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Risk aversion and pesticide use: further insights from Prospect Theory

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Abstract

Prospect Theory suggests that farmers' attitudes toward pest risks depend on the situation they refer to when facing crop protection decisions. Farmers referring to the 'protected crop' situation may implement self-insurance pesticide treatments while farmers referring to the 'unprotected crop' situation are risk neutral toward pest risks. Importantly, farmers are more likely to refer to the 'protected crop' situation when pesticides are relatively inexpensive. This in turn leads to original results related to the regulation of agricultural pesticide uses. For instance, pesticide taxes would not only impact pesticide expected profitability but also farmers' attitude toward pest risks.

Keywords: **prospect theory, pesticide use, risk aversion, reference point**

1 Introduction

Pesticides are key production factors in the agricultural production systems used by farmers in industrialized countries. Production practices targeting high yield levels and based on short crop rotation schemes tend to increase pest and weed risks and, as a result, rely on effective crop protection. Chemical pesticides being effective and easy to use crop protection inputs, they are heavily used by farmers (Aubertot et al, 2005). As the adverse effects on human health or on the environment of these inputs are now considered as major concerns, the reduction of agricultural pesticide use has become an important objective in many countries.

This article provides new insights on the mechanisms underlying farmers' pesticide uses under risk, with particular focuses on the effects of risk aversion and of pesticide prices. Although mainly theoretical, our results allow original analyses of the possible effects of pesticide taxes or of policy instruments aimed at reducing agricultural pesticide uses.

Agricultural production economists have primarily investigated two pesticide specific features: the protective role of pesticides in agricultural technology models (see, e.g., Lichtenberg and Zilberman, 1986; Chambers et al, 2010) and the impact of risk aversion on famers' pesticide uses (see, e.g., Feder, 1979; Antle, 1988). The intuition underlying the common wisdom about the effects of pest risk on pesticide uses is simple. Because they reduce production loss risks, pesticides are expected to increase the mean and to decrease the randomness of crop yields. Also, the more farmers are risk averse, the more they are expected to use pesticides. The effects of pesticides on yield risk and the relationship between risk aversion and pesticide uses were empirically investigated – albeit to a very limited extent owing to the variety of contexts in which pesticides are used (Sexton et al, 2007) – with mixed results. Studies confirm the intuitive wisdom (see, e.g., Antle, 1988; Saha et al, 1997; Liu and Huang, 2013; Gong et al, 2016) while other do not (Shankar et al, 2008).

However, the empirical investigation of farmers' pesticide use is particularly difficult, due to methodological reasons as well as due to data limitations.[1] In most empirical and theoretical studies pesticide uses are analysed by considering pesticide expenditures at the crop level, or at the farm

[1] For instance, the use of standard farm data only rises serious specification and identification issues. Production technology and preference features of the pesticide use process need to be simultaneously disentangled (see, e.g., Lence, 2009).

level, and by relying on the standard Expected Utility theory (EUT). To consider pest management at the crop level singularly complicates the analysis of pesticide use decisions. This aggregation level involves farmers' global crop protection strategy, and more generally farmers' global crop management. This requires considering multiple risks and the use of other inputs (see, *e.g.*, Pannell 1991; Horowitz and Lichtenberg, 1994). To rely on EUT gives a crucial role to the shape of the marginal utility function and on how pesticides affect the yield level probability distribution (see, e.g., Ramaswami, 1992). For instance, Feder (1979) and Leathers and Quiggin (1991) show that a tax on pesticides may increase pesticide uses under two widely accepted assumptions: pesticides are production risk-reducing inputs and farmers' exhibit decreasing absolute risk aversion in income. This result is particularly puzzling for economists as it suggests that Pigouvian taxes might not 'work' for reducing pesticide uses under reasonable assumptions.

We address a simpler issue in this study. As in Feder (1979), we focus on single pesticide use decisions, i.e. to spray a pesticide against a given pest or not. Single pesticide use decisions are of primary interest because pest management involves a sequence of such decisions. Pest management must be consistent with the chosen crop production practice and single pesticide use decisions must be consistent with the implemented pest management strategy. But single pesticide use decisions must primarily provide suitable responses to the pest problem targeted by the considered pesticide treatment.

We argue that farmers' single pesticide use decisions can suitably be analysed as isolated risky choices and that these decisions might be affected by psychological biases not accounted for by EUT. In that, we refer to choice patterns that are now extensively documented in economic psychology and behavioural economics: narrow bracketing, loss aversion and reference-dependent risk attitude (see, e.g., Wakker, 2010; Kahneman, 2011). The assumptions and intuitions underlying our theoretical analysis are grounded on elements gathered upon discussions with farmers and crop protection experts – agricultural scientists and extension experts – as well as on results obtained by sociologists and agronomists analysing farmers' pesticide uses from their own disciplinary perspectives (see, e.g., Jorgensen et al, 2008; Lamine, 2011; Bürger et al, 2012).

