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Lexicographic Ordering and Loss Aversion among Low-Income Farmers

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Abstract

As Richard Day explained, expected utility theory suffers from procedural irrationality. This and other problems are illustrated here in the context of decision-making among low-income farmers. Farmers in developing countries are commonly thought to underinvest in modern techniques because their low incomes make them especially risk averse. In addition to the procedural leap of faith, highly restrictive assumptions are needed to apply expected utility theory to the problem. Nor does expected utility theory, as usually prescribed, fit the narrative of loss aversion. The reader is introduced to a procedurally rational substitute called *lexicographic safety first*. The model is illustrated for the case of rice fertilization in the Philippines, and policy implications are drawn. To illustrate the potential appeal of lexicographic ordering for other applications involving thresholds, a lexicographic model of rational addiction is also provided.

KEYWORDS: technology adoption, agricultural development, risk, subsistence, satisficing

JEL CLASSIFICATION: D21, D81, O33, Q16

I. Introduction

Expected utility theory was a subject of Richard Day's eloquent criticism. Here we expand on his critique in the context of low-income farmers. A persistent belief in development economics is that low-income farmers underinvest in modern techniques because their low incomes make them especially risk averse. Using the expected utility model to evaluate the hypothesis is problematic, however. It does not fit the popular narrative regarding loss aversion, highly restrictive assumptions are used in its application, and it is procedurally untenable.

In what follows, I introduce the reader to a procedurally rational model of loss aversion and illustrate it with a problem of fertilizer adoption in the Philippines. The model is designed to be especially useful for problems wherein behavior is thought to depend on an identifiable threshold suggestive of lexicographic ordering. The model is illustrated for the case of fertilizer adoption in the Philippines. To show the

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[1] Professor Emeritus, University of Hawaii at Manoa. This paper was written as a tribute to the late Richard Day. Thanks to Karl Jandoc and Mark Pingle for helping to tailor the manuscript into its present form.

potential promise for other applications, a related model is sketched for the case of rational heroin addiction.

Section II gives an overview of the theory and evidence behind the popular notion that risk aversion inhibits low-income farmers from adopting modern techniques and concludes that expected utility theory, as typically applied, is not suitable for evaluating the hypothesis. Following principles proposed by Richard Day, Section III suggests that even if the restrictive assumptions behind applications of expected utility were somehow removed, it would still be implausible on procedural grounds. A procedural *correspondence principle* is accordingly proposed. Section IV provides the model of lexicographic safety first (LSF), which satisfies procedural rationality, ranks techniques that are not "safe enough," as well as those that are, and embodies satisficing regarding loss aversion. Section V illustrates LSF with an application to fertilizer use in Philippine rice production, rejecting the hypothesis that loss aversion inhibits the use of modern inputs such as fertilizer, and Section VI suggests implications for subsidized crop insurance. Section VII discusses the appeal of LSF for other cases of identifiable thresholds with an application to rational addiction. Section VIII concludes.

II. The RAUI hypothesis: Risk Aversion causes Under-Investment in modern production techniques

The green revolution of the 1960s and 70s and the alleged failure of low-income farmers to adopt the high yielding varieties (HYVs) of rice and wheat, along with recommended inputs, presented a paradox to economists. On the one hand, Schultz's (1964) treatise on responsiveness among low-income farmers was said to imply that farmers in developing countries were mostly "poor but efficient."[2] On the other hand, recommended modern "packages" of techniques were not widely adopted, suggesting that farmers were not efficient after all.[3] The resolution of the paradox was provided by the theory that expected-utility-maximizing, but risk-averse, farmers will stint on inputs that increase risk, especially fertilizer.[4] Several authors have formalized this claim and found supporting evidence (e.g. Antle 2010, Rajsic et al. 2009, Khor 2018 and the studies cited in Feder 1980 and Roumasset et al. 1989). The logic of this view can be summarized as follows:

1. Due to their proximity to subsistence levels of income, poor farmers are markedly risk averse (e.g. Chetty and Looney 2006).

[2] See, e.g. Duflo (2006) for a critical review of this line of thinking.
[3] Initial adoption of green revolution varieties of wheat and rice was rapid but limited to favorable (e.g. irrigated) areas. In addition, fertilizer and pesticide recommendations were not widely adopted (e.g. Falcon 1970).
[4] Wharton (1968) was possibly the first to articulate this view, along with the proposition that farmers will be especially risk averse when their very survival is at issue.

2. Modern inputs in the new technology package increase risk.
3. Therefore, low-income farmers will underinvest in new techniques (relative to recommended practices).

Without definitions of risk and risk aversion, however, the logic is incomplete. To complete the logic, we need to make implicit assumptions more explicit, e.g. as follows:

1. Utility functions in one-period money exist and are uniformly concave.
2. Modern inputs such as fertilizer increase expected profits but also increase their variance. This effect reduces expected-utility maximizing inputs below their expected profit maximizing level.
3. Expected-utility maximizing farmers will therefore underinvest in modern inputs relative to the expected-profit maximizing solution, which is presumed to be socially efficient.

This more nuanced formulation reveals flaws in the argument, even if farmers are indeed expected-utility maximizers.

1. Rationality does not imply that farmers have uniformly concave utility functions in one-period money, the model typically employed to obtain both qualitative and quantitative results about optimal choice of technique (e.g. Feder 1980, Feder et al. 1986, Hardaker et al. 2015). In general, such functions do not exist in the sense that they can be inferred from intertemporal utility functions.[5] In the special case wherein the intertemporal utility functions are additively separable, an indirect utility function can be derived in one-period money, but it depends largely on transaction costs and how they shape borrowing and lending rates. The resulting indirect function tends to have both concave and convex segments. Accordingly, characterizations of anything but local risk aversion are meaningless. The decision maker is risk averse and risk preferring to different degrees at different income levels.[6]
2. A Taylor-series expansion of expected utility reveals that increasing the variance of profits has an unambiguous negative effect for the case of strict and uniform concavity (Antle 1983, 2010). In the case of convex as well as convex segments, increased variance can increase or decrease expected utility.
3. In the presence of strictly convex segments, including the prototypical utility function of prospect theory (Kahneman and Tversky 1979), loss-aversion may imply a preference for variance. Poorer farmers may need higher threshold incomes to meet existential needs such as minimal nutrition

[5] Spence and Zeckhauser (1972).

[6] In the case of buying prices above selling prices due to a transaction cost wedge, marginal utility is constant, then falls, then is bounded from below due to the constant selling price as production income increases (Roumasset, 1979, de Janvry et al. 1991)

and maintaining cultivation rights, and traditional technologies may be less likely to meet that threshold than a new technology. That is, desperation can result in new technologies presenting lower risks of loss than traditional ones (Banerjee 2000).

