choice variables is included to avoid unnecessary complications in the comparative statics analysis.[4] Some alternative consumption-smoothing possibilities which may be available to farm households are excluded. First, the absence of complete markets in the sense of Arrow and Debreu means that no market exists in which households can hedge against income uncertainty by trading contingent claims.[5] Second, farm households earn no off-farm income. Hence, labor

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[3] This framework has been used to study many theoretically interesting and policy relevant economic problems (Sandmo 1985, Dardanoni 1988). The advantage of a two-period model, compared to a multi-period model, is its mathematical tractability, while retaining the essence of decision making. Indeed, Fama (1968) has shown that under very general conditions, the empirically observable implications that can be derived from a multi period model of saving and consumption are indistinguishable from those implied by a two-period model.

[4]The comparative statics of a conventional farm household model are usually uninformative even under the deterministic setting because of the ambiguity associated with a large number of direct and indirect effects (Singh et. al. 1986). It is conceivable that the comparative statics under the stochastoc setting would be even more difficult to interpret.

[5]This assumption will be relaxed in subsequent section.

supply decisions are excluded. Third, farm households are not allowed to borrow for consumption purposes. Although these assumptions are unrealistic and tend to bias the results in favor of precautionary savings, they do serve to focus the analysis on the importance of precautionary saving.

Characterization of Stochastic Farming Income

To begin, assume that the farm household knows its first period (present) income, but not its second period (future) income. This formulation allows one to examine the production effects of precautionary savings and relevant policies[6] in both a deterministic and stochastic setting simultaneously. The non-stochastic profit of the i^{th} farm household in period 1 is[7]

$$\pi_1 = p_1 y_1 - c_1(y_1) \tag{1}$$

where p is a vector of output prices, y is a vector of output, $c(\cdot)$ is the total variable cost function, and subscript 1 indicates the first period. The regularity conditions for a cost function are satisfied, with $c'(\cdot) > 0$ and $c''(\cdot) \geq 0$.

The profit in the second period is affected by all the random factors (both price and production). Let the price distribution in the second period be characterized by a joint density $F(p_2)$. The stochastic production function in the second period is denoted as $g(x_2, \theta)$, where x_2 is a vector of inputs in the second period, θ is a vector of random factors, representing the sources of production risk, and subscript 2 indicates the second period. The joint density of θ is denoted by $F(\theta)$. Consequently, the cumulative distribution function of the second period profit, $F(\pi_2, \sigma)$, is deduced from $F(p_2)$,

[6] One recent policy innovation in Canadian agriculture, the Net Income Stabilization Account (NISA), effects farmer's precautionary saving which can be analyzed by using this framework (Chen 1995).

[7] Subscript i is omitted for the notation simplicity.

$g(x_2,\theta)$, and $F(\theta)$, where σ is a measure of riskiness. $\nabla F_\sigma(\pi_2^-,\sigma)$ and $\nabla F_\sigma(\pi_2^+,\sigma)$ is assumed to be twice differentiable in π_2 and σ and, in particular, the partial derivatives $F_{\pi_2}, F_\sigma, F_{\pi_2\pi_2}$, and $F_{\pi_2\sigma}$ exist. For all σ, the support of $F(\pi_2,\sigma)$ is contained in a compact interval $[\pi_2^-,\pi_2^+]$; that is, $F(\pi_2^-,\sigma)=0$ and $F(\pi_2^+,\sigma)=1$,for all σ. It follows that the gradients $\nabla F_\sigma(\pi_2^-,\sigma)$ and $\nabla F_\sigma(\pi_2^+,\sigma)$ are each row vectors with zeros everywhere. The expected profit in the second period is hence given by

$$\pi_2 = \int_{\pi_2^-}^{\pi_2^+} [p_2 y_2 - c_2(y_2)] dF(\pi_2,\sigma) \tag{2}$$

Characterization of Intertemporal Risk Preference

The household's expected utility is assumed to be a function of the goods consumed. As this study is less interested in disaggregate demands, an approach adopted in macroeconomic studies which defines a constant price aggregate of expenditures on various goods and services as C is used. The required assumption necessary to define a utility function over consumption aggregates is homothetic preferences (Deaton and Muellbauer 1980).[8] This formulation allows one to simplify the exposure of the comparative statics analysis considerably. The farm household's preferences are described by the following von Neumann-Morgenstern utility function

$$E[U(C_1,C_2)] \tag{3}$$

where E is the expectations operator and C_t is the aggregate index of consumption in period t $(t=1,2)$. It is assumed that the utility function satisfies the following regularity

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[8]Homothetic preference is a restrictive assumption used in many disaggregate demand analyse. It requires additive seperable preferences. Since the focus of this thesis is on the implication of consumption variability for production, this shortcoming is less damaging.

conditions: (i) defined and continuous from above for C_t, (ii) strictly concave in its arguments, and (iii) non-decreasing in C_t.