From a technical viewpoint, we apply the analytical framework recently proposed by Kőszegi and Rabin (2007) to the analysis of farmers' pesticide use. These authors propose models of risky decisions that can be interpreted as extensions of the Prospect Theory and Cumulative Prospect Theory (PT) models proposed by Kahneman and Tversky (1979, 1992). By proposing models describing how individuals determine their reference point in risky choice situations, Kőszegi and Rabin (2007) address a critical issue for applying reference-dependent models such as PT models.[2] As is shown below, the determination process of the reference point plays a crucial role in our analysis of pesticide uses.

Our focusing on single pesticide decisions and applying Kőszegi and Rabin's (2007) results enable us to derive a set of original theoretical results related to the main drivers of farmers' pesticide uses under pest risk. According to these results, farmers can be sorted according to the crop protection level they refer to when evaluating their pesticide use decisions. These reference crop protection levels (*i*) depend on farmers' loss aversion as well as on pesticide expected returns and (*ii*) directly impact farmers' attitude toward pest risks. In particular, availability of relatively inexpensive pesticides induces high reference crop protection levels that in turn induce risk averse attitudes toward pest risks. This induced risk aversion can finally motivate self-insurance pesticide uses. We also provide original insights on observed pesticide retailers' pricing strategies.

Our results involves formulas and conditions easy to interpret and to use. We also feel that these results based on PT have more intuitive interpretations than some results based on EUT. In particular, while EUT analyses of the effects of pesticide prices on pesticide uses are mostly inconclusive, our

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[2] See also Koszegi (2005, 2010) for further insights and, e.g., Heidhues and Kőszegi (2008) or Crawford and Meng (2011) for applications.

analysis unambiguously suggests that pesticide taxes would decrease farmers' pesticide uses.

The outline of the article is as follows. The second section presents the basic choice problem we consider and discusses the application of PT to this problem. The third section describes our analysis of single pesticide use decisions in a risky context and provides simple comparative statics results. Policy relevant issues are considered in the fourth section. The last section presents concluding remarks, including results related to extended versions of the basic choice problem considered here.

2 Pesticide spray decisions, reference situation, and loss and risk aversion

It is now widely accepted that large stake risky decisions tend to be rational while small to modest stake risky decisions tend to be affected by psychological biases that are now extensively documented (see, *e.g.*, Kahneman, 2011). Also, if large stake choices – such as the choice of a global pest management strategy – are suitably analysed by relying on EUT, modest stake choices require a different analytical framework (see, e.g., Kőszegi and Rabin, 2007). Farmers' pest management involves a sequence of single pesticide use decisions: to spray a pesticide against a given pest or not. Each of these risky choice situations involves moderate stakes, at least when compared to the stakes involved in acreage or investment decisions. Moreover, many pesticide use decisions have to be taken relatively rapidly, if not in a hurry.[3] This suggests that farmers' single pesticide use decisions are likely to be subject to the so-called narrow-bracketing effect affecting moderate stake and quick risky decisions. Accordingly, we assume that farmers analyse each of their single pesticide decision in the narrow context defined by what they know about this specific choice situation.

In order to be able to obtain results in closed form solutions and to highlight interesting features of farmers' pesticide uses, we analyse simple choice situations. We consider a single crop yielding the sure return y when free of any pest damage. Farmers are assumed to face a dichotomous pest risk. According to their perception, the considered infestation occurs with probability p_i – with $p_i \in (0,1)$ – and implies an economic loss of δ – with $\delta > 0$. A pesticide spray at a given dosage, allows reducing the pest damage when it occurs at cost w – with $w \in (0,\delta)$. The pesticide treatment is assumed to be perfectly efficient.[4] If farmers decide to spray the considered pesticide ($s = 1$) then their crop return is certain and equal to $\pi_{s=1} = y - w$. If farmers decide to not spray the pesticide ($s = 0$) then their crop return $\tilde{\pi}_{s=0}(p_i)$ is random. It is equal to $y-\delta$ with probability p_i (damaged crop) and equal to y with probability $1 - p_i$ (healthy crop). Of course, risk neutral farmers implement the pesticide treatment if and only if the expected return of the pesticide treatment is positive, i.e. if and only if $w \leq p_i\delta$.

PT has emerged as the leading alternative to EUT for analysing moderate-scale and/or quick risky choice in economics (see, e.g., Barberis, 2013). In agricultural production contexts, Bocquého et al (2009) find that PT does a better job at explaining experimental risky choices of a sample of French farmers. Babcock (2015) shows that PT is more suitable than EUT for describing US farmers' choices of insurance contracts.

As in many applications of the modelling framework of Kahneman and Tversky (1979, 1992), our analysis primarily makes uses of two key features of PT: its dependence on a reference point that distinguishes gain from losses and the loss aversion assumption.[5] Individuals conforming to PT evaluate risky prospects by distinguishing losses – below the reference point – from gains – above

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[3] The efficiency of pesticide treatment is only ensured at specific stages of the pest and crop biological cycles and under specific climatic conditions.

[4] As discussed below, the fixed dosage and perfect technical efficiency assumptions can be relaxed without affecting the main results to be presented in this article.