In addition to these conceptual issues, attempts to estimate farmers' utility functions often rely on lottery questions or gambling experiments (e.g. Binswanger 1980) that are unrelated to farmers' experiences and rely on the assumption of downward concavity everywhere for which there is no conclusive evidence. And if one adopts a flexible-enough utility function to admit convex as well as concave segments, it is unclear how one would estimate it.[7] Estimating rules of thumb, on the other hand, allows the researcher to base thresholds on the economic conditions facing a particular farmer (e.g. Day and Singh 1977, 1979).

III. Procedural rationality

As just discussed, several difficulties arise in using expected utility to test the hypothesis of loss aversion among low-income farm households. To render the model tractable, highly restrictive assumptions are invoked, including the existence of utility in one-period money and uniform concavity. In addition, risk preferences are measured based on hypothetical gambling games, not on the actual financial situation facing the farm household at a particular time.

Even more fundamentally, there is no known procedure by which farmers could actually maximize expected utility. As Day (1971) put it: "Rational men do not behave according to models that smart men can't solve."[8] And as Gans (1996) later showed in an issue of JEBO, computers can't solve them either (see also Kramer 1967). Indeed, the impossibility of a fully optimal decision under uncertainty goes back to Dick's cofounder of JEBO, Sidney Winter, who demonstrated that maximizing expected utility under costly information involves an infinite regress.[9] As Winter puts it: "I take it for granted that this regress must be stopped, that 'the set of all procedures for choosing a procedure from the set of all procedures from the set of all procedures … (ad inf.)' is not sufficiently well-defined to be the foundation for a theory of rational choice."[10]

At the same time, there are some potential advantages to full optimality approaches. Profit and utility maximization provide rigorous foundations for the theory of demand, supply, and equilibrium (Debreu

[7] One possibility is to estimate one-period utility as an indirect function of additively separable lifetime utility and transaction costs (Roumasset 1979). This approach has not been attempted empirically however.
[8] Modern behavioral economics bases the need for a new theory of decision making on the failure of traditional theory to explain experimental results (e.g. Kahneman and Tversky 1979 and Thaler and Sunstein 2008). Day's critique was more fundamental and grounded in traditional theory's lack of realism.
[9] See also Kramer (1967), Day and Pingle (1991), and Nishimura (2014).
[10] Winter's (1971) introduction provides a brief history of thought regarding behavioralism and managerialism going back to the 1940s.

1959) and the econometric analysis thereof (e.g. Diewert 1971). These in turn facilitate a tractable foundation for assessing the consequences of alternative economic policies, e.g. via comparative statics and numerical estimates. Without such full optimality foundations, a decision model is subject to *Lucas Critique* (Lucas 1976), i.e. the possibility that policy changes will change the model parameters (or rules of thumb). For some applications, it may be useful to design a model that is both fully optimal and behaviorally rational.

Indeed, plausible behavioral models may have full-optimality properties. For example, Day and Robinson (1971) showed that even lexicographic ordering leads to well-defined demand functions. Likewise, Day (1967) shows that a model of the satisficing firm, converges to the familiar marginal cost equals marginal revenue rule from neoclassical calculus.

Simon (1978) contrasts the *substantive* approach of most economists to decision making (utility maximization) with the *procedura*l approach in behavioral psychology and has helped moved economics in the behavioral direction. Procedural rationality emphasizes process rather than product, in particular the sequential *recognition* of possible choices and a *heuristic* search among those choices, neither one of which needs to be exhaustive (Simon 1995 and Munier et al. 1999). Substantive rationality may be irrational in the sense that "only by discarding the tools of [strong rationality] "are the most economical choices made possible" (Day and Pingle 1991).

On the other hand, full optimality need not be automatically discarded on the grounds of experimental anomalies or procedural issues. As Quiggin (1982) and others have shown, some of the "anomalies" (e.g. the *Allais Paradox*) said to violate full rationality can be rationalized by extending expected utility theory. And abstracting from procedural issues may be useful for some applications. As Georgescu-Roegen (1971, p. 319) put it, "abstraction is the most valuable ladder of any science." A higher level of abstraction may be more tractable for obtaining clear results. It is really a matter of judgment when the abstraction has gone too far and thereby reduced the usefulness for a particular application.

In the area of organizational economics, Dixit (1996) provides a taxonomy of levels of analysis and suggested their respective domains of application. Political economy models (with "endogenous coalition formation") are classified as *third best*; those with transaction costs are labeled *second best*; and those that abstract from both are termed *first best*.[11] His intent is not to judge the veracity of different models but to make researchers aware that the level of abstraction is an important choice of the analyst. While a similar

[11] In the arena of agricultural policy, for example, Roumasset (1995) suggests that first-best models are appropriate for understanding the terms of agricultural contracts, second-best models are needed for explaining the forms of those contracts, and third-best models are needed to explain the public choice of agricultural policy.

taxonomy has yet to be developed for decision theory, the behavioral analyst needs to consider the pros and cons of alternative models, including the tradeoff between the analytical benefits of abstraction and accounting for the realities of procedure.

For present purposes, a hybrid model is suggested—a full rationality model that nonetheless satisfies procedural rationality. Just as Samuelson (1947) establishes a *correspondence principle* (regarding stability conditions for market equilibrium), a behavioral model should have a *corresponding*, plausible decision process. As argued below, lexicographic ordering under uncertainty satisfies this criterion.

IV. Lexicographic safety first

Inasmuch as expected utility maximization is inappropriate as a model of low-income farmer decision making, we seek an alternative model with a plausible corresponding decision process. The model should also provide an operationally sound definition of risk and be capable of evaluating the hypothesis that loss aversion inhibits adoption of expected-profit maximizing techniques.

Loss aversion can be represented by the principle of *safety first*, as reviewed by Day et al. (1971). The idea is that there is a salient target income needed to avoid severe consequences for the farm family, which can be measured according to necessary household and farm expenses, including urgent debts, whose failure to repay would undermine the sustainability of the farm enterprise. For example, if the draft animal (e.g. water buffalo) had to be sold, that could render land preparation infeasible and force the family to sell their land or otherwise surrender cultivation rights. Risk, in this set up, is the subjective probability of falling below the target income threshold and *safety* is one minus risk. (Note that this framework provides a definition of risk that corresponds closely with a prominent dictionary definition of the word, i.e., *the chance of a significant loss*.) *Safety first* refers to priority that the decision-maker places on safety.

