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Flat Earth Economics: The Far-reaching Consequences of Flat Payoff Functions in Economic Decision Making

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Economists tend to emphasize the optimum, but in many cases, even large deviations from optimal decisions make little difference to the payoff. This has far-reaching implications that are under-recognized, including: (*a*) decision makers often have a wide margin for error in their production planning decisions, and flexibility to pursue factors not considered in the calculation of payoffs; (*b*) optimizing techniques are sometimes of limited practical relevance for decision support; (*c*) the value of information used to refine management decisions is often low; and (*d*) the benefits of using "precision farming" technologies to adjust production input levels are often low.

Within the neighborhood of any economically "optimal" management system, there is a set of alternatives that are only slightly less attractive than the optimum. Often this set is large. For example, in the 1980s, my colleagues and I modeled dryland crop-livestock farms in Western Australia to estimate the optimal percentage of land to allocate to crop production (Morrison et al.; Kingwell and Pannell). We often found that within a wide range of cropping percentages, the farm profit was within 10% of the maximum. Figure 1 shows an example where this is true for cropping percentage between 51% and 92%. Given the inevitable imprecision and uncertainty of data used in such an analysis, apparent gains of as little as 10% may well be illusory.

Models used to evaluate economically optimal levels of production inputs at the field scale also typically find wide profit plateaus. Examples in agriculture include models of production response to fertilizers, herbicides, insecticides, and soil ameliorants. Figure 2 shows profit as a function of herbicide dose rate for the empirical model estimated by Pannell. Although a dose of 0.26 kg ha^{-1} gives the maximum profit, any dose between 0.15 and 0.44 would yield profits within 5%

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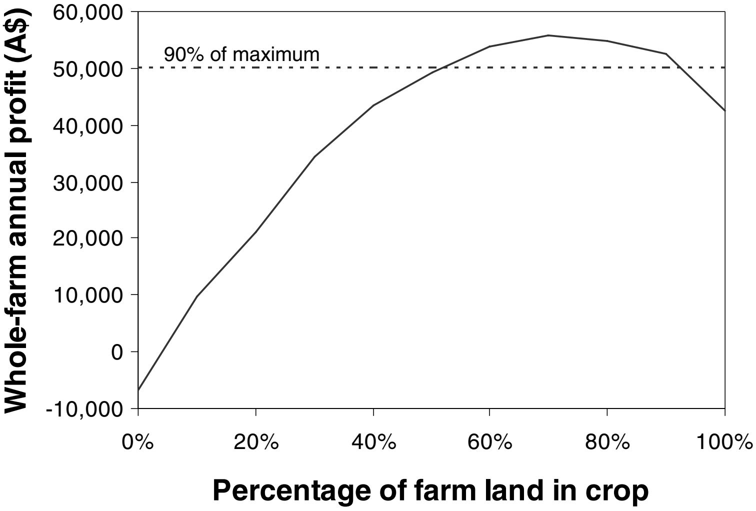
Figure 1. A typical result for Western Australian farms in the 1980s, showing a wide plateau with near-optimal profits



Source: Pannell and Bathgate

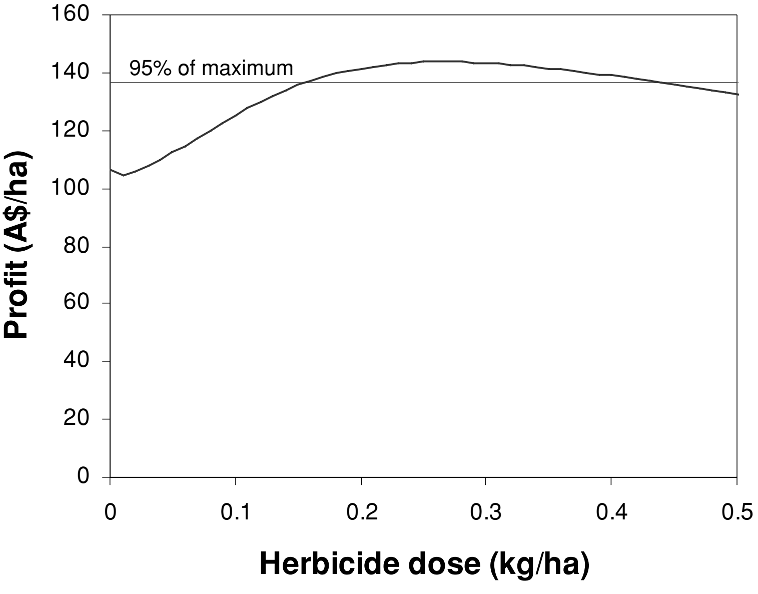
of the maximum. In this sense, the margin for error is –40% to +70% around the optimum.