Risk averse preferences are characterized by the curvature properties of the utility function in (ii). It is also assumed that all farm households possess identical risk-averse preferences. Further, the two period utility function is assumed to have an additively separable form

$$E[U(C_1, C_2)] = U(C_1) + \beta EU(C_2) \tag{4}$$

where $\beta = (1+\delta)^{-1}$ is a discount factor. Intertemporal separability is a strong assumption. It can be defended on the grounds that it is widely applied in the literature of intertemporal optimization and that it has been shown by Sandmo (1969) and Kimball (1990) that a general utility function yields little in the way of interpretive results. The use of equation (4) permits definitions of the Arrow-Pratt coefficients of risk aversion in the usual way. The temporal Arrow-Pratt coefficients of risk aversion in terms of consumption, are $R^a(C_2) = -\frac{EU''(C_2)}{EU'(C_2)}$ for absolute risk aversion and $R^r(C_2) = -C_2 \frac{EU''(C_2)}{EU'(C_2)}$ for relative risk aversion. The fact that the risk aversion function depends only on C_2 results from the assumption of an additive utility function.

Some recent work has used a different formulation of preferences than that represented by (4). The motivation is based on the idea that intertemporally additive preferences, such as that contained in equation (4), forges an inverse relationship between the intertemporal elasticity of substitution and risk attitudes (Hall 1989, Weil 1990). As a result, Epstein and Zin (1989), Svensson (1989), and Weil (1990, 1993) moved away from the intertemporal expected utility framework. Instead, they use a recursive utility framework developed by Kreps and Porteus (1978, 1979) in order to achieve the desired separation between intertemporal substitution and risk aversion. Others (e.g. van der Ploeg 1993), following work by Kihlstrom and Mirman (1974), separate intertemporal substitution and risk aversion through a concave transformation of a time-separable objective function within the intertemporal expected utility framework. Reformulation of preferences is a currently very active area of research. However, as argued in Deaton (1992), time and uncertainty are so intimately connected that there is strong intuitive support for a relationship between attitudes towards risk and attitudes towards substitution. Consequently, these alternative specifications are not pursued further and equation (4) forms the basis for the following analysis.

The decision problem facing the farm household is to decide at the end of the first period, prior to the realization of the second period's income shock, how much to save and how much to produce. The farm household attempts to maximize the expected value of utility for the two periods subject to a two-period budget constraint. The budget constraint indicates that the total expenditures on consumer goods cannot be greater than the total income obtained by the household. The household's income consists of net income obtained from the farm's operation, represented by the net income function as well as a capital income earned in the future period. Initial assets are assumed away to reduce the notations of the model.

Formally, the two-period expected utility maximization problem of the i^{th} farm household can be written as

$$\underset{(C_1, C_2)}{\text{Max}}\, E[U(C_1, C_2)] = U(C_1) + \beta EU(C_2) \tag{5}$$

subject to

$$C_1 = \pi_1 - S_1 \tag{6a}$$

$$C_2 = \pi_2 + (1+r)S_1 \tag{6b}$$

where S_1 is savings made in period 1 and r is the exogenous rate of return on savings. It is important to note that saving here corresponds to both life-cycle and precautionary motives (bequest motive for saving is automatically assumed away since the model concerns only one generation). To interpret S_1 as precautionary saving, it is further assumed that $r = \delta$.[9] In other words, saving is now solely due to income uncertainty. Furthermore, the borrowing constraint implies that $S_1 \geq 0$ (Deaton 1991). It should also be noted that the specifications characterized in (5), (6a), and (6b) implicitly reflect the absence of complete markets.

Since precautionary saving and production decisions are the focus of this study, the above maximization problem, as described by equations (5), (6a), and (6b), can be reformulated compactly as

$$\begin{aligned} \underset{(S_1, y_1, y_2)}{\text{Max}} \; EU(\cdot) = {} & U[p_1 y_1 - c_1(y_1) - S_1] \\ & + \beta \int_{\pi_2^-}^{\pi_2^+} U[p_2 y_2 - c_2(y_2) + (1+r)S_1] dF(\pi_2, \sigma) \end{aligned} \tag{7}$$

The first order conditions (FOCs) for this problem are

$$EU_{S_1} = EU'(C_2) - U'(C_1) = 0 \tag{8a}$$

$$EU_{y_1} = U'(C_1)[p_1 - c_1'(y_1)] = 0 \tag{8b}$$

$$EU_{y_2} = \beta EU'(C_2)[p_2 - c_2'(y_2)] = 0 \tag{8c}$$

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[9] As a result, intertemporal substitution between the current consumption and future consumption is ruled out. In the absence of uncertainty, today's consumption is the same as yesterday's consumption.

The second order sufficient conditions (SOCs) require the strict concavity of expected utility which is met provided the utility function is strictly concave and the cost function is convex over all y.

The equations (8a) to (8c) indicate a linkage between precautionary savings (thus consumption) and output decisions. The condition for optimal savings, described by (8a) is similar to the pure consumption case (Henderson and Quandt 1980). The reason is that at the time of the savings decision, current income is known. Optimal precautionary savings requires holding income back from current consumption such that the marginal utility of current consumption, $U'(C_1)$, is equal to the present value of future consumption, $EU'(C_2)$, so that expected lifetime utility is maximized. It is clear that income risk in the second period affects current consumption through its effect on future expected marginal utility. If there is precautionary saving, the optimal intertemporal consumption bundle (C_1^*, C_2^*) is altered. A more interesting question is under what conditions precautionary savings arises.

Equation (8b) states that the condition for optimal production in the first period is similar to that in the deterministic setting. The farm household chooses the optimal output bundle y_1^* by equating output price and marginal cost. Income risk has no effect on the first period production decision, implying a separability between consumption and the first period production decision. This is a standard result in farm household models, the existence of competitive markets implies a separation of the consumption and production decisions of the farm household under deterministic conditions (Sasaki and Maruyama 1966, Jorgenson and Lau 1969).