Day et al. (1971) note that the safety-first principle has typically been modelled as *chance-constrained programming* (Charnes and Cooper 1959), wherein expected profit is maximized subject to the constraint of an acceptable risk level. However, in a high-risk environment such as farming, there may be no available technique that is safe enough. In this case, chance-constrained programming fails to rank alternative production techniques and deliver a preferred choice. Lexicographic ordering provides a way out of this dilemma. Consider a vector-valued objective function where the first argument is "safety," defined as one minus the risk of a production technique, and the second argument is its expected profit. One further modification can be made to accommodate satisficing—the idea that a technique is safe enough. As shown by Day's colleague Jose Encarnacion (1965),[12] lexicographic ordering can accommodate satisficing under uncertainty by specifying a maximum safety level beyond which further improvements are not counted. This means that all techniques that are safe enough will tie according to the safety criterion and ties will have to be resolved by the second criterion.

Accordingly, *Lexicographic Safety First* (LSF) can be formalized as follows.

The decision maker's preference ordering corresponds to a lexicographic ordering of the vector,

$W_i = (V_i , E_i)$

where

$V_i = 1 - Max[\alpha, F_i(d)]$ is *satisficed* safety of the ith technique,

d = threshold income level below which the consequences of loss are especially severe,

α = acceptable risk (as in hypothesis testing, set according to the ability to tolerate loss),

$F_i(X)$ = the cumulative distribution of profits for the ith technique (where X is a vector of inputs), and

E_i = expected profit of the ith technique.

Note that $F_i(d)$ is a measure of the risk (i.e., probability) that profits of the ith technique fall below the "disaster" level of income d. For techniques with risk less than α, *satisficed risk* (the safe-enough level) is just α. Therefore, V_i is the satisficed level of safety or security. If more than one technique is safe enough, these techniques tie according to V, and the tie is resolved by the second criterion, expected profit E. When all techniques are more risky than α, the technique with the lowest risk, F_i (highest V_i) is chosen.

LSF provides a complete ranking of alternative production techniques, unlike chance constrained programming. The model formalizes "loss aversion" (Kahneman and Tversky (1979) without the contrivance of a real-valued utility function in one-period money. LSF is a full optimality model in the sense that it leads to a complete and consistent preordering of the *i*'s. It is also a behavioral model in the sense that it corresponds closely to the following decision process. The decision maker first screens out techniques that are not viable in the sense of satisfying the risk constraint. S/he then uses the criterion of

[12] Encarnacion accepted Day's invitation to serve as visiting professor at the University of Wisconsin, during the academic year 1969-1970.

expected profits to choose the best of the viable acts. When none of the feasible techniques is safe enough, the decision maker picks the risk-minimizing technique.[13]

V. An Illustration: Did loss aversion inhibit adoption of HYV technology in the Philippines?

Very early in the *green-revolution* process of HYV diffusion, several luminaries suggested that risk aversion was inhibiting adoption (Mellor 1966, Wharton 1969, Dillon and Anderson 1971, and Binswanger 1980 and 1981). The hypothesis has now reached the status of conventional wisdom (e.g. Chetty and Looney 2006, World Bank 2008, and Karlan et al. 2014). Several difficulties stand in the way of a credible test, however. First one must define risk and risk-aversion in a relevant way, measure both for a particular technique, show that substantial under-investment occurs, relative to some standard, and finally demonstrate that incorporating risk aversion into a suitably chosen model significantly improves its explanatory power, relative to risk neutrality.

The objective here is to provide a fully optimal model of decision-making under uncertainty that can be solved by a plausible process. The model draws on Day et al.'s (1971) review and development of safety-first modeling and Encarnacion's (1964) demonstration of how satisficing can be represented as a full optimality model.

The application focuses on the early years of the green revolution in rice in the Philippines. Adoption of the varieties themselves is not a suitable focus of the risk-aversion-implies-underinvestment (RAUI) hypothesis. Adoption of new varieties was extremely rapid and limited primarily by the availability of seeds (Ruttan 1977). Moreover, the new technology was characterized as a package of inputs especially fertilizer, inasmuch as the high yielding varieties were developed largely to be more responsive to nitrogenous fertilizer and to accommodate larger amounts per hectare before they tipped over of their own weight. Accordingly, the RAUI hypothesis will be implemented for nitrogenous fertilization in the Philippines during the early days of the green revolution.

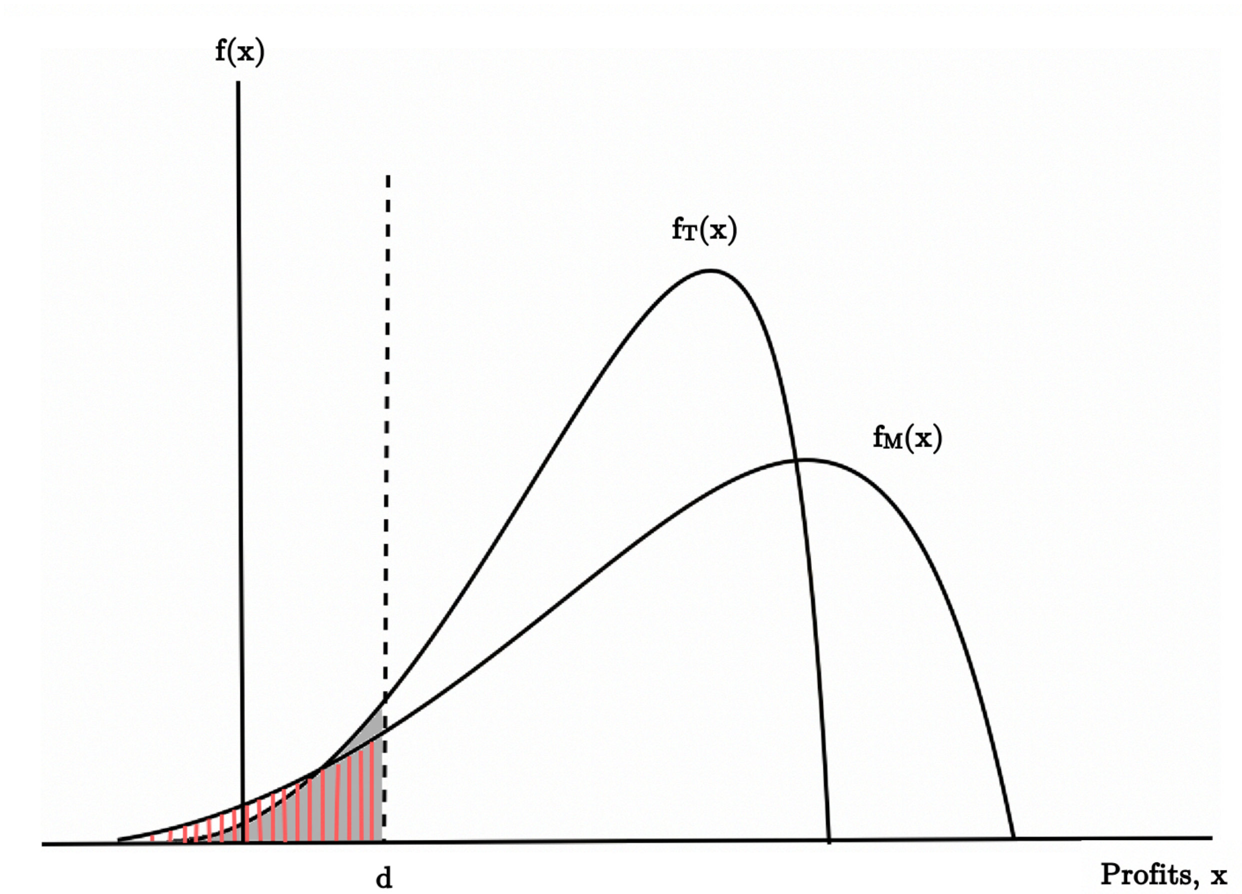
In the standard approach with uniformly concave utility functions, the positive effect of fertilizer on the variance of profits implies that the utility-maximizing fertilizer level is less than the risk-neutral (expected profit maximizing) level (e.g. Roumasset et al. 1989). As shown by Day (1965) for corn yields in the U.S., and verified for the case of rice yields in the Philippines (Rosegrant and Roumasset 1985), nitrogenous fertilizer increases negative skewness as well as variance. The same holds for the distribution of profits. This means that increasing variance may not increase risk. For the LSF case, loss aversion does