[5] I.e., we ignore three phenomena accounted for by in PT: probability weighting, risk aversion in the gain domain and risk loving in the loss domain. According to Wakker (2010: 292), '… more than half of the risk aversion empirically observed has nothing to do with utility curvature or probability weighting, but is generated by loss aversion, the main empirical phenomenon regarding preference dependence.'

the reference point – and tend to overweight losses – loss aversion. These features can explain risk averse choices as avoiding a loss generates more value than a corresponding gain.

A crucial question arises when using the PT model for analysing risky decisions: what is the reference point of the decision-maker – i.e. the outcome level distinguishing gains from losses according to the decision-maker viewpoint – in the considered choice risk situation? The reference situation is often defined by the analyst as the one defined by the *status quo* choice, as in EUT. In the choice situation considered here, this would imply that farmers' reference situation is the 'unprotected crop' situation. Indeed, this reference situation appears to be rational.

But the 'unprotected crop' raises two problems as a reference situation. The first one is due to the randomness of the income yielded by the 'unprotected crop' situation. How to accommodate the PT model for accounting for risky reference point? The second problem raised here is that choosing the 'unprotected crop' as the reference situation appears to be debatable. Indeed, agronomists or sociologists analysing farmer's pesticide uses generally observe that most farmers plan their pesticide sprays far in advance and tend to use more pesticides than recommended by crop protection experts because they tend to follow their predetermined pesticide use schedule (see, e.g., Jorgensen et al, 2008; Bürger et al, 2012). It has also been observed that many farmers struggle with deciding to not treat their crop even in relatively low pest risk situations (see, e.g., Lamine, 2011). This suggests that farmers' initial intention is often to protect their crops rather than to not protect them, i.e. that their reference situation is the 'protected crop',. Indeed, farmers' treatment decision against a given pest can be formulated as 'Is this treatment useful?' or as 'Is this treatment useless?' These questions are equivalent from a rational – EUT – viewpoint but they differ as regards to the situation they refer to. From the PT viewpoint this raises the following question: what is the reference situation of farmers facing pest risks, the 'protected crop' situation or the 'unprotected crop' situation?

Kőszegi and Rabin (2007) propose solutions to both problems described above. In the rest this section, we describe how these authors propose to handle random reference situations and then show that the reference situation plays a crucial role in how farmers use pesticides.

According to the model proposed by Kőszegi and Rabin (2007), individuals rely on the following value function:

(1) $\bar{u}(\pi \mid \tilde{\pi}_r) = \pi - aE[\max\{0, \tilde{\pi}_r - \pi\}]$

when evaluating risky prospects at the outcome level π with $\tilde{\pi}_r$ as their random reference outcome. The term a denotes farmers' loss aversion. Farmers are strictly loss averse if $a > 0$. They are loss neutral as well as risk neutral if $a = 0$. In empirical and experimental settings the loss parameter a is generally found to be close to 1, indicating that individuals are usually loss averse. The term $aE[\max\{0, \tilde{\pi}_r - \pi\}]$ accounts for the effects of loss aversion in the valuation function $\bar{u}(\pi \mid \tilde{\pi}_r)$. As shown below, this term induces risk averse attitudes toward risky prospects when these prospects involve gains and losses.

In the case where the reference income level is fixed, with $\tilde{\pi}_r = \pi_r$, the valuation of the outcome π is given by the usual PT utility function $u(\pi \mid \pi_r) = \bar{u}(\pi \mid \pi_r)$. The term $u(\pi \mid \pi_r)$ simply distinguishes gains with $u(\pi \mid \pi_r) = \pi$ if $\pi \geq \pi_r$ from losses with $u(\pi \mid \pi_r) = \pi - a(\pi_r - \pi)$ when $\pi < \pi_r$. The term $a(\pi_r - \pi)$ can be interpreted as the 'psychological cost' of losing $\pi_r - \pi > 0$ when $\pi < \pi_r$. From a technical viewpoint, the usual PT utility function $u(\pi \mid \pi_r)$ is concave in π since it is kinked at π_r with a slope equal to 1 above π_r and equal to $1 + a \geq 0$ below π_r. This kink generates first order risk aversion in $\bar{u}(\pi \mid \pi_r)$ and can thus induce strongly risk averse choices (Segal and Spivak, 1990).

The randomness of $\tilde{\pi}_r$ is simply accounted for in Kőszegi and Rabin's (2007) valuation function $\bar{u}(\pi \mid \tilde{\pi}_r)$. The term $\bar{u}(\pi \mid \tilde{\pi}_r)$ is the expectation, with $\bar{u}(\pi \mid \tilde{\pi}_r) = E[u(\pi \mid \tilde{\pi}_r)]$, of the standard PT utility function $u(\pi \mid \tilde{\pi}_r)$ over the probability distribution of the reference outcome $\tilde{\pi}_r$. Of course, individuals evaluate a risky prospect $\tilde{\pi}$ according to its expected utility value $E[\bar{u}(\tilde{\pi} \mid \tilde{\pi}_r)]$.