Equation (8c) shows that the optimal output in the second period may be affected by income risk and this hinges on the farm household's risk preferences. The optimal amount of precautionary savings to be kept for next year depends on expected income and thus production next year, but optimal production next year depends on the amount of income saved. Consequently, the presence of precautionary savings forges a potential link between the consumption and production decisions of a farm household. This result is consistent with earlier findings that risk appears to threaten separability between the consumption and production decisions in farm household models (Baunum and Squire 1979, Roe and Graham-Thomasi 1986, Febella 1988, Finkelshtain and Chafant 1991). How this happens and under what conditions will be rigorously examined using comparative statics below.

Comparative Statics: Change in Risk

Since the optimal output level y_1^* is not affected by income risk, only the impact of changes in exogenous variables on S_1^* and y_2^* are considered. Equations (8a) and (8c) may be rewritten as

$$EU_{S_1}\left(\beta, r, \sigma, p_2, w_2, S_1^*, y_2^*\right) = 0 \tag{9a}$$

$$EU_{y_2}\left(\beta, r, \sigma, p_2, w_2, S_1^*, y_2^*\right) = 0 \tag{9c}$$

Changes in the parameters $\beta, r, \sigma, p_2,$ and w_2 affecting EU_{S_1} and EU_{y_2} will induce changes in the equilibrium levels of precautionary saving and output supply as well as farm household welfare. To derive the comparative statics, the equilibrium conditions in (9a) and (9c) are totally differentiated with respect to S_1 and y_2, yielding

$$\begin{bmatrix} EU_{S_1S_1} & EU_{S_1y_2} \\ EU_{y_2S_1} & EU_{y_2y_2} \end{bmatrix} \begin{bmatrix} dS_1 \\ dy_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{10}$$

where $EU_{S_1S_1} = (1+r)EU''(C_2) + U''(C_1)$,

$EU_{y_2y_2} = \beta EU''(C_2)(p_2 - c_2')^2 - EU'(C_2)c_2''$, and

$EU_{S_1y_2} = EU_{y_2S_1} = EU''(C_2)(p_2 - c_2')$.

Given that the SOCs are satisfied, the following conditions must hold

$$EU_{S_1S_1} < 0, EU_{y_2y_2} < 0, \left(EU_{S_1S_1} EU_{y_2y_2} - EU_{S_1y_2}^2\right) > 0 \tag{11}$$

Increasing Risk

The definition of increasing risk advanced in Rothschild and Stiglitz (1970) is used. One income distribution is riskier than another if it has the same mean and more weight in its tails. Formally,

Definition 1 (Diamond and Stiglitz 1974): *an increase in σ implies a Rothschild and Stiglitz (RS) increasing risk if and only if the following two conditions hold:*

$$\int_{\pi_2^-}^{\pi_2^+} F_\sigma(\pi_2, \sigma) d\pi_2 = 0 \tag{12a}$$

$$\int_{\pi_2^-}^{\pi_2^0} F_\sigma(\pi_2, \sigma) d\pi_2 \geq 0 \ \forall \ \pi_2^0 \in \left[\pi_2^-, \pi_2^+\right] \tag{12b}$$

Denoting the impact of an RS increasing risk on equations (8a) and (8c) by $EU_{S_1\bullet}$ and $EU_{x_2\bullet}$ gives

$$EU_{S_1\sigma} = \int_{\pi_2^-}^{\pi_2^+} \left[U_2'(C_2) - U_1'(C_1)\right] dF_\sigma(\pi_2, \sigma) \tag{13a}$$

$$EU_{y_2\sigma} = \int_{\pi_2^-}^{\pi_2^+} \beta U_2'(C_2)\left[p_2 - c_2'\right] dF_\sigma(\pi_2, \sigma) \tag{13b}$$

Intergrating equation (13a) and (13b) by parts twice results in

$$EU_{S_1\sigma} = \int_{\pi_2^-}^{\pi_2^+} U_2''' \left[\int_{\pi_2^-}^{\pi_2^0} F_\sigma(\pi_2, \sigma)\right] d\pi_2 \tag{14a}$$

$$EU_{y_2\sigma} = \beta \int_{\pi_2^-}^{\pi_2^+} \left\{ U_2''' C_2 + 2U_2'' + U_2''' \left[y_2 \left(c_2 - y_2 c_2' \right) - (1+r) S_1 \right] \right\} \left[\int_{\pi_2^-}^{\pi_2^0} F_\sigma \right] d\pi_2 \tag{14b}$$

where U_2'' and U_2''' are the second and third derivatives of the utility function $U(C_2)$. The derivation of equations (14a) and (14b) are presented in Appendix A.

Given equation (12b), the sign of $EU_{S_1\bullet}$ hinges on the sign of U_2''', while the sign of $EU_{x_2\bullet}$ hinges on both the sign and magnitude of U_2''' because the properties of $c_2(\cdot)$ imply that $c_2(\cdot) \le y_2 c_2'(\cdot)$. To help in interpreting the results, the concept of prudence is introduced below.