The width and flatness of the profit plateau varies, but the presence of a profit plateau is almost universal in economic production models with continuous decision variables. Within many standard economic models, there are flat payoff functions. For example, figure 3 is based on a standard monopololy model, with linear demand and linear marginal cost. It shows the monopolist's payoff as a function of the price charged for the product. In this simple numerical example, any price within 25% of the optimal price has a payoff within 10% of the maximum payoff.

This paper reviews and discusses the implications of flat payoff functions for decision makers and analysts, with a focus on agriculture. The existence of flat payoff functions in agriculture was well recognized in the past, at least among production economists. There was a wide range of literature from the 1950s to the 1970s in which the issue was acknowledged and discussed, including that by Hutton and Thorne; Havlicek and Seagraves; and Doll. However, over time, explicit recognition of the issue has largely disappeared from the literature, probably reflecting changes in the interests of agricultural economists. Similarly, in general economics, recognition of the issue is infrequent, with (Bhalotra) providing a rare recent example.[1]

Among noneconomist agriculturalists, it appears that only a small minority recognized the issue. Jardine (1975b) noted that on presenting information to agronomists about flat profit curves for fertlizers, he "observed such reactions as complete disbelief, blank incomprehension, incipient terror, and others less readily categorized" (p. 200). I suspect that among many biological scientists, the responses would be similar today.

Figure 2. Profit from wheat production as a function of herbicide dose



Anderson's and Jardine's (1975b) contributions were part of a spirited debate among researchers, prompted by Jardine (1975a) and including responses by White; Godden and Helyar; and Brown. As far as I know, no similar exchange has graced the pages of any agricultural journal since, and even at that time some of the contributors to the debate missed the point. Only occasionally is the issue acknowledged (e.g., Dillon; Dillon and Anderson; Keating et al.) and it is generally not featured as an issue of outstanding importance.

Figure 3. Payoff to a monopolist as a function of price charged

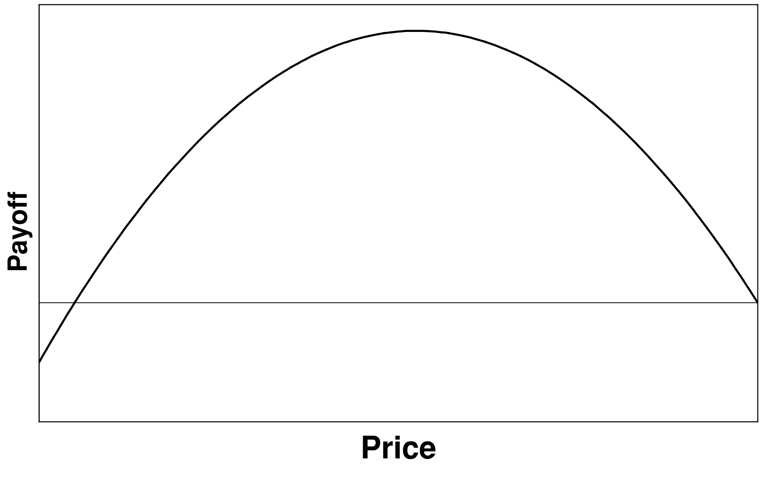
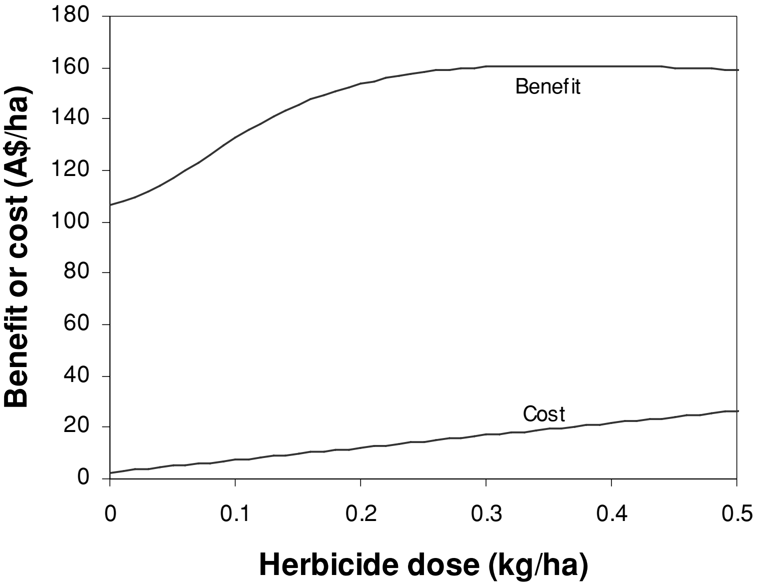