Importantly, the loci of the kinks in the PT valuation function $\bar{u}(\pi \mid \tilde{\pi}_r)$ determine the shape of this function and, as a result, the risk aversion it implies at given levels of loss aversion. As these loci depend on the reference revenue $\tilde{\pi}_r$, different reference revenue imply different attitude toward pest risks that may in turn imply different pesticide use decisions.

The upper panel of Table 1 reports the expected value of the 'protected crop' crop return $\pi_{s=1}$ and of the unprotected crop return $\tilde{\pi}_{s=0}$ when $\pi_{s=1}$ – 'protected crop' situation – or $\tilde{\pi}_{s=0}$ – 'unprotected crop situation' – are the reference crop returns. We successively analyse the treatment decision in these two cases for highlighting the impact of the reference situation on how farmers decide their pesticide uses.

The 'protected crop' is the reference situation. When their reference situation is the 'protected crop', farmers do not incur any psychological cost if they decide to protect their crop. Their crop return, $y - w$, is certain and equals their expected utility $E[\bar{u}(\pi_{s=1} \mid \pi_{s=1})]$. But, if they decide to not protect their crop, their crop return is random, with mean $y - p_i\delta$, and they incur a loss risk. When compared to the reference protected crop return, they lose $\delta - w > 0$ if the infestation actually occurs. This loss risk generates the psychological cost $ap_i(\delta - w)$ in the expected utility level $E[\bar{u}(\tilde{\pi}_{s=0} \mid \pi_{s=1})]$.

Comparing $E[\bar{u}(\pi_{s=1} \mid \pi_{s=1})]$ and $E[\bar{u}(\tilde{\pi}_{s=0} \mid \pi_{s=1})]$ simply yields that farmers with the 'protected crop' reference situation decide to protect their crop if and only if:

$$(2) \qquad w \leq \gamma(p_i, \delta; a) = \frac{1+a}{1+ap_i} p_i\delta .$$

It is easily shown that $\gamma(p_i, \delta; a) > p_i\delta$ if $a > 0$. Consequently, loss averse farmers referring to the 'protected crop' situation are more likely to protect their crops than loss neutral ones. *I.e.*, such farmers behave as risk averse farmers when facing pest risks. If $w \leq p_i\delta$ then the pesticide treatment has a non-negative positive expected return and it is expected to be implemented by any farmer. If $p_i\delta \leq w \leq \gamma(p_i, \delta; a)$ the treatment is justified for loss averse farmers by self-insurance motives (Ehrlich and Becker, 1972). It has a negative expected return but it eliminates the loss risk due to pests, a property valued by such farmers. Finally, it is also easily demonstrated that the term $\gamma(p_i, \delta; a)$ is increasing in p_i and *a*, with $\gamma(p_i, \delta; 0) \in [p_i\delta, \delta)$.[6] This implies that farmers referring to the 'protected crop' situation treat their crop if they are sufficiently loss averse, if the treatment is sufficiently inexpensive and/or if the infestation is sufficiently likely.

The 'unprotected crop' is the reference situation. Farmers incur psychological costs whatever they decide when their reference situation is the 'unprotected crop'. They take the risk of losing δ if they do not protect their crop. This generates the psychological cost $a(1 - p_i)p_i\delta$ in $E[\bar{u}(\tilde{\pi}_{s=0} \mid \tilde{\pi}_{s=0})]$. They take the risk of losing the treatment cost if they protect a healthy crop. This induces the psychological cost $a(1 - p_i)w$ in $E[\bar{u}(\pi_{s=1} \mid \tilde{\pi}_{s=0})]$.

Comparing $E[\bar{u}(\pi_{s=1} \mid \tilde{\pi}_{s=0})]$ and $E[\bar{u}(\tilde{\pi}_{s=0} \mid \tilde{\pi}_{s=0})]$ yields that farmers with the 'unprotected crop' as the reference situation decide to protect their crop if and only if the chemical treatment has a non-negative expected return, i.e. if and only if $w \leq p_i\delta$. This shows that loss averse farmers behave as risk neutral farmers if they adopt the 'unprotected crop' as their reference situation, whatever their loss aversion level.

Indeed, the risk entailed in random reference situations is accepted, even if only partly, by individuals adopting such reference situations. Risky choices appear to be more acceptable to individuals having adopted the risky prospect implied by this choice as their reference prospect, even when these choices entail significant loss risks.

Taken together these results tend to show that loss aversion – the intrinsic risk preference characteristics considered here – is not sufficient for farmers to exhibit risk aversion toward pest risks. Farmers must be loss averse and must adopt the 'protected crop' as their reference situation for exhibiting risk aversion toward pest risks.