Degree of Prudence

In a recent paper, Kimball (1990) proposed the concept of prudence as a measure of the sensitivity of choice to risk. Like risk aversion, which identifies the factors determining the magnitude of the effects of risk, prudence identifies the factors that determine the magnitude of the optimal response of decision variables to risk. Using a theory of precautionary saving, Kimball established a formal link between the theory of risk aversion and prudence. With regard to a difference between prudence and risk aversion, Kimball states that "the term 'prudence' is meant to suggest the propensity to prepare and forearm oneself in the face of uncertainty, in contrast to 'risk aversion' which is how much one dislikes uncertainty and would turn away from uncertainty if one could." Formally,

Definition 2 (Kimball 1990): *Given a thrice differential, additively separable von Neumann-Morgenstern utility function,* $E[U(C_1, C_2)] = U(C_1) + \beta EU(C_2)$, *the following functions measure the strength of prudence*

$$P^a = -\frac{U'''(C_2)}{U''(C_2)} \tag{15a}$$

and

$$P^r = -C_2 \frac{U'''(C_2)}{U''(C_2)} \tag{15b}$$

where P^a is the coefficient of absolute prudence and P^r is the coefficient of relative prudence.

Equations (15a) and (15b) indicate that a positive third derivative of the utility function guarantees a positive coefficient of prudence. In light of definition 2, equations (14a) and (14b) are converted in terms of prudence

$$EU_{S_1\sigma} = \int_{\pi_2^-}^{\pi_2^+} \left(-\beta U_2'' P^a\right)\left[\int_{\pi_2^-}^{\pi_2^0} F_\sigma(\pi_2, \sigma)\right] d\pi_2 \tag{16a}$$

and

$$EU_{y_2\sigma} = \beta \int_{\pi_2^-}^{\pi_2^+} \left\{2U_2'' - U_2'' P^r - U_2'' P^a \left[y_2\left(c_2 - y_2 c_2'\right) - (1+r) S_1\right]\right\}\left[\int_{\pi_2^-}^{\pi_2^0} F_\sigma\right] d\pi_2 \tag{16b}$$

Given equation (12b) and $U_2'' < 0$, a positive coefficient of prudence implies that $EU_{S_1 \bullet} > 0$. To show the sign of $EU_{x_2 \bullet}$, let's define function $\upsilon = U_2'(C_2)C_2$. Hardar and Seo (1991, 1993) showed that $\upsilon = U_2'(C_2)C_2$ is concave in $U_2'' < 0$. This implies that $\upsilon'' < 0$. Writing out the expression for υ'' yields

$$\upsilon'' = U_2''' C_2 + 2U_2'' < 0 \tag{17}$$

It follows that $\upsilon'' < 0$ implies $P^r < 2$. Since $c_2(\cdot) \le y_2 c_2'(\cdot)$ is given, the condition for $EU_{y_2 \bullet} < 0$ is that $0 < P^r < 2$.[10] It suffices to know that $0 < P^r < 2$ is consistent with increasing, constant, and decreasing relative risk aversion.

[10] The relationship between risk aversion and prudence is discussed in Chen (1995).

Obtaining the impact of the marginal RS increase in risk on the optimal values of S_1 and y_2 requires solving for the comparative static derivatives

$$\frac{\partial S_1^*}{\partial \sigma} = -\frac{EU_{S_1\sigma}EU_{y_2y_2} - EU_{y_2\sigma}EU_{S_1y_2}}{H} \tag{18}$$

and

$$\frac{\partial y_2^*}{\partial \sigma} = -\frac{EU_{y_2\sigma}EU_{S_1S_1} - EU_{S_1\sigma}EU_{y_2S_1}}{H} \tag{19}$$

where H is the determinant of the Hessian matrix $\begin{bmatrix} EU_{S_1S_1} & EU_{S_1y_2} \\ EU_{y_2S_1} & EU_{y_2y_2} \end{bmatrix}$. SOCs imply that $EU_{S_1\sigma} > 0$ and $EU_{y_2\sigma} < 0$.

As shown above, $EU_{S_1\sigma} > 0$ under certain restrictions. Given $EU_{y_2y_2} < 0$, the sign of equation (18) hinges on the sign of $EU_{y_2S_1}$. It can be shown that $EU_{y_2S_1} > 0$ is implied by decreasing absolute risk aversion (DARA), $EU_{y_2S_1} = 0$ is implied by constant absolute risk aversion (CARA), and $EU_{y_2S_1} < 0$ is implied by increasing absolute risk aversion (IARA). Hence, under CARA and IARA, $\frac{\partial S_1^*}{\partial \sigma} > 0$, while under DARA, the sign of (18) is indeterminate. The assumption of a prudent farm household requires $\frac{\partial S_1^*}{\partial \sigma} > 0$. To ensure $\frac{\partial S_1^*}{\partial \sigma} > 0$ under DARA, $EU_{y_2\sigma}EU_{S_1y_2} > EU_{S_1\sigma}EU_{y_2y_2}$ must be held given that $0 < P^r < 2$. This condition is, unfortunately, difficult to interpret intuitively. This discussion leads to proposition 1.

Proposition 1: *A positive third derivative of the utility function implies a positive precautionary saving if either of the following conditions holds: (1)* S_1 *and* y_2 *are stochastical independence (implied by CARA), (2)* S_1 *and* y_2 *are stochastic substitutes* *(implied by IARA), or (3)* S_1 *and* y_2 *are stochastic complements (implied by DARA),* $EU_{y_2\sigma}EU_{S_1y_2} > EU_{S_1\sigma}EU_{y_2y_2}$ *and* $P^r < 2$.