[13] Since E is a continuous variable, we assume there are no ties among the viable techniques. If there were, complete ordering would require the specification of a third variable in the vector-valued function.

not necessarily diminish the attraction of the risk neutral solution. Consider the case of the expected-profit-maximizing quantity of fertilizer vs. a lower amount. If both techniques are “safe enough” in the sense they tie with respect to the first lexicographic criterion, the higher fertilizer level is preferred even though it carries a higher level of variance.

As a consequence of the negative skewness, the high-mean/high-variance technique may be preferred because of a lower (or the same) risk level for the case where neither satisfies the safety aspiration. Indeed increasing fertilizer beyond the risk neutral level may be preferred for its lower risk level (thereby formalizing Banerjee’s, 2000, “desperation”). Figure 1 illustrates the case where the modern technique, e.g. fertilizer application, has a greater variance than the traditional technique along with greater negative skewness. As shown, it also has a greater chance of loss. For even modest “disaster” levels, such as d, however, the traditional technique carries a greater risk, i.e. the cumulative frequency for the traditional technique, $F_T(d)$, is greater than that of the modern technique, $F_M(d)$. Greater variance may involve lower downside risk.

Figure 1. Modern technique has a higher variance but lower risk.



Tempting as it is to devise some generality for behavior (farmers stint on modern investment because they are risk averse), people also behave differently because they face different circumstances. Low-income farm households, even those growing the same crop, face different agro-climatic conditions, different prices, different contractual obligations and privileges, different thresholds, and different states of the world. These idiosyncrasies need to be accounted for in testing a behavioral hypothesis. In the present case, since risk depends on farmer characteristics as well as the distribution-generating stochastic production functions, testing the hypothesis that loss aversion decreases fertilizer use requires specifying these for each farmer and comparing the ability of LSF vs. the risk neutral hypothesis to explain actual choices of nitrogenous fertilizer.

Available data was taken from two Philippines provinces during 1971-2 (Roumasset 1973 and 1976). Each of the 67 sample farmers were surveyed to determine their individual effective price ratios and RSI's. Farmers were also classified according to the *undamaged production function*, the production function fit to experimental data, corresponding to their solar radiation category (Barker et al. 1972, Roumasset 1976, and Rosegrant and Roumasset 1985).[14]

To convert these functions from highly controlled conditions into stochastic functions corresponding to farmer circumstances, farmers were also surveyed according to the frequency, type, and severity of damages experienced in recent seasons. These were used to specify a matrix of damage states and their probabilities for the respective farmer villages (Roumasset 1976, ch 5.) This in turn was used as the basis of a multiplicative, stochastic production function for each village, the fraction of yield remaining in each state being given by one minus the percentage of damage.

Stochastic production functions were based on three experimental production function drawn from controlled conditions and a multiplicative variable created from farmer interviews about sources of crop damages, the percentages lost and the likelihood of each of those damage states-of-the-world. The expected-profit-maximizing (risk neutral) prediction of each farmer's application of nitrogenous fertilizer per hectare is given by:

Max $E(N) = S_O P Ye(N) - R - S_I(1 + i)P_N N - C$

where

S_o = the decision maker's share in the output,

P = the farm-gate price of rice,

R = rent (for leaseholders),

S_1 = the decision maker's share in fertilizer costs,

P_N = the price of fertilizer (P/kgN),

N = kg nitrogen per hectare,

C = fixed costs paid by the decision maker,

i = the interest rate per season for farm expenses, and

Ye = expected yield, given the "undamaged" production function, f(N), and the distribution of U's, the "percentages remaining," under various possible damage states.[15]

[14] Sample farmers were located in Laguna and Albay provinces. The former has relatively higher solar radiation.
[15] Calculation of the U's was based on weather-station stochastic variables, farmer recollection of past damages, and farmer expectations (Roumasset 1976).

The level of *N* that maximizes expected profit to the decision maker (N^*) is that which equates the expected marginal product of nitrogen to the effective price ratio of nitrogen and rice, $S_i(1+i)P_N/S_OP$.

The effective relative price of fertilizer varies widely from farmer to farmer. A regime whereby the tenant gets two-thirds of the harvest, pays for all of the fertilizer and can borrow from the landlord at 50 percent interest is exactly equivalent to one in which the tenant's share of the output and fertilizer are equal but in which he must pay 100 percent interest. The centrality of the ratio also exposes a fallacy in the popular assertion that if the tenant's share in the variable costs is equal to his output share, then his decision will maximize profits to the farm operation, not merely his personal share. As is easily seen from the formula, this only follows for $i = 0$.[16]

Applying lexicographic safety first allows the researcher to base risk preferences on observable components of income thresholds, as opposed to hypothetical gambles for example. How much income does a farmer need to avoid adverse consequences that threaten the sustainability of the farm enterprise? This entails an assessment of liabilities (necessary household expenditures and high interest loans coming due) and available assets to pay for them in addition to farm income (such as savings, durable consumption goods that can be sold, and available loans). Instead of playing lottery games, the researcher is thus directed to the real consequences of gain and loss.