The results presented above also hold when farmers define their reference situation with an estimated

[6] The term $\gamma(p_i, \delta; a)$ can be interpreted as the pesticide expected return 'corrected for loss aversion'.

infestation probability equal to p_i but face an infestation probability equal to $p_{i|\hat{e}}$. In this case, the (random) unprotected profit level is denoted by $\pi_{s=0|\hat{e}}$: it is equal to y with probability $1-p_{i|\hat{e}}$ and to $y-\delta$ with probability $p_{i|\hat{e}}$. Such choice situations occur when farmers receive information on the pest risk they have to cope with shortly before having to decide whether to spray the relevant pesticide or not. According to Kőszegi and Rabin (2007), in such cases farmers are likely to update their infestation probability estimates without updating their reference situation. The results collected in the lower panel of Table 1 allow for demonstrating that farmers referring to the 'protected crop" situation (at p_i) treat their crop if and only if $w \leq \gamma(p_{i|\hat{e}}, \delta; a)$ while those referring to the 'protected crop" situation (at p_i) protect their crop if and only if $w \leq p_{i|\hat{e}}\delta$.

According to these results, the reference situation adopted by farmers has an anchorage effect on their actual decisions. Farmers' decisions tend to conform to the decision characterizing their reference situation. In particular, farmers referring to the 'protected crop' situation are reluctant to skip pesticide treatments when the pest risk they actually face is lower than anticipated in the first place. Contrary to farmers referring to the 'unprotected crop' situation, farmers referring to the 'protected crop' situation fully accept the risk of losing useless pesticide costs. Indeed, farmers referring to the 'protected crop' situation consider crop protection costs as standard production costs whereas farmers referring to the 'unprotected crop' situation consider pesticide treatments as risky investments. These later farmers consider useless pesticide expenditures as losses, not as standard production costs.

Of course, given the impact on farmers' decisions of the reference situation, to be able to determine farmers' reference situations is necessary for analysing farmers' pesticide uses. The analytical framework of Kőszegi and Rabin (2007) also provides tools for determining farmers' reference situation.

Importantly, provided that the reference revenue $\tilde{\pi}_r$ determines the shape of the valuation function $\bar{u}(\pi \mid \tilde{\pi}_r)$ at given levels of loss aversion, to consider that the reference revenue are chosen by farmers imply that their attitude toward pest risks is partly endogenous.

3 Farmers' attitude toward pest risk: determination process and drivers

According to Kőszegi and Rabin (2007) individuals tend to choose the reference situation so that (*a*) the probability distribution of their optimal income equals that of their reference income and (*b*) their expected utility level is maximised by their reference situation choice.

Condition (*a*) states that individuals choose their reference situation as a *personal equilibrium*.[7] Let consider an individual *i* facing a choice situation *c* where lotteries $\tilde{\pi}$ have to be chosen in the set $\mathcal{L}$. A lottery $\tilde{\pi}^e$ is a personal equilibrium if and only if $\tilde{\pi}^e \in \arg\max_{\tilde{\pi}\in\mathcal{L}} E[u(\tilde{\pi} \mid \tilde{\pi}^e)]$.

Condition (*b*) states that if individuals have several personal equilibria for a given choice situation, then they are expected to choose their reference situation among their *preferred personal equilibria*, i.e. among the personal equilibria maximizing their expected utility level. Let $\mathcal{E}$ define the personal equilibrium set of individual *i* in choice situation *c*. Lottery $\tilde{\pi}^p$ is a preferred personal equilibrium if and only if $\tilde{\pi}^p \in \arg\max_{\tilde{\pi}^e\in\mathcal{E}} E[u(\tilde{\pi}^e \mid \tilde{\pi}^e)]$.

The personal equilibrium notions capture simple intuitions. Individuals facing a risky choice know how their reference situation affects their decisions and choose this reference situation such as to maximize their expected outcome while seeking to minimize the psychological costs induced by loss risk expectations. Reference situations determined as personal equilibria are appealing because the lesser the actual decisions deviate from the ones characterizing the reference situation, the more individuals avoid sensations of loss.

In the pesticide use context considered here, the results presented in the preceding section directly

[7] The term 'personal equilibrium' is used here as a shorthand for the term 'unacclimating personal equilibrium' used by Kőszegi and Rabin (2007).

yield that to protect the crop leads to a personal equilibrium if and only if $w \le \gamma(p_i, \delta; a)$, and that to not protect the crop leads to a personal equilibrium if and only if $w \ge p_i\delta$. Provided that $\gamma(p_i, \delta; a) \ge p_i\delta$ for loss averse farmers, the 'protected crop' situation is the unique personal equilibrium if $w \le p_i\delta$ whereas the 'unprotected crop' situation the unique personal equilibrium if $w \ge \gamma(p_i, \delta; a)$.

When $\gamma(p_i, \delta; a) \ge w \ge p_i\delta$ both the 'protected crop' and 'unprotected crop' situations are personal equilibria. But the 'protected crop' situation is the unique farmers' preferred personal equilibrium in this case: it is easily shown that the condition $w \le \gamma(p_i, \delta; a)$ implies the inequality $E[\bar{u}(\pi_{s=1} \mid \pi_{s=1})] \ge E[\bar{u}(\tilde{\pi}_{s=0} \mid \tilde{\pi}_{s=0})]$. Kőszegi and Rabin (2007) interpret this tendency to choose the sure reference situation as a reluctance for random reference situations. Sure reference situations are more comfortable than random ones from a psychological viewpoint. For instance, farmers with the 'unprotected crop' as their reference situation incur psychological costs whatever their spray decision is while farmers referring to the 'protected crop' don't incur any psychological cost when they decide to protect their crop.