The theoretical condition under which precautionary saving arises in response to earning uncertainty was explored by Leland (1968), Sandmo (1970), and Dreze and Modigliani (1972). The main result is that income uncertainty increases saving if the third derivative of the utility function is positive. Proposition 1 shows that this result can be directly extended to a case of non-decreasing absolute risk aversion even though the household's income is endogenous. However, with decreasing absolute risk aversion, a positive third derivative of the utility function becomes neither a necessary nor a sufficient condition for positive precautionary saving when the household's income is endogenous. To ensure a farm household holds positive precautionary savings, additional restrictions on the utility function, as implied by (3) in proposition 1, are needed.

Similarly, the sign of equation (19) also depends on risk preference. Since the focus of this study is how a prudent farm household adjusts its optimal output in response to an RS increase in risk, it is constructive to rewrite (19) as

$$\frac{\partial y_2^*}{\partial \sigma} = -\frac{EU_{y_2S_1}}{EU_{y_2y_2}}\frac{\partial S_1^*}{\partial \sigma} - \frac{EU_{y_2\sigma}}{EU_{y_2y_2}}. \qquad (19)$$

Equation (20) provides an explicit link between precautionary savings and the supply decision of the farm household and leads to the following proposition 2.

Proposition 2: *With positive precautionary savings, the farm household adjusts its output in the following ways when facing a RS increase in risk:*

(1) it reduces the optimal level of output if either of the following conditions hold:

a) DARA and $\frac{\partial S_1^*}{\partial \sigma} > -\frac{EU_{y_2\sigma}}{EU_{y_2S_1}}$,

b) CARA and IARA;

(2) it does not change the optimal level of output if DARA and $\frac{\partial S_1^*}{\partial \sigma} = -\frac{EU_{y_2\sigma}}{EU_{y_2 s_1}}$ *;or*

(3) it increases the optimal level of output if DARA and $\frac{\partial S_1^*}{\partial \sigma} < -\frac{EU_{y_2\sigma}}{EU_{y_2 s_1}}$.

The results of this proposition show that output response by a prudent farm household is ambiguous under DARA, while it is unambiguous under CARA and IARA. This result can be understood by decomposing a change in risk on the optimal output level into two effects: a direct effect and a wealth effect. The wealth effect is ambiguous, while the direct effect is always negative. When a prudent farm household faces a RS increase in risk, it reduces output (direct effect) and increases precautionary savings. With an increase in precautionary savings, a farm household's risk attitude may change. As a result, the prudent farm household may change the level of output (wealth effect). Under CARA, the wealth effect is zero so that $\frac{\partial y_2^*}{\partial \sigma} < 0$. Indeed a CARA prudent farm household behaves exactly in the same way as a myopic risk-averse firm as discussed in Sandmo (1971). Under IARA, the wealth effect is negative so that $\frac{\partial y_2^*}{\partial \sigma} < 0$. However, the magnitude of the output response for IARA prudent farm households is greater than that for CARA prudent farm households. In other words, IARA prudent farm households produce less output than myopic risk-averse farm firms.

For DARA prudent farm households, the intuition is more complicated. The direction and size of the output response to an increase in risk is hinged on the magnitude of prudence. Suppose that a DARA prudent farm household, in response to a RS increase in risk, increases its precautionary savings in a way such that $\frac{\partial S_1^*}{\partial \sigma} > -\frac{EU_{y_2\sigma}}{EU_{y_2 s_1}}$. In this case the wealth effect is less than the direct effect so that $\frac{\partial y_2^*}{\partial \sigma} < 0$. That is, a DARA prudent farm household behaves qualitatively the same as CARA and IARA prudent farm households. However, the size of the output response for a DARA prudent farm household is smaller than that of CARA and IARA prudent farm households. That is, a

DARA farm household produces more output than a myopic risk-averse farm household and produces less than a risk-neutral farm household.

If a DARA prudent farm household adjusts its precautionary savings in such a way that $\frac{\partial S_1^*}{\partial \sigma} = -\frac{EU_{y_2\sigma}}{EU_{y_2 S_1}}$, then the wealth effect is the same as the direct effect and $\frac{\partial y_2^*}{\partial \sigma} = 0$. In this case, a DARA prudent farm household behaves in the exact same way as a risk-neutral farm household.

If a DARA prudent farm household adjusts its precautionary savings in a way such that $\frac{\partial S_1^*}{\partial \sigma} < -\frac{EU_{y_2\sigma}}{EU_{y_2 S_1}}$, then the wealth effect is greater than the direct effect and $\frac{\partial y_2^*}{\partial \sigma} > 0$. That is, a DARA prudent farm household behaves as if it is risk-loving in the production decision and produces more output than a risk-neutral farm household. Although the likelihood of this result may be small, it cannot be excluded mathematically.

The foregoing discussion does not imply that precautionary savings is the only channel for mitigating income risk, only that it impinges in a non-trivial fashion on the output decision. By facilitating stable consumption over time, precautionary savings enables prudent farm households to absorb more risk than they could in the absence of precautionary savings. This insurance aspect of precautionary savings results in the different risk behaviors of farm households. Output responses of the prudent farm households, the myopic risk-averse farm households, and the risk-neutral farm households to an increase in risk are summarized in Table 1.