Figure 4. Benefits and costs of wheat production, treating herbicide dose as the only variable input



Despite the current neglect, flat payoff curves remain as frequent and as important as ever. Their implications are numerous and diverse and touch on some prominent modern trends in agriculture. The next section discusses the origins and causes of flat payoff functions in economic models, particularly for agriculture. I also present and discuss a wide range of implications and consequences of flat payoff functions.

Why Are They Flat?

In decision making about production inputs, the profit plateau arises from the usual shape of the production function. "The relative insensitivity of profit arises because the response function is generally smoothly rather than sharply curved, and because marginal profitability is thus necessarily close to zero in the region of best operating conditions" (Dillon, p. 60). In agriculture, this "smooth" curvature generally reflects the biological behavior of the production system. Figure 4 illustrates the absolute benefits and costs of wheat production as herbicide dose is varied. It uses the same production function that underlies figure 2; the profit function of figure 2 is the difference between the benefits and costs depicted in figure 4.

The benefit curve in figure 4 directly reflects the way that crop yield responds (mainly due to decreasing weed competition) as herbicide dose is increased. It is obvious that whenever a production function takes this classic shape, as assumed in every microeconomics text, the smooth and concave-down shape of the curve in the region of the optimum will guarantee that there is some region where profits are very close to their maximum. The width of this region will depend on the biological and technical forces that forge the actual production function.

Anderson noted that the issue not only affects input response functions; it is "a much more general phenomenon which pervades all optimization processes and models" (p. 195). He gave as examples whole-farm economic models and cost functions.

Where the decision is a choice among a portfolio of production options (e.g., figure 1), the existence of a profit plateau is less assured than for input choices, but it is still common. A plateau is more likely if there is an internal solution to the portfolio problem (a mixture of production activities) rather than a corner solution (focus on a single option). A number of factors contribute to diversification of production activities in agriculture, which is another way of saying that there is an internal solution. These factors include: (*a*) nonuniformity of resource quality (e.g., Morrison et al.; Kingwell, Morrison, and Bathgate); (*b*) resource constraints, such as on machinery capacity (Pannell, Malcolm, and Kingwell); (*c*) complimentarity between enterprises, such as nitrogen fixation by legumes grown in rotation with cereal crops (Pannell); and (*d*) risk aversion (Samuelson).

A sizable set of near-optimal plans will exist whenever these factors combine to result in a diversified farm plan being optimal, as illustrated in figure 1.