This finally implies that farmers are expected adopt the 'protected crop' as their reference situation if and only $w \le \gamma(p_i, \delta; a)$. I.e., farmers are likely to adopt the 'protected crop' as their reference situation when pesticides are relatively inexpensive, when they believe that infestations are likely and/or when there are loss averse.[8] Table 2 summarizes our results on the determination of the reference situation.

Importantly, the inequality $p_i\delta \le \gamma(p_i, \delta; a)$ shows that farmers can adopt the 'protected crop' as their reference situation even if the expected return of the pesticide treatment is negative. This expected return just needs to be large enough for the self-insurance motivation to justify the treatment. More generally, the results presented above also tend to show that the availability of relatively inexpensive pesticides induces risk averse attitudes toward pest risks: inexpensive pesticides favour the adoption of the 'protected crop' as the reference situation and loss averse farmers referring to the 'protected crop' situation can implement pesticide sprays for self-insurance motives.

Of course, our results are mainly theoretical. The extent to which farmers actually refer to the 'protected crop' situation or to the 'protected crop' situation is an empirical issue. Nevertheless, and as argued above, observed facts and crop protection expert opinions often suggest that farmers generally refer to the 'protected crop' situation. For instance, interviews reported by Lamine (2011) suggest that farmers using Integrated Crop Management (ICM) practices tend to refer to the 'unprotected crop' situation whereas farmers using conventional crop production practices tend to refer to the 'protected crop situation'. These results are consistent with ours. ICM practices are designed so as to lower pest risks. This implies that the expected returns of preventive pesticide uses are lower with ICM practices than with conventional ones. According to our results, ICM farmers are likely to refer to the 'unprotected crop' situation while conventional farmers are likely to refer to the 'protected crop' situation.[9] Yet, ICM farmers might also be less loss averse than conventional ones.

4 Pesticide taxes, public information and retailers' marketing strategy

For highlighting important consequences of the results described above let now assume that p_i is the 'true' probability of the crop infestation in the considered choice situation for the considered farmer population. Under this condition, farmers can be sorted into two groups according to their reference crop protection level depending on their loss aversion level. Sufficiently loss averse farmers, i.e.

[8] Of course, farmers can adopt different references depending on the risks they face.

[9] Interestingly, during an informal discussion in 2014 with the authors, an ICM farmer interviewed by Lamine in the course of her sociological study declared: 'It's often hard for me to stick on a decision to not treat a crop. Even if I know that the pest risk is low, who knows what's going to happen? And seeing my conventional neighbors spraying pesticides in their fields makes it even harder. Indeed, it's cool to be a conventional farmer. You don't even wonder whether the treatment is useful or not. You spray. And then enjoy a good sleep!'

farmers for whom the condition $a \geq \alpha(p_i, w\delta^{-1})$ holds where

$$(3) \qquad \alpha(p_i, w\delta^{-1}) = -p_i \frac{p_i - w\delta^{-1}}{1 - w\delta^{-1}},$$

are expected to choose the 'protected crop' as their reference situation while the others are expected to refer to the 'unprotected crop' situation. Since $\alpha(p_i, w\delta^{-1})$ is negative if $w \leq p_i\delta$, all farmers are expected to choose the 'protected crop' as their reference situation if the pesticide treatment has positive expected return. More generally, the term $\alpha(p_i, w\delta^{-1})$ being decreasing in the treatment cost *w*, an increase in the pesticide price is expected to decrease the share of the farmer population choosing the 'protected crop' as their reference situation.

Let now assume that farmers receive information leading them to believe that the infestation probability equals $p_{i|\hat{e}}$ instead of p_i. Provided that farmers decide to implement the pesticide treatment if $w \leq p_{i|\hat{e}}\delta$ when their reference situation is the 'unprotected crop' and if $w \leq \gamma(p_{i|\hat{e}}, \delta; a)$ when their reference situation is the 'protected crop', pesticide taxes would unambiguously decrease agricultural pesticide uses through two effects. First, holding the reference situations constant, such taxes would decrease the expected profitability of the pesticides sprays for all farmers, according to a standard price effect. I.e., *w* could shift from below to above $\gamma(p_{i|\hat{e}}, \delta; a)$ for farmers' referring to the 'protected crop', and from below to above $p_{i|\hat{e}}\delta$ for farmers' referring to the 'unprotected crop' situation. Second, because they would shift *w* from below $\gamma(p_i, \delta; a)$ to above this threshold when *a* lies in the neighbourhood of $\alpha(p_i, w\delta^{-1})$, pesticide taxes would encourage farmers to switch from the 'protected crop' reference to the 'unprotected crop' one.

Pesticide taxes would reduce farmers' welfare level. Yet, farmers' decreases in expected profits can be compensated, at least partly, by direct payments designed so as to preserve the incentive effects of the taxation scheme.[10] However, farmers shifting their reference situation from the 'protected crop' situation to the 'unprotected crop' one would suffer additional costs. The 'unprotected crop' situation is a random reference situation generating higher psychological costs than those induced by the sure 'protected crop' situation.