A corollary can be stated as follows:

Corollary 1: *Separability between precautionary savings (thus consumption) and output holds if a prudent farm household displays CARA preferences.*

This corollary is of interest because it justifies a large number of popular models in the farm household literature even under the presence of precautionary savings. Roe and Graham-Thomasi (1986) investigated the implications of yield risk in a dynamic farm

Table 1 Output Response of Different Types of Farm Households to an Increase in Risk[a,b]

Risk Preferences	Types of Farm Households		
	Prudent Farm Household	Myopic Risk-Averse Farm Household	Risk-Neutral Farm Household
DARA	+,0,-[l]	-[m]	0
CARA	-[m]	-[m]	0
IARA	-[h]	-[m]	0

[a] +, 0, and - denote the direction of supply effects as positive, zero, and negative.
[b] -[l], -[m], and -[h] measure the relative size of supply reduction from low (l) to medium (m) and high (h).

household model and found that an additive risk specification led to separability between consumption and production. Febella (1988) reached similar result for an additive income risk in a static farm household model.

Agricultural Insurance

Consider a farm household which now has the option to purchase income insurance. From a private company with coverage q dollars, against income loss and at a premium rate of z dollars per dollar of coverage. Let $1+\phi$ be a loading factor that reflects the administrative and selling costs of the insurance. The farm household pays $(1+\phi)zq$ to the insurer at the end of the present period in exchange for the insurer's promise to pay him q if an income loss (below q) occurs in the next period. Would a prudent farm household fully insure when offered actuarially fair income insurance?

Consumption in the first period equals the difference between the household's farming income and whatever it chooses to allocate to savings and its insurance expenditures

$$C_1 = \pi_1 - S_1 - (1+\phi)zq \tag{20}$$

Consider a world with only two states of nature. The good state is represented by a superscript 0, and a bad state by 1. There is a probability that the income loss occurs, denoted as α. Only two states of the world are possible, 1-α is thus the probability of no loss. Hence, consumption in the second period is

$$C_2^0 = \pi_2^0 + (1+r)S_1 = p_2^0 y_2^0 - c_2^0\left(y_2^0\right) + (1+r)S_1 \text{ if no loss occurs.} \tag{21a}$$

and

$$C_2^1 = \pi_2^1 + (1+r)S_1 + q = p_2^1 y_2^1 - c_2^1\left(y_2^1\right) + (1+r)S_1 + q \text{ in case of loss} \tag{21b}$$

Suppose an actuarially fair premium is set according to

$$(1+r)zq = E(\alpha L) \tag{22}$$

where L is the income loss when the bad state of nature occurs.

Formally, the maximization problem, in the absence of moral hazard[11], is

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[11]Adverse selection is ruled out by identical risk preferences of farm households.

$$\underset{(S_1,q,y_1,y_2)}{\text{Max}} \; EU = U\left[p_1 y_1 - w_1 x_1 - S_1 - (1+\phi)zq\right]$$
$$+\beta\left\{\alpha EU\left[p_2^1 y_2^1 - c_2^1\left(y_2^1\right) + (1+r)S_1 + q\right]\right.$$
$$\left. +(1-\alpha)U\left[p_2^0 y_2^0 - c_2^0\left(y_2^0\right) + (1+r)S_1\right]\right\} \tag{23}$$

The FOCs are

$$EU_{S_1} = -U'\left(C_1\right) + EU'\left(C_2\right) = 0 \tag{24a}$$
$$EU_q = -(1+\phi)zU'\left(C_1\right) + \beta\alpha EU'\left(C_2^1\right) = 0 \tag{24b}$$
$$EU_{y_1} = U'\left(C_1\right)\left[p_1 - c_1'\left(y_1\right)\right] = 0 \tag{24c}$$
$$EU_{y_2} = \beta EU'\left(C_2\right)\left[p_2 - c_2'\left(y_2\right)\right] = 0\,. \tag{24d}$$

In a static model of the demand for insurance, complete insurance is optimal if it is available at actuarially fair rates and does not alter expected losses (Arrow 1963). Does this result carry over to a prudent farm household? A prudent farm household has the option to either self insure through precautionary savings or purchase an insurance contract against income risk. If the insurance is available at an actuarially fair rate, then

$$z = \frac{\alpha}{(1+r)} \text{ and } \phi = 0\,. \tag{25}$$

Substituting (3.25) into (24b) gives

$$U'\left(C_1\right) = EU'\left(C_2^1\right) \tag{26}$$

Note that $EU'\left(C_2\right) = \alpha EU'\left(C_2^1\right) + (1-\alpha)U'\left(C_2^0\right)$. Combining (24a) and (26) gives

$$U'(C_1) = EU'(C_2^1) = EU'(C_2^0) \tag{27}$$

Equation (27) indicates that marginal utility is constant over time as well as across states of nature. Recall that the marginal utility is always positive. As a result, equation (27) implies that $C_2^1 = C_2^0$. This follows that $q^* = \pi_2^0 - \pi_2^1$. A prudent farm household would buy full coverage. In other words, complete coverage is optimal for a prudent farm household. Given equation (27), equation (24d) is simply

$$p_2 - c_2'(y_2) = 0 \tag{24d)'$$

which is a standard result of optimal output level for a risk neutral firm.