There are implications here for the degree of detail used by whole-farm modelers. Simpler farm models sometimes neglect to represent some of these four factors, with the result that the existence of a flat region of the payoff function is not recognized. Often the failure of simple mathematical programming models to identify an internal solution is attributed to their nonrepresentation of risk aversion, although the other factors listed above can be at least as important (Pannell, Malcolm, and Kingwell).[2]

Consequences and Implications of Flat Payoff Functions

Margin for Error

A flat payoff function provides some comfort for the decision maker, in that there is a margin for error in the decision. A failure to optimize the decision will not be costly unless the decision departs substantially from the optimum. In agriculture, farmers often do not take great care and detailed effort over their production decisions. Many farmers do not employ sophisticated analytical methods to support their decisions, and indeed many make production decisions on a somewhat intuitive basis. Where payoff curves are flat, this is probably a sensible prioritization of effort, particularly if it allows farmers to allocate additional time to other aspects of management that are more likely to pay off (e.g., increasing their knowledge of production technologies and systems or investigating innovative practices).

Another consequence of a flat payoff function is that it empowers the decision maker to consider additional factors that are not reflected in the calculation of payoffs. For example, farmers often have personal preferences for, or interests in, some production options relative to others (e.g., a farmer may be comfortable with crop production and dislike dealing with animals). If the financial consequences of a choice between options are minimal, such personal preferences may become the decisive factor in the decision. Sheriff proposed a variety of reasons why farmers tend to apply more fertilizer than would be economically optimal. In addition to the reasons he suggested, flat payoff functions mean there is likely to be little economic loss from over-application, except in extreme cases.

There are also implications for analysts developing decision support systems for farmers. The forgiving nature of many production decisions means that optimizing techniques have limited practical relevance. A modeler can usually be more helpful to the decision maker by identifying the shape of the payoff function, and especially the range over which it is relatively flat, rather than emphasizing a single optimal solution. This highlights the relevance of methods such as sensitivity analysis (Pannell). It does not imply that optimization models should not be used, but has implications for the way that they should be used in decision support.

The Value of Monitoring Sustainability Indicators and Other Management Indicators

During the 1990s, there was a growing interest in the use of so-called "sustainability indicators," in the hope that they would allow more "sustainable" management of agricultural lands (Pannell and Glenn). The issue is essentially one of providing additional information for use in management decisions, and is similar in many respects to monitoring standard economic variables, such as prices, interest rates, exchange rates, and debt.

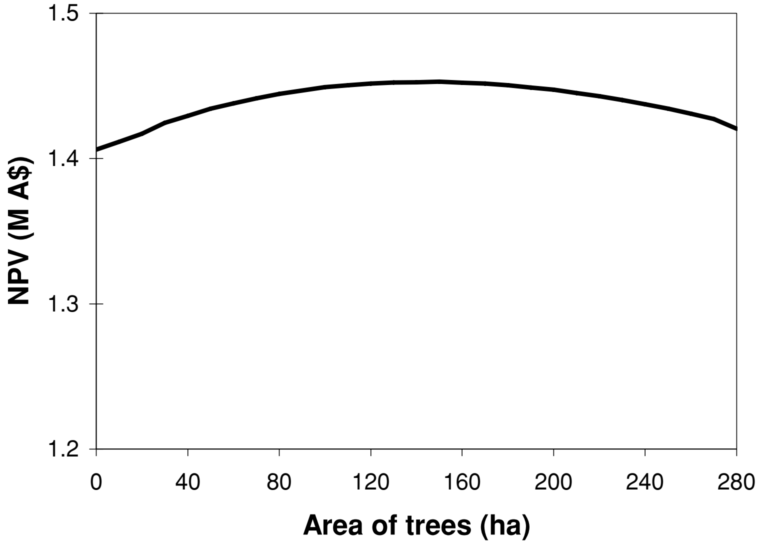
One way or another, information costs money (the costs of searching for, collecting, communicating, storing, analyzing, or buying it). An important question is whether the benefits of acquiring information exceed its cost. Flat payoff functions influence the result.

Before we consider that influence, we need some background on the estimation of information value. A decision-theory framework (Anderson, Dillon, and Hardaker) is very helpful in understanding and estimating the value of information used to make management decisions. Here is a brief outline of the thought process involved in estimating the value of information in a farming context.