The computation of the nitrogen per hectare level under LSF requires a specifying a critical threshold income level for each farmer. Even in the early 70s, rice farmers in irrigated areas were not at risk of falling below subsistence income levels. Rather, the critical income threshold was that below which they would have to sell non-liquid assets to finance what they considered to be necessary household expenses. Off-farm income, liquid assets, farm size, and loans at "reasonable" interest rates were taken into account so that this minimum income level could be expressed in terms of annual profit per hectare from rice production, i.e. the threshold "risk sensitivity index,"

$$RSI = [NE + EE + UD - (OFI + LA + S + EL)]/Ha$$

where

NE = expenses for household necessities in the past year

EE = anticipated expense for sending dependents to elementary school

[16] If, on the other hand, profits to the farm operation are defined to be net of the opportunity costs of loanable funds, and we assume in addition that landlords have access to a perfect loanable funds market at rate, *r*, then the result cited only follows for $i = r$.

UD = urgent debts (consequences of non-payment greater than 100%/yr)

OFI = anticipated off-farm income (estimated from past year)

LA = liquid assets

S = savings

EL = amount of emergency loans obtainable at less than 100 percent interest

Ha = anticipated number of hectares planted to 1 rice in coming year.

The risk of falling below the critical threshold for a given nitrogen level, N, is just $R_N(d) = F_N(d)$ and the "safety" of that technique is one minus R or α, whichever is higher. If multiple levels of N have risk levels less than α for a particular farmer, then they tie according to the "safe enough" criterion and the expected profit maximizing N is chosen from those candidate techniques. If no N level is safe enough, then the optimal level of N is that which minimizes the risk.

The actual per hectare levels of nitrogen for each farmer, the N's, were recorded as part of the survey. The effective price ratios, the RSI's, and the village-level stochastic production functions, are then sufficient to calculate the risk neutral N*'s and the optimal fertilizer inputs under LSF, the N**'s.

The explanatory power of LSF can be compared to the null hypothesis that risk doesn't matter by regressing actual N on N** (the optimal N level by LSF) and comparting that to N on N*. The results for the null hypothesis and then for LSF (with t-values in parentheses) are:

$$N = -17.02 + \underset{(9.37)}{.99} N^{*}; \quad R^2 = .58$$

and

$$N = -14.99 + \underset{(8.57)}{.95} N^{**}; \quad R^2 = .53$$

Ordinarily, one would conduct an F-test to see whether accounting for loss aversion significantly improved explanatory power. Since the explanatory power of LSF is actually lower than that of the null hypothesis, however, we can reject the hypothesis that it explains behavior significantly better. (This does not mean that the loss-aversion model is significantly worse either.)

The reason for this negative result is that, while fertilization increases the variance of yields, it does not typically increase risk. For the most loss-averse farmers, with disaster levels, d, above 400 pesos per hectare, fertilization decreases risk. For the moderately risk averse (d = 200 to 400), risk is a U-shaped function of N, but the risk-minimizing level of N is typically slightly above N*, not below as usually expected. Only for the least risk averse (T below 200) does risk increase with N. For this last group, N* qualifies as safe enough such that N** = N*. Where there is a tradeoff between safety and expected profits, it is in the opposite direction usually supposed, i.e. N** > N*. Indeed, N* stochastically dominates N** for all positive threshold levels.

Despite the common belief regarding "the more risk-averse choosing more conservative options,"[17] the RAUI hypothesis is difficult to confirm even using expected utility models. Walker and Ryan (1990) explain why risk aversion is seldom relevant in explaining non-adoption of new farming varieties and methods. If the gain in expected profits is large and the increase in risk is small or none, adoption occurs without drawing on risk aversion. On the other hand, if the increase in risk causes expected profits to fall, risk aversion does not improve the prediction made by expected profits alone. Only when an increase in risk is accompanied by a moderate increase in profitability is there a chance for the risk-aversion-inhibits-innovation hypothesis to succeed. Even in this Goldilocks case, farmer reticence may be accounted for by transaction costs and other idiosyncrasies, i.e. once idiosyncrasies are accounted for, risk aversion may no longer improve explanatory power (Williams 1987).

Duflo et al. (2008) reject the hypothesis that risk aversion accounts for the non-use of fertilizer for their sample of Kenyan farmers. Because the returns to fertilization are substantial, they are only slightly "riskier" than not using fertilizer, and the cost of risk bearing is arbitrarily small, since fertilizer can be used in small amounts. Just and Pope (2003) note that many explanations are possible for farmer behavior under uncertainty, only one of which is curvature of the utility function. Duflo et al.'s (2011) preferred explanation is that farmers under-save at harvest time, relative to a fully optimal ideal, and cannot finance fertilizer once the next planting season arrives. Other negative tests of the RAUI hypothesis include Walker (1981) and Maertens et al. (2014). Feder (1980) also finds theoretically that risk aversion does not inhibit fertilization, because cutting back on fertilizer is dominated by the risk management technique of diversification, given endogenous hectarage allocation. In general, even if increased fertilizer resulted in Rothschild and Stiglitz's "mean-preserving spread" of profits, lowering fertilizer use is not necessarily part of the optimal risk-management portfolio.

Specification difficulties may also plague attempts to verify RAUI, including accounting for the covariance between price and yield, learning lags, differences between buying and selling prices, and the dependence of risk on agroclimatic zone and economic conditions.

[17] Binswanger (1981) citing Binswanger et al. (1980).

In sum, we cannot generalize the finding that risk aversion is always irrelevant to the choice-of-technique since risk and risk-averse profiles will be different for different technique choices and farmer characteristics. Nonetheless, the combination of factors required for risk aversion to be a major determinant of choice of technique is unlikely to occur with a high frequency. Specifically, what is required is a situation wherein farmers are strongly risk averse and in which the expected profit-maximizing technique is considerably more risky than alternative techniques. In order to demonstrate the importance of risk aversion, one needs to estimate the parameters of a risk averse decision model and show that it outperforms a fully specified risk neutral model for a particular sample of farmers.

VI. Policy implication: Crop insurance

As Duflo (2000) points out, Schultz's (1964) "efficient but poor" conclusion leaves open the possibility that low-income farmers are privately, but not socially, efficient. Indeed it is often surmised that risk aversion and incomplete insurance markets are important sources of both inefficiency and poverty (Banerjee 2000 and 2010) and World Bank 2008). Relatedly, Chetty and Looney argue that, while poor households manage to smooth consumption, they do so at great cost such that subsidies of "social insurance" would be of substantial benefit to those households, possibly in excess of their cost. While crop insurance would seem to qualify as a suitable example, no example of an all-risk crop insurance program has been found that generates greater benefits than costs (Wright 2014).

The ad hoc case for crop insurance in developing countries may be stated as follows.

1. Low-income farmers are risk averse.
2. Modern farming techniques are more risky than traditional practices.
3. Therefore, low-income farmers will be inhibited or be slow to adopt modern practices.
4. Modern techniques are more productive, therefore government should subsidize their adoption by crop insurance or other means.

As shown above, there are a number of fallacies with this logic.