The above results imply that, when insurance is available at an actuarially fair rate, a prudent farm household makes consumption and production decisions as if it is risk-neutral. Hence, if income risk is insurable, then the farm household can insure and need not take income risk into account in choosing savings and production. The model does illustrate another cost associated with insurance that must be ruled out if complete insurance is to be optimal, namely the opportunity cost of forgone interest. However, as long as the insurer discounts premiums in recognition of the time that elapses before benefits are paid, implicitly paying consumers the interest that they could have earned by saving, then all costs of insurance are eliminated and complete insurance is again optimal. The reason behind this is simple. Precautionary savings enables a farm household to stabilize consumption across time, but it is still exposed to uncertainty within periods. In other words, a farm household with precautionary savings is able to consume equal amounts in both periods, but the level of this consumption depends on which state of nature is realized in the second period. In contrast, actuarially fair insurance enables farm households to eliminate all uncertainty.

Why is precautionary savings a concern then? This is because the premium rates for insurance are not always actuarially fair. First, loading factors such as administration costs are not negligible. Second, random factors generating uncertain farm income are likely to be correlated across farmers in a given region. Third, there likely exists asymmetric information between the insured and insurer (moral hazard and adverse selection). It is thus possible that insurance actually offered in the market will not be purchased by the optimizing prudent farm households. In fact almost exclusively around world, crop and revenue insurance in agriculture is provided by governments. With the provision of subsidized insurance the above results no longer hold. The choices of precautionary savings, insurance coverage, and production may be interrelated and market insurance no longer dominates precautionary savings as protection against income risk.

Ehrlich and Becker (1972) concluded, using a static model, that self-insurance and market insurance are always substitutes. This result is intuitively appealing. Do the same result holds for a prudent farm household? Suppose that the premium rate offered is not actuarially fair due to the loading factor. The answer to the above question can be found by deriving comparative statics regarding the effects of an increase in the price of market insurance on optimal precautionary savings, insurance coverage, and farm production. Unfortunately, comparative static results obtained are difficulty to interpret. A shortcut, however, is available, because changes on precautionary saving and insurance coverage with production held constant are of interest.

To derive the comparative statics of precautionary saving and insurance coverage, the equilibrium conditions in (24a) and (24b) are totally differentiated yielding

$$\begin{bmatrix} EU_{S_1S_1} & EU_{S_1q} \\ EU_{qS_1} & EU_{qS_1} \end{bmatrix} \begin{bmatrix} dS_1 \\ dq \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{28}$$

where $EU_{S_1S_1} = (1+r)EU''(C_2) + U''(C_1)$,

$$EU_{qq} = (1+\phi)^2 z^2 U''(C_1) + \alpha EU''(C_2);$$
$$EU_{S_1 q} = EU_{qS_1} = (1+\phi) z U''(C_1) + \alpha EU''(C_2).$$

Given that the SOCs are satisfied, the following conditions must hold:

$$EU_{S_1 S_1} < 0, EU_{qq} < 0, \left(EU_{S_1 S_1} EU_{qq} - EU_{S_1 q}^2\right) > 0.$$

The effect of a *decrease* in the price of market insurance can be determined by totally differentiating equations (24a) and (24b) with respect to ϕ and solving to obtain

$$\frac{\partial S_1^*}{\partial \phi} = -\frac{EU_{S_1 \phi} EU_{qq} - EU_{q\phi} EU_{S_1 q}}{H} \tag{29}$$

and

$$\frac{\partial q^*}{\partial \phi} = -\frac{EU_{\phi z} EU_{S_1 S_1} - EU_{S_1 \phi} EU_{qS_1}}{H} \tag{30}$$

where $EU_{S_1 \phi} = qU''(C_1)$ and $EU_{q\phi} = \phi q U''(C_1) - U'(C_1)$.

Since all $U''(\cdot)$ are negative and all $U'(\cdot)$ are positive, all $EU''(\cdot)$ are negative. As a result, the sign of equations (29) and (30) cannot be determined. A decrease in the price of market insurance on the optimal market insurance coverage and precautionary savings has two effects, an 'income' effect and a 'substitution' effect.

In equation (29) the first term is the income effect which is always positive. The second term is the substitution effect which is always negative. When a prudent farm household faces an increase in the price of market insurance, it may or may not decrease its insurance coverage.

In equation (30), the first term is the substitution effect which is always positive. The second term is the income effect which is always negative. Similarly, when a prudent farm household faces a decrease in the price of market insurance, it may or may not decrease its precautionary saving.

To help interpret these results, equations (29) and (30) can be rewritten to obtain

$$\frac{\partial q^*}{\partial \phi} = -\frac{EU_{qS_1}}{EU_{qq}}\frac{\partial S_1^*}{\partial \phi} - \frac{EU_{q\phi}}{EU_{qq}} \tag{31}$$

This illustrates how the effects of a decrease in the price of market insurance on the demand for market insurance depends on the effect of precautionary saving. Two interesting cases may be identified, depending on the sign of $\frac{\partial S_1^*}{\partial \phi}$:

(i) If $\frac{\partial S_1^*}{\partial \phi} \geq 0$, then $\frac{\partial q^*}{\partial \phi} < 0$. That is, if a prudent farm household does not decrease its precautionary saving when facing a decrease in the price of market insurance, it would demand less insurance coverage.

(ii) If $\frac{\partial S_1^*}{\partial \phi} < 0$, then the sign of $\frac{\partial q^*}{\partial \phi}$ is unknown. Three special cases may be identified, depending on the relative magnitude of the substitution and income effects:

(a) If the income effect is greater than the substitution effect, $\frac{\partial q^*}{\partial \phi} < 0$.

(b) If the income effect is the same as the substitution effect, $\frac{\partial q^*}{\partial \phi} = 0$

(c) If the income effect is less than the substitution effect, $\frac{\partial q^*}{\partial \phi} > 0$.