Suppose that a farmer has a decision to make, and the optimal decision depends on a number of variables, which I will call indicators. In general, the farmer will have some preconceptions about the indicators. Without observing the indicators, their values are not known with certainty, but the farmer has subjective views about the ranges within which they are likely to fall, and the likelihoods that they will take different values within those ranges. These preconceptions could be based on past experience, observations of other farms, or external advice.

It would be possible for the farmer to make a best-bet decision based solely on preconceptions. Alternatively, the farmer could observe relevant indicators before making the decision. With the extra information from these observations, an improved decision may be possible. The extent of improvement depends on issues such as:

Figure 5. Payoff for decision on area of trees (discount rate 10%)



- whether the observation is significantly different from the farmer's preconceptions;
- how accurately the indicator can be observed;
- how applicable the observation is to the whole area for which a decision is needed; and
- how responsive the payoff is to changed management.

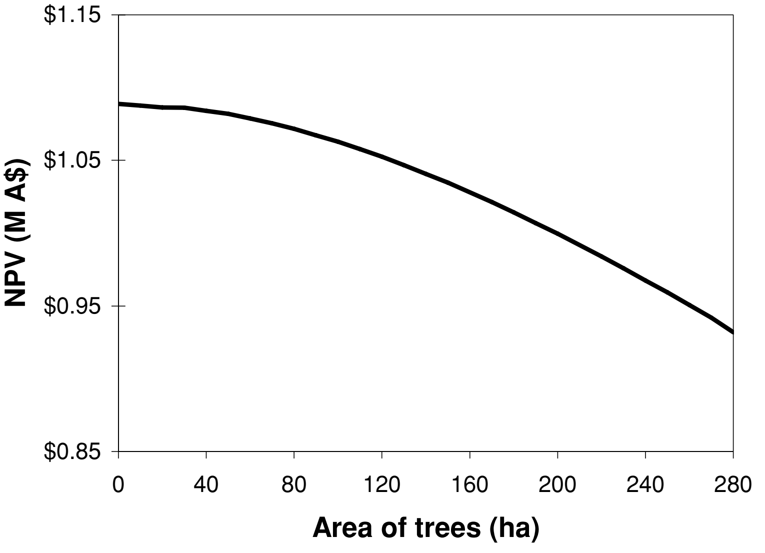
Considering such issues makes it possible to assess the likely benefits from observing the indicators. The expected value of the information obtained by observing the indicators is the difference between the expected benefits and the costs of collecting the information.

Pannell and Glenn provided a numerical example that will help us to explore the issue. A farmer must choose the area of land that should be planted to trees. Land not devoted to trees is used for wheat production. Figures 5 and 6 show the payoff curves for two discount rates, based on assumptions and parameters presented in the original study.

Pannell and Glenn found that the value of collecting additional information to support the decision was low; zero in some cases. There are different reasons for the low values in the two cases, 10% and 15% discount rates. In the 10% case, the payoff function is very flat (figure 5). As a result, even if the farmer chooses an area of trees that differs substantially from the true optimum, the loss of profit relative to the optimum is low. If refining decisions does not make much difference to the payoff, the value of monitoring the indicators is low.

On the other hand, with a 15% discount rate, the optimal choice (to grow no trees) is so clear that there is no information that would alter it. Since the additional information cannot alter the decision, it cannot change the payoff, and so the information has zero value.

Figure 6. Payoff for decision on area of trees (discount rate 15%)



Agricultural research or extension organizations often encourage farmers to monitor various variables on their farms, but the argument presented above presents such organizations with a serious conundrum. Ideally, they would like the payoff to farmers from monitoring their proposed indicators to be high. However, if the treatment is either highly advantageous or clearly uneconomic, the best decision is obvious and the value of any further information will be low. Conversely, if the payoffs from different decision options are similar enough so that the optimal decision is unclear and can be clarified by further information, then the overall payoff curve is likely to be flat, so that again the information is of limited value.

The Value of Precision Farming

"In pursuing . . . optimal levels of decision variables, precision is pretence and great accuracy is absurdity" (Anderson, p. 195).