1. Concavity of the utility function is not well-suited to capturing attitudes toward risk. Moreover, poor farm-households may accept large risks out of desperation (Banerjee 2000).
2. Modern techniques are not necessarily more risky, despite having a higher variance. In the case of fertilizer, the CDFs with fertilizer are likely to dominate those without, except for low threshold values (those with the least loss aversion). In the case of LSF, when N** was different than N*, it

is usually higher, precisely because fertilizer increased variance but lowered the chance of falling below the relevant income threshold.

3. Fertilizer recommendations are not well-tailored to the very diverse effective price ratios and density functions across farmers.

In addition, costs of crop insurance are high. Even in the U.S., indemnities plus administrative costs were 2.5 times premia received in the 1980s and have not decreased since (Wright and Hewitt 1994, Wright 2014). They are presumably higher in developing countries due to smaller farms and difficulties of monitoring (but still imperfectly governing) moral hazard and adverse selection (Roumasset 1978, Hazell et al. 1986). What is less appreciated is that the benefits of crop insurance are likely to be negative. Institutions for risk sharing, such as the stock market, create benefits by lowering the aggregate risk premium (Arrow and Lind 1970). What crop insurance does instead is cut off the bottom part of the objective function, thereby inducing moral hazard. The one-period utility function, to the extent one exists, is largely created by transaction costs and the resultant wedges between buying and selling prices. These reflect real costs, and distorting these signals via crop insurance blunts a welfare-increasing mechanism (Roumasset, 1979).[18]

Price subsidies, e.g. for fertilizer, should be similarly regarded with skepticism, inasmuch as farmer inefficiency, which must be established for highly idiosyncratic farm and farm-household characteristics, is not well enough understood to implement costly policies to counteract it.

VII. Other applications: the case of rational addiction

Addicts are commonly thought to be irrational because of their apparently self-destructive behavior. But the fact that addicts undermine their own long-run satisfaction does not imply that they have inconsistent preferences (Becker and Murphy 1988). But while addiction is often thought to be manifested in a completely inelastic (Marshallian) demand, actual consumption is remarkably variable.

Rational addiction can be represented with lexicographic safety first. Preferences can be characterized by three thresholds: subsistence income (including necessary leisure), the minimum amount of heroin needed to “take the sick off” (function without withdrawal symptoms), and the maximum amount, beyond which overdose occurs. While all three thresholds could be used in an LSF model, consider the case for simplicity. The *lexicographic addict* now spends discretionary income solely on the drug of choice, say

[18] Given these perverse incentives, Emerick et al. (2016) recommend technological improvements that target downside risk as promising alternatives to crop insurance.
Bulte and Lensink (2023) note that heavily subsidized crop insurance may also erode the relationships between small farmers and rice buyers who provide farm inputs, to the long-run detriment of farmers.

heroin, up to the maximum, and spends any remainder on other consumption. The addict's preferences can now be represented by a lexicographic ordering of the *W*s, where:

$V = \min[H, H_{MAX}]$

$W = [V, (Y_D - P_H H)]$,

H = heroin consumption

Y_D = discretionary income,

and $P_H H$ = heroin expenditure

Note that H_{MAX} is the *satisficed* level of heroin consumption beyond which overdose occurs. The addict is thus portrayed as prioritizing heroin spending and only spending on discretionary consumption once the heroin demand has been fully satisfied.

LSF lends itself to a very convenient empirical application relative to, say, an elaborate econometric procedure to estimate the utility-based Becker and Murphy (1988) approach. In the case of Oakland, California, for example, mature addicts (with at least six months of consumption) in the early 1970s typically had threshold levels ranging from one to ten "dime bags" ($10 each) representing the minimum and maximum consumption levels. Unlike the stereotypical addict who consumes the same amount daily (inelastic demand), consumption by actual addicts varies enormously from day to day depending on income, especially from the sale of stolen goods (Roumasset and Hadreas 1974). The thresholds in question can be readily identified via interviews.

In the context of an expanded model, where subsistence expenditures up to a maximum are the first argument of the welfare (W) vector, then the Marshallian price elasticity is zero up to the point where the subsistence requirement is satisfied and again after H_{MAX} is reached. The model brings out the importance of income in the demand for illicit drugs. Since "addiction capital" declines when H_{MIN} cannot be sustained, regulating addict's income may be a powerful tool in addition to interdiction, treatment, and "prevention." Regulating pawn brokers who regularly deal in stolen goods is one example (Roumasset and Hadreas 1974).

VIII. Conclusions

Richard Day's critique of expected utility theory is extended and applied. A case is made against using expected utility theory for testing the hypothesis that low-income farmers stint modern inputs due to risk aversion. In order to apply expected-utility theory, researchers typically add highly restrictive assumptions, including the existence of utility in one-period money and uniform concavity of the utility function. These in turn lead to the misleading narrative that low-income farmers stint variance-increasing inputs, even though these very inputs may decrease downside risk. Finally, and more fundamentally, no program of procedural rationality has been specified that makes the model credible.

A model of lexicographic safety first (LSF) is posited, with roots in the writings of Richard Day, that corresponds to a plausible decision-making process and that fits the narrative of low-income farm households with their very livelihoods at risk. Unlike chance-constrained programming, the model is capable of fully ranking feasible choices. It also embodies satisficing with respect to production techniques that are "safe enough." Instead of relying on hypothetical lottery games, the model parameters are based on the asset-liability position of a specific farm household, thereby capturing the idiosyncrasies of farms, contractual obligations, and household circumstances in a particular season.

Understanding farmer behavior under uncertainty requires knowing both the household specific thresholds and how the frequency distributions of profits depend on farm-specific effective prices and production parameters. Applying LSF to the problem of fertilizer use in small farm Philippine rice farming yields the result that incorporating loss aversion leads to a slight decrease in explanatory power, i.e. that the loss-aversion-implies-underinvestment hypothesis is rejected in the context studied. More generally, and as Williams (1986) argues in another context, once transaction costs and other idiosyncrasies are taken into account, it may not be necessary to invoke risk aversion to explain behavioral stylized facts.

Prematurely accepting the RAUI hypothesis may lead policy makers to accept welfare-reducing policy measures such as subsidized crop insurance, often justified as needed to enhance risk-sharing in the face of alleged market failures in credit and insurance markets. But much of what goes into household-specific risk attitudes is transaction costs, especially the wedges between buying and selling prices (Roumasset 1979, de Janvry et al. 1991). These are not "spreadable" in the sense of the theory of risk bearing. Not only are crop insurance programs very costly (Wright 2014), the benefits may well be negative, due to blunted incentives facing individuals in unique situations (Roumasset 2014). Prescriptions to correct other "asset-market failures" (Banerjee and Moll 2010) may be similarly subjected to an assessment of costs and benefits.