Case (c) is probably one that most conflicts with a conventional point of view. The intuition runs as follows: the income effect of an exogenous decrease in the price of insurance (e.g. a premium subsidy) could conceivably result in an increase in precautionary savings and a decrease in risk aversion so that a compensating decrease in insurance purchases would result.

Implications

The previous findings are useful in several areas of agricultural economics:

First, to make a farm household prudent, decreasing absolute risk aversion is no longer sufficient. This result departs from that of a standard consumer model of precautionary saving in which a non-increasing absolute risk aversion is sufficient condition for a positive precautionary savings. It is thus important to distinguish exogenous and endogenous income in the study of precautionary savings.

Second, in the presence of precautionary savings, the farm household model is not separable in general. Precautionary savings presents an explicit link between production and consumption decisions of farm households. Since agriculture in developed economies is generally considered by agricultural economists to be a highly competitive industry, conventional models normally dichotomize the production and consumption decisions of farm households (Huffman and Evenson 1989). However, if these farm households are precautionary savers, such practices are valid only if these farm households display CARA risk preferences. This is unlikely to be the case for agriculture as more studies have found DARA risk preference (Chavas and Holt 1991, van Massow and Weersink 1992, Saha *et. al.* 1994).

Third, the coefficients of prudence provide an alternative to studying the role of risk in agriculture. The empirical significance of the coefficients of prudence has been examined more fully in Chen (1995).

Fourth, under the market structure presented, the farm household can protect consumption fluctuations with a non-governmental self-insurance scheme in the form of precautionary savings. A farm household can face a great deal of income risk, while exposing itself to little risk in terms of consumption. Consequently, a prudent household might choose to ignore income risk in favor of greater expected returns when making production decisions. That is, a prudent farm household may display near risk neutral behavior in production.

This result has two implications for agricultural policy and the measurement of risk. Farmers may not be as income risk averse as they are presumed to be in a typical static neoclassic production model. Under plausible assumptions, the conventional wisdom of the importance of farm income risk is either a testable hypothesis about relative magnitudes or a normative statement. Farmers' willingness to pay for insuring against future contingency through market insurance schemes may be rather low thus explaining the low acceptance rates for public stabilization/insurance programs if the programs are not heavily subsidized. In other words, the existence of income risk alone cannot rationalize government intervention in agriculture, even if there is a market failure. The proposition that precautionary saving is important in a developed country context requires a reexamination of existing farm policy as many policies appear to be set up to mitigate risk.

On the other hand, agricultural policies are often being accused of encouraging riskier farm production. If farm households have a precautionary motive for savings, the magnitude of such a production effect may be much smaller than presumed. This is consistent with arguments made by some economists (Wright 1993) that a static risk model of policy analysis might overestimate the risk reduction effect of government policy. Policy analysis that ignores risk may be not as misleading as many perceive.

A second implication lies in the interpretation of the standard empirical production model under risk. The findings show that near risk neutral preferences do not expose the true preferences of the farm household in all circumstances. In several plausible cases, measuring attitudes towards risk in the traditional fashion is not appropriate, and doing so will lead to a bias towards risk neutrality.[12] The current analysis suggests that the role of

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risk in production depends critically on the strength of the precautionary saving motive in addition to the structure of risk preferences.

Conclusions

This paper has shown that many of the familiar results from production models of risk may no longer hold when farm households have precautionary motive for savings. An expected utility-maximizing, prudent farm household may find it optimal to produce either more, less or the level of output as that which maximizes expected utility of terminal wealth or profits. The conditions for such behavior show that risk aversion is not sufficient for a prudent farm household to reduce output under risk. The conditions that put restrictions on the measures of prudence as well as the magnitudes of wealth and direct effects provide a characterization of the level of output. However, if market insurance is available at actuarially fair rate, a complete insurance is still optimal for prudent farm households. Hence the importance of precautionary savings hinges on the existence of incomplete markets. As incomplete markets are characteristics of agriculture, the precautionary savings deserves more attention from agricultural economists.

Since this study represents the first attempt to study precautionary savings in agriculture, undoubtedly it is subject to some limitations of scope and method. This in turn provides recommendations for future research. Though the prudent farm household model developed is general enough to study the behavior of farm households in both developed and developing countries, some of the assumptions may be further relaxed when applied to specific settings. Three areas can be identified for future work. First, the model assumes that a farm household does not consume its own products. This is not plausible for farm households in some regions as the consumption of a portion of its own farm product is an important characteristic of the farm household in developing countries

[12] A similar argument was made in Morduch (1993) in which she emphasized the importance of credit rationing on the consumption and production behavior of farm households.

(Haessel 1975, Toquero *et. al.* 1975, Renkow 1990). Second, borrowing should be allowed. Langemeier and Patrick (1990, 1993) examined the consumption behavior of Illinois and Kansas grain farm households. Their results indicated that, while disposable incomes of farm households fluctuate widely from one year to the next, farm consumption adjusts only slightly to these large changes in income. They speculated that the reason behind this phenomenon is that in low income years consumption displaces other uses of funds, and agricultural lenders, in spite of their stated intentions, may actually be providing liquidity for farm household consumption. Finally, one has to note the simple form of precautionary savings considered in this thesis. A more detailed account of capital formation would provide richer practical implications than the current model. In this respect, recent developments in the dynamic theory of investment (Abel 1983, 1991) should be useful.

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