Of course, these results suggest that pesticide taxes should be the keystone of any agri-environmental policies aimed at reducing agricultural pesticide uses. In particular, pesticide taxes could be complementary to other policy instruments. For instance, such taxes would spur the adoption of pesticide saving production practices through two effects. Pesticide saving practices are designed so as to lower pest risks for decreasing crop protection requirements. As a result, pesticide taxes would decrease the expected returns of the conventional production practices more than those of the pesticide saving practices. Also, when pesticides are relatively inexpensive conventional farmers are likely to refer to the 'protected crop' situation whereas farmers using pesticide saving practices necessarily refer to the 'unprotected crop' one. This gap in the reference situations tends to deter the adoption of pesticide saving practices: the 'protected crop' situation is a more comfortable reference situation than the 'unprotected crop' one. Pesticide taxes would reduce this gap by leading conventional farmers, at least the less loss averse ones, to adopt the 'unprotected crop' situation as their reference situation.

Interestingly, the results presented above allows for analysing a specific pricing strategy of the pesticide retailers observed in France, the so-called rebates on off-season pesticide purchases (*achats de morte saison*). French farmers can buy pesticides at prices reduced by up to 8% if they engage their purchases at the beginning of the cropping season, i.e. before reliable information on pest risks are available. Of course, the opportunity to buy pesticides at lower prices is likely to induce increases in pesticide uses through a standard price reduction effect. This price effect would be the only one at

[10] Such a compensation scheme could be designed as per crop and per region lump sum payments, for accounting for differences in pesticide uses across crops and pedo-climatic conditions. If the total tax revenue were to be redistributed for compensation purpose, farmers would be rewarded or penalized depending on their pesticide expenditures relative to the regional crop average expenditures.

work if farmers (*a*) could easily stock pesticides without fearing efficiency losses and (*b*) couldn't return pesticides at the end of the cropping season. Yet, French pesticide retailers, at least some of them, allow farmers to return any left over at the end of the season at no cost.

Our analysis of farmers' pesticide uses provide further insights as regards to the advantages of the off-season rebate strategy for pesticide retailers. Pesticide early purchases at reduced price levels tend to favour the adoption of the 'protected crop' as the reference situation by farmers at the beginning of the cropping season. This in turn induces risk averse attitudes toward pest risks leading farmers to be less likely to skip planned pesticide treatments when receiving news indicating medium to low pest risks during the cropping season. Indeed, by inducing farmers to referring to the 'protected crop' as their expected situation, the off-season rebate strategy not only lead farmers to use more pesticides due a standard price reduction effect, it also sets up the conditions limiting farmers' return requests.

Farmers' pesticide uses respond differently to good news – low pest risk, with $p_{i|\hat{e}} < p_i$ – or to bad news – high pest risk, with $p_{i|\hat{e}} > p_i$ – depending on their loss aversion level. The likelihood of the adoption of the 'protected crop' reference situation increases in the loss aversion level. Farmers referring to the 'unprotected crop' situation would only treat their crop after receiving bad news about pest risks. Those referring to the 'protected crop' situation at the beginning of the cropping season would skip treatments after receiving good news only. As $\gamma(p_{i|\hat{e}}, \delta; a)$ increases in the loss aversion level *a*, highly loss averse farmers tend to be less responsive to good news. I.e., only news leading to very low pest risk would convince them to skip the treatments they intend to implement.

Public information on pest risks are provided to farmers in some countries. For instance, the US department of agriculture delivers free forecasts of the soybean rust outbreaks (see, e.g., Roberts et al, 2006). The French department of agriculture delivers free 'Crop health notices' (*Bulletin de Santé du Végétal*) informing farmers about major crop pest risks on a weekly basis and at a regional scale. Such information are usually not precise enough for suitably informing farmers' pesticide treatment decisions.[11] However, by gradually delivering information on pest risks such notices can change farmers' attitude toward pest risks during the cropping season, especially the attitude of moderately loss averse farmers. Good news may induce such farmers to refer to the 'unprotected crop' situation in place of the 'protected crop' situation they referred to at the beginning of the cropping season. To switch to the 'unprotected crop' reference situation is a first step toward skipping pesticide treatments in low – but not necessarily insignificant – pest risk situations.

5 Concluding remarks

Our use of the PT analytical framework with endogenously determined reference situation enables us to provide original insights on farmers' pesticide uses. Our most striking results stem from the determination process of farmers' reference situation with respect to pest risks. Farmers' attitudes toward pest risks are not determined by exogenous risk preferences only, as in EUT. In the analytical framework proposed by Kőszegi and Rabin (2007), farmers' attitudes toward pest risks depend on farmers' exogenous loss aversion as well as on technical and economic factors. In particular, relatively low pesticide prices tend to induce farmers' aversion toward pest risks because they foster farmers' adoption of the 'protected crop' as their reference situation.