A second information-related example concerns so-called "precision farming," which is an innovative approach to managing agricultural inputs. This term encompasses a range of technologies and approaches, but all involve the use of information to adjust levels of an agricultural input to suit conditions in different locations in a field. This spatial variability of inputs recognizes that physical conditions also vary spatially, so that the optimal input level is higher or lower in different locations. Some of the technologies involved are expensive, so accurately estimating the benefits derived from precision farming is important to farmers. The issues are fundamentally the same as those described earlier for monitoring of an indicator for improved decision making by farmers, but they operate on a microscale and with automated decisions. If the precision farming technology results in low-to-moderate changes in input levels at a given location within the

Table 1. Incremental benefits (AU$/ha/year) of increasing the information intensity of decisions about lime application to treat soil acidity

Zone	Soil Type	Change from Very Low to Low Precision	Change from Low to Moderate Precision
Low rainfall	Deep sand	14	4
	Clay	8	2
Medium rainfall	Deep sand	35	3
	Clay	19	2
High rainfall	Deep sand	7	3
	Clay	21	0

Source: O'Connell, Bathgate, and Glenn.

field, there is a high probability that the improvement in profit will be very low due to a flat payoff function.

Bennett and Pannell found very low benefits from use of a precision agriculture system for herbicides. Flat payoff functions contributed to that result, although corner solutions (or near-corner solutions) were the main causal factor.

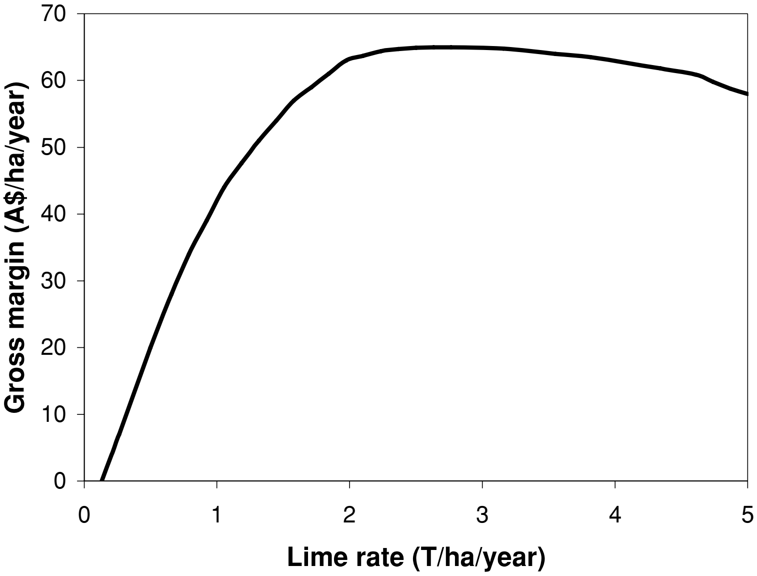
In general, flat payoff functions cause diminishing marginal returns to precision in decisions about agricultural inputs. O'Connell, Bathgate, and Glenn quantified the extent of this diminution for a particular example: application of lime to treat soil acidity. Their example considered three levels of information and precision in the decision:

1. Very low information use/precision: the same rate of lime would be applied in all situations.
2. Low information use/precision: generalized recommendations were made for each soil type and rotation in each of three regions, based on typical biophysical conditions for those situations.
3. Moderate information use/precision: biophysical information was collected on a field-by- field basis to refine the recommended rate to best suit that particular situation.

One could envisage a fourth strategy involving high precision, in which the rate would be varied within each field, but that was not examined in the study.

Table 1 shows the gross values of increasing precision from very low to low, and from low to moderate. It reveals a marked reduction in the marginal value of precision in this decision. One would anticipate that the additional value of even greater precision in this decision (as in a "precision farming" approach) would be close to zero. The reason for this diminishing marginal value is the flat payoff function for this problem. (Figure 7 shows an example for one of the scenarios of the analysis.) Once the precision of a decision is high enough to ensure a high probability of targeting a rate within the payoff plateau, further precision has very limited benefit.

Figure 7. A typical payoff function for lime application underlying the result in table 1



Source: O'Connell, Bathgate, and Glenn.