Applying LSF to the theory of rational addiction underscores its empirical advantages. Where utility functions with concave and convex segments may be difficult to estimate, behavioral thresholds, such as the amount of heroin required to "take the sick off," may be easier to identify. Addiction can be well represented with reference to various income thresholds, and these lead in turn to additional policy levers that make drug policy more effective.

The purpose here is not to bury utility theory but to provide additional insights into its practical drawbacks, and, as Dick said many times, to suggest a possible direction for improvement. One needn't conclude that utility theory is "wrong," indeed it may be conceptually equivalent to lexicographic ordering (Day and Robinson 1973). Rather the researcher can assess which approach yields greater insights in a particular application. Like the art in the beholder's eye, that is ultimately subjective.

The context provided here has been to static decision models. But as Day (1979) has himself noted, safety first principles can also be incorporated into adaptive models of decision making, such as cautious optimizing (e.g. Day and Singh 1979).

References

Antle, 1983. Testing the Stochastic Structure of Production: A Flexible Moment-Based Approach. Journal of Business & Economic Statistics, 1(3): 192-20.

Antle, J. 2010. Asymmetry, partial moments, and production risk. *Am. J. Agric. Econ.* 92, 1294–1309.

Arrow, K. and R. Lind. 1970. Uncertainty and the Evaluation of Public Investment Decisions. American Economic Review, 60(3): 364-78.

Banerjee, A. 2000. The Two Poverties. Nordic Journal of Political Economy, 26(2): 129-141.

Banerjee, A. and B. Moll. 2010. Why Does Misallocation Persist? American Economic Journal: Macroeconomics, 2(1): 189-206.

Barker, R., V. Cordova, and J. Roumasset. 1972. The Economic Analysis of Experimental Results in Nitrogen Response of Rice, Conference on Economics of Fertilizer Use, Asian and Pacific Council, Food and Fertilizer Technology Center, Taipei.

Begho, T., V. Eory, and K. Glenk. Demystifying risk attitudes and fertilizer use: A review of factors associated with agricultural nitrogen emissions in South Asia. Frontiers in Sustainable Food Systems, V.6(Sept.): 1-12.

Becker, G. and K. Murphy. 1988. A Theory of Rational Addiction. Journal of Political Economy, 96(4): 675-700.

Binswanger, H. 1980. Attitudes towards risk: Experimental measurement in rural India. American Journal of Agricultural Economics, 62(3): 395-407.

Binswanger, H. 1981. Attitudes Toward Risk: Theoretical Implications of an Experiment in Rural India. The Economic Journal, 91(364): 867-890.

Bulte, E. and R. Lensink. 2023. Why agricultural insurance may slow down agricultural development. American Journal of Agricultural Economics, 108(4): 1197-1220.

Charnes, A. and W. Cooper. 1959. Chance-Constrained Programming." Management Science, 6(October): 73-79.

Chetty, R. and A. Looney. 2006. Consumption Smoothing and the Welfare Consequences of Social Insurance in Developing Economies. Journal of Public Economics. 90(12): 2351-2356.

Debreu, G. 1959. Theory of Value: An Axiomatic Analysis of Economic Equilibrium. New Haven and London: Yale University Press.

De Janvry, E. Sadoulet, M. Fafchamps. Household Behavior with Missing Markets: Some Paradoxes Explained. The Economic Journal,101(409): 1400-1417.

Diewert, W. E. An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function," Journal of Political Economy, 79 (1971), 481-507.

Dillon, J. and J. Anderson. 1971. Allocative Efficiency, Traditional Agriculture, and Risk. American Journal of Agricultural Economics, 53(1): 20-32.

Dixit, A. 1996. The *Making of Economic Policy*: A Transaction-Cost Politics. Approach. Cambridge: MIT Press.

Duflo, E. 2006. "Poor but Rational?" In Understanding Poverty, A. Banerjee, R. Benabou, and D. Mookherjee, eds. Oxford: Oxford University Press.

Duflo, E., M. Kremer, and J. Robinson. 2011. Nudging Farmers to Use Fertilizer: Theory and Evidence from Kenya. American Economic Review, 101(6): 2350-90.

Duflo, E., M. Kremer and J. Robinson. 2008. How High are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya. American Economic Review, 98(2): 482-88.

Gans, J. 1996. On the Impossibility of rational choice under incomplete information. Journal of Economic Behavior & Organization, 29(2): 287-309.

Emerick, K., A. de Janvry, E. Sadoulet, and M. Dar. 2016. Technological Innovations, Downside Risk, and the Modernization of Agriculture. American Economic Review. 106(6):1537–1561.

Encarnacion, J. 1964a. A note on lexicographical preferences", *Econometrica* 32(1-2):215-217.

Encarnacion, J. 1964b. Constraints and the Firm's Utility Function," Review of Economic