Interestingly, the 'protected crop' *versus* 'unprotected crop' dichotomy appear to be intuitively appealing for crop protection experts. In particular, extension agents seeking to encourage pesticide use reductions often describe their main problem as convincing farmers who are used to high crop protection levels to skip pesticide treatments in low pest risk situations (Lamine, 2011). Even if they are aware and willingly to account for these farmers' loss aversion, these extension agents often fail to find arguments for farmers' skipping treatments. A possible explanation is as follows. Only farmers referring to the 'protected crop' situation want to protect their crop for self-insurance motives. Such self-insurance treatments appear useless for extension agents (rationally) referring to the 'unprotected

[11] For instance, the 'Crop health notices' systematically encourage farmers to scout pests in their crops before their treatment decisions.

crop' situation whereas skipping these treatments entail too much risk taking for farmers referring to the 'protected crop' situation.

Our analysis tends to reinforce the role of the economic factors as key factors for explaining the current levels of pesticide uses. Farmers implement chemical pesticide treatments (*a*) when these treatments have positive expected returns or (*b*) for self-insurance motives when the corresponding expected returns are not too negative and farmers are sufficiently loss averse. Indeed, to assume that farmers refer to the 'protected crop' situation for deciding pesticide uses is equivalent to assume that pesticides are sufficiently inexpensive for leading farmers to take high crop protection levels for granted. Also, to sufficiently increase pesticide prices would reduce farmers' endogenous aversion toward pest risks.

Of course, our analytical framework relies on admittedly restrictive assumptions. However, most of the considered 'technical' assumptions can be relaxed without affecting our main results. To assume that pesticide treatments eliminate only part of the damage would only slightly modify the conditions and formulas presented above. Similarly, the main results presented in this article also continue to hold when farmers can choose the pesticide dosage, as in Feder (1979) or Lichtenberg and Zilberman (1986). Farmers' reference and chosen crop protection levels increase in the loss aversion level and in the pest risk level, and decrease in the pesticide price. Nevertheless, non-dichotomous pest risks are technically more challenging and deserves further research efforts.

The dichotomous pest risk and dichotomous decision framework is convenient for obtaining results described by simple conditions and formulas. This is especially useful for further investigating farmers' pesticide uses. First, results presented in this article can provide a useful background for addressing difficult issues. For instance, in a companion paper we obtain original results related to farmers' willingness to pay for pest risk information and to the effect of the use of such information on pesticide uses. In particular, it can be shown that farmers' willingness to pay for pest information increases (decreases) in pesticide prices when farmers refer to the '(un)protected crop' situation. Second, such a simple choice situation provides a tractable framework for conducting empirical investigations of the mechanisms underlying farmers' pesticide uses, e.g. for empirically testing the theoretical results presented in this article.

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7 Tables

Table 1. Expected utility levels of the crop returns with and without protection, and with the 'protected crop' or the 'unprotected crop' situations as the reference situation

	Reference situation	
	Protected crop	***Unprotected crop***
	Reference crop return: $\pi_{s=1}$	Reference crop return: $\tilde{\pi}_{s=0}$
	Expected utility level, estimated infestation probability p_i	
To spray	$E[\bar{u}(\pi_{s=1} \mid \pi_{s=1})]$ $= y - w$	$E[\bar{u}(\pi_{s=1} \mid \tilde{\pi}_{s=0})]$ $= y - w - a(1-p_i)w$
To not spray	$E[\bar{u}(\tilde{\pi}_{s=0} \mid \pi_{s=1})]$ $= y - p_i\delta - ap_i(\delta - w)$	$E[\bar{u}(\tilde{\pi}_{s=0} \mid \tilde{\pi}_{s=0})]$ $= y - p_i\delta - a(1-p_i)p_i\delta$
	Expected utility level, estimated infestation probability $p_{i\mid\hat{e}}$	
To spray	$E[\bar{u}(\pi_{s=1\mid\hat{e}} \mid \pi_{s=1})]$ $= y - w$	$E[\bar{u}(\pi_{s=1} \mid \tilde{\pi}_{s=0})]$ $= y - w - a(1-p_i)w$
To not spray	$E[\bar{u}(\tilde{\pi}_{s=0\mid\hat{e}} \mid \pi_{s=1})]$ $= y - p_{i\mid\hat{e}}\delta - ap_{i\mid\hat{e}}(\delta - w)$	$E[\bar{u}(\pi_{s=0\mid\hat{e}} \mid \tilde{\pi}_{s=0})]$ $= y - p_{i\mid\hat{e}}\delta - a(1-p_i)p_{i\mid\hat{e}}\delta$

Table 2. Personal equilibria and reference situations

	Conditions on the choice situation parameters: a, w, δ **and** p_i		
	$w \le p_i\delta$	$p_i\delta \le w \le \gamma(p_i, \delta; a)$	$\gamma(p_i, \delta; a) \le w$
Personal equilibria	'Protected crop'	'Unprotected crop' 'Protected crop'	'Unprotected crop'
Preferred personal equilibrium	'Protected crop'		'Unprotected crop'