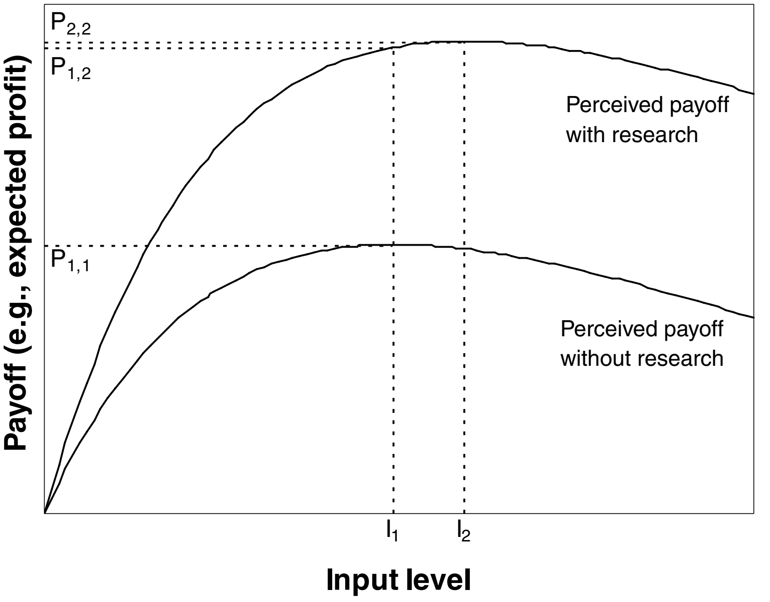
The Value of Research and Extension

Flat payoff curves affect the likely values of research and development (R&D) of different types: R&D to develop new technologies versus R&D to generate information to improve decision making about existing technologies (Pannell). In conducting evaluations of R&D benefits, it is not uncommon for analysts to fail to distinguish between these two categories. However, because of flat payoff functions, the distinction can be crucial for accurate estimation of benefits.

For improved decision making about existing technologies, R&D often only allows refinement of management decisions within a payoff plateau. In this case, the resulting improvement in payoff will be low. In my judgment, it is common for analysts to overstate the benefits of this category of R&D, sometimes substantially so. Sometimes analysts confuse information that a technology is more profitable than was previously believed with an actual improvement in its profitability. They may not recognize that a change in management in response to the new information still involves movement along a flat payoff function.

To illustrate, consider figure 8. It shows the payoff to a hypothetical (but typical) agricultural input. Without research, the perceived payoff to different input levels follows the lower curve. Suppose that research provides information that the true payoff curve is substantially higher. What is the value of this information? Without research, the input level that appears to be optimal is I_1 and the anticipated payoff from this input level is $P_{1,1}$. After the research, I_2 is revealed as the optimal input level and the anticipated payoff from this input level is $P_{2,2}$. However, note that

Figure 8. The value of information from information that a payoff function is higher than expected is $P_{2,2} - P_{1,2}$, not $P_{2,2} - P_{1,1}$



the research does not actually shift the payoff function, it only provides improved information about it. If we assume that the perceived payoff function with research (the higher curve) is true, then application of the original input level I_1 would have resulted in payoff $P_{1,2}$. The improved payoff resulting from the research is the short vertical distance between $P_{1,2}$ and $P_{2,2}$. In other words, the value of the information from this research is very low.

On the other hand, the first category of research (to develop new technologies) would more likely result in an actual rise in the payoff function (e.g., through breeding of higher yielding crop varieties). If the shift in the payoff function illustrated in figure 8 was an actual result from R&D, the value of the R&D to this decision maker would be the full difference $P_{2,2} - P_{1,1}$. The benefits of this type of R&D are not compromised by the presence of any flat payoff function. Other things being equal, there are good reasons to expect that successful R&D intended to improve management decisions about existing technologies will pay off less than successful R&D to develop new, higher performing technologies.

For similar reasons, payoffs from agricultural scientific communication (extension or technology transfer) that provides information useful for management decisions about existing farming technologies will also struggle to overcome the influence of flat payoff functions. Unless the information suggests management practices that are substantially different from those in current use, increases in payoffs are unlikely to be large. This suggests the need for extension to target issues where the technologies are new and unfamiliar to farmers, or where for some reason farmers have developed clear and important misperceptions about the technologies.