Studies, 31: 113-19.
Encarnacion, J. 1965. On Decisions Under Uncertainty. The Economic Journal, 75(298): 442-444.
Day, R. 1967. Profits, Learning and the Convergence of Satisficing to Marginalism. *Quarterly Journal of Economics*, 81:302-311.
Day, R. 1971. Rational Choice and Economic Behavior. Theory and Decision, 1(1):229-251.
Day, R., D. Aigner, and K. Smith. 1971. Safety Margins and Profit Maximizing in the Theory of the Firm. Journal of Political Economy. 79(6):1293-1301.
Day, R., S. Morley, and K. Smith. 1974. Myopic Optimizing and Rules of Thumb in a Micro Model of Industrial Growth. *American Economic Review*, 64:11-23.
Day, R. and S. Robinson. 1973. "Economic Decisions with L** Utility," with S.M. Robinson in J.L. Cochrane and M. Zeleny (eds.), *Multiple Criteria Decision Making*. Columbia: The University of South Carolina Press
Day, R. and M. Pingle. 1991. Economizing Economizing. in: R. Franz, H. Singh and J. Gerber, eds., Handbook of Behavioral Economics, 2B, Greenwich, Connecticut, JAI Press.
Day, R. and I. Singh. 1979. Cautious Suboptimizing. In J. Roumasset, J. Boussard, and I. Singh, Risk, Uncertainty, and Agricultural Development. Los Banos, Philippines: Southeast Asian Regional Center for Graduate Study and Research in Agriculture.
De Janvry, A., M. Fafchamps, and E. Sadoulet. 1991. Peasant Household Behaviour with Missing Markets: Some Paradoxes Explained. The Economic Journal 101(409): 1400-1417.
Georgescu-Roegen, N. 1971. The Entropy Law and the Economic Process. Cambridge: Harvard University Press.
Falcon, W. 1970. The Green Revolution: Generations of Problems. American Journal of Agricultural Economics, 52(5): 698-710.
Feder, G. 1980. Farm Size, Risk Aversion, and the Adoption of New Technology under Uncertainty. Oxford Economic Papers, 32(2): 263-83.Hazell, P., C. Pomareda, and A. Valdes (eds.).1986. Crop Insurance for *Agricultural Development: Issues and Experience*. Baltimore: Johns Hopkins University Press.
Just, R. and R. Pope. 2003. Agricultural Risk Analysis: Adequacy of Models, Data, and Issues. American Journal of Agricultural Economics, 85(5): 1249–56.
Lucas, R. Econometric Policy Evaluation: A Critique. In Meltzer, A. (eds.). The Phillips Curve and Labor Markets. Carnegie-Rochester Conference Series on Public Policy. Vol. 1. New York: American Elsevier.
Maertens, A., A. Chari, and D. Just. 2014. Why Farmers Sometimes Love Risks: Evidence from India. Economic Development and Cultural Change, 62(2): 239-274.
Kahneman, D. and A. Tversky. 1979. Prospect Theory: An Analysis of Decision under Risk. Econometrica, 47(4): *263–291.*
Karlan, D., R. Osei, I. Osei-Akoto, and C. Udry. 2014. Agricultural decision-making after relaxing credit and risk constraints. Quarterly Journal of Economics, 129(2): 597-652.
Khor, L., S. Ufer, T. Nielson, and M. Zellner.2018. Impact of risk aversion on fertiliser use: evidence from Vietnam. *Oxf. Dev. Stud.* 46, 483–496.
Kramer, G. 1967. An Impossibility Result Concerning the Theory of Decision-Making. In J.L Bernd (Ed.), Mathematical applications in political science III, University Press of Virginia, Charlottesville (1967), pp. 39-51. (Also available as Cowles Discussion paper 218, 1967).
Mellor, J. 1966. The Economics of Agricultural Development. Ithaca: Cornell University Press.
Mukasa, A. 2018. Technology adoption and risk exposure among smallholder farmers: panel data evidence from Tanzania and Uganda. *World Dev.* 105, 299–309.
Munier, B., R. Selten, D, Bouyssou, Paul Bourgine, Richard Day, Nigel Harvey, Denis Hilton, Mark J. Machina, Phil Parker, Hon Sterman, J. Sterman, Elke Weber, Birger Wernerfelt and Robin Wensley Bounded Rationality Modeling. Marketing Letters , Aug., 1999, Vol. 10, No. 3, HEC Choice Symposium (Aug., 1999), pp. 233-248.

Nishimura, H. 2014. Non-existence of continuous choice functions.Journal of Economic Theory, 153: 376-391.
Rajsic, P., A. Weersink, and M. Gandorfer. 2009. Risk and nitrogen application levels. *Can. J. Agric. Econ.* 57, 223–239.
Rothschild, M. and J. Stiglitz. 1970. Increasing Risk: I. A Definition. Journal of Economics Theory, 2(3): 225-243
Rosegrant, M. and J. Roumasset. 1985. The Effect of Fertiliser on Risk: A Heteroscedastic Production Function with Measurable Stochastic Inputs. Australian Journal of Agricultural Economics, 29(2):107-121.
Roumasset, J. 1973. Risk and choice-of-technique for peasant agriculture: the case of Philippine rice farmers. University of Wisconsin Diss.
Roumasset, J. 1976. Rice and Risk. Amsterdam: Elsevier.
Roumasset, J. 1978. The case against crop insurance for developing countries. Philippine Review of Business and Economics, 15(1): 87-108.
Roumasset, J. 1979. Risk Aversion, Agricultural Development, and the Indirect Utility Function," In Roumasset, J. et al. (Eds.), *Risk, Uncertainty and Agricultural Development*. Los Banos, Philippines: SEARCA and A/D/C.
Roumasset, J. Reflections on the Foudations of Development Policy Analysis. 2014. In A. Balisacan, M. Ravago, and U. Chakravorty. Sustainable Economic Development: Resources, Environment and Institutions. Amsterdam: Elsevier.
Roumasset, J. The nature of the agricultural firm. Journal of Economic Behavior & Organization, 26(2): 161-177
Roumasset, J., M. Rosegrant, U. Chakravorty, and J. Anderson. 1989. Fertilizer and Crop Yield Variability: A Review, in J. Anderson and P. Hazell, Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries. Maryland: The International Food Policy Research Institute, 223–233.
Ruttan, V. 1977. The Green Revolution: Seven Generalizations." International Development Review 19 (December 1977): 16-23.
Schultz, T. 1964. Transforming Traditional Agriculture. New Haven and London: Yale University Press.
Simon, H. A. (1995) The Information-Processing Theory of Mind, The American Psychologist, 5.
Spence, M. and Zeckhauser. 1972. The Effect of the Timing of Consumption Decisions and the Resolution of Lotteries on the Choice of Lotteries. *Econometrica*, 40(2): 401-403.
Thaler, Richard H. 1992. *The Winner's Curse: Paradoxes and Anomalies of Economic Life.* Princeton: Princeton University Press
Thaler, R. and C. Sunstein. 2008. Nudge: Improving Decisions about Health, Wealth, and Happiness. New Haven: Yale University Press.
Winter, S. 1969. Concepts of Rationality in Behavioral Theory. Discussion Paper 7, Institute for Public Policy Studies, University of Michigan.
Hardaker, J.B., R. Huirne, J. Anderson, G. Lien. 2015. Coping with Risk in Agriculture: Applied Decision Analysis, 3rd edition. Oxford University Press.
Walker, T. 1981. Risk and Adoption of Hybrid Maize in El Salvador. *Food Research Institute Studies,,* 58(1): 59: 88.
Walker, T. and J. Ryan. 1990. Village and Household Economies in India's Semi-Arid Tropics. Baltimore: Johns Hopkins University Press.
Wharton, C. 1968. Uncertainty and the Subsistence Farmer: Technological Innovation and Resistance to Change in the Context of Survival. Annual Conference of the American Economic Association.
Williams, J. 1987. Futures Markets: A Consequence of Risk Aversion or Transactions Costs? Journal of Political Economy, 95(5): 1000- 1023.
World Bank. 2008. World Development Report. Washington DC: The World Bank.
Wright, B. and J. Hewitt. 1994. All-Risk Crop Insurance: Lessons from Theory and Evidence. Chapter 4

in D. Hueth and W. Furtan (eds.), *Economics of Agricultural Crop Insurance: Theory and Evidence*, Boston: Kluwer Academic.

Wright, B. 2014. The Role of Agricultural Economists in Sustaining Bad Programs. In A. Balisacan, U. Chakravorty, and M. Ravago, Sustainable Economic Development: Resources Environment, and Institutions. Amsterdam: Elsevier.