Table 2. Cost to farmers in Western Australia in terms of lost potential certainty equivalent (CE) from implementing the herbicide dosage from a model with a risk-neutral objective function

Farmer's Relative Risk Aversion	Cost of Using Risk-Neutral Model (%)
0.0	0.0
0.8	0.038
1.6	0.18
2.4	0.46
3.2	0.95

Source: Pannell, Malcolm, and Kingwell.

Risk

Risk aversion on the part of a decision maker generally only makes a modest difference to optimal decisions relative to a risk-neutral decision maker. As we have seen, when payoff functions include wide flat regions, modest differences to decisions often translate into very small benefits to the decision maker. From the point of view of a decision analyst, this can mean that inclusion of risk aversion in models intended to be used for decision support is of low priority (Pannell, Malcolm, and Kingwell).

To understand this conclusion, it is necessary to appreciate that if a graph of expected profit versus the decision variable includes a flat region near the optimum, then so will a graph of "certainty equivalent" (CE) (i.e., expected profit minus a risk premium), although it will probably be slightly shifted left or right. Now, suppose an advisor ignores the fact that a farmer is risk averse and uses a risk-free model as the basis for advice to the farmer. In many cases, such an oversight will matter little. If the payoff function (in this case, representing CE rather than profit) is flat, small-to-moderate errors in decisions make little difference to the payoff. Table 2 shows how little difference it makes for a decision based on the herbicide dose model cited earlier. The results are for levels of relative risk aversion up to 3.2, which is considered high.

In relation to these results, Pannell, Malcolm, and Kingwell observed that, "The primary reason for the low impact of risk aversion lies in the unresponsiveness of certainty equivalent to changes in farm management within the region of the optimum" (p. 72). They noted that, "Because of this flatness, consideration of complexities such as risk aversion, which only change the optimal strategy by moderate amounts, does not greatly affect farmer welfare. Thus the argument is not that risk aversion does not affect the farmer's optimal plan, but that the impact of the changes on farmer welfare is small" (p. 72).

Conclusion

"Obviously, this is a proposition with which economists, as specialists in optimization, are deeply uncomfortable" (anonymous reviewer of this article).

The implications of flat payoff functions in economic models have not received the attention they deserve. Economists in universities teach their students how to identify optimal solutions to various types of decision problems, and applied economists and operations researchers advise decision makers about optimal management strategies, but in each case they sometimes fail to mention that payoff curves are generally flat near their maxima. Since this flatness is of far greater practical significance than the identification of the optimum, such a failure warrants criticism. Perhaps decision analysts should take greater efforts to address a key question about the information they generate: what difference will it make to payoffs (e.g., Havlicek and Seagraves)?

The insights presented here have implications for the type of advice that analysts addressing economic problems should give to decision makers, and for the way that decision problems should be analyzed. The implications of flat payoff functions include that:

(*a*) decision makers often have a wide margin for error in their production planning decisions, and flexibility to pursue factors not considered in the calculation of payoffs;
(*b*) for many types of problems, optimizing techniques are of limited practical relevance for decision support;
(*c*) the value of information used to refine management decisions is often lower than what might be expected;
(*d*) there is a decreasing marginal value of precision in farming decisions. The use of "precision farming" technologies to adjust production input levels is often of lower value than what might be expected; and
(*e*) representation of risk aversion in models used for decision support is often of low importance.

Overall, these insights are important to decision analysts in prioritizing the approach they take to economic modeling in various contexts, particularly for decision support. There may be unmet opportunities for decision analysis to improve the welfare of decision makers through greater appreciation of these insights.

Endnotes

[1]Radner and Stiglitz referred to flatness in the value of information, but in a different context and with a different meaning. They did not address the issues raised here.

[2]A reviewer noted that flatness of a sort may also arise through the operation of markets. For example, if a monopoly supplier prices an agricultural input so as to extract most rents from users of that input, producers considering use of that input have little to gain by using it, compared to not using it.

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