Trading Risk: Consumption versus Health under Pesticide Application

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June 17, 2019

Abstract

This paper looks at the trade-off between reducing the production risk and increasing the risk in health outcomes as a consequence of pesticide application. The paper differentiates between developing and developed countries by restricting or allowing off-farm opportunities.

This is a preliminary draft, please treat it as such. Prepared for the Economics Seminar at School of Economics and Finance, Massey University. Thank you.

1 Motivation

Classical risk management instruments offer a tradeoff between variation and mean consumption. Risk averse consumers are willing to accept lower risk at the expense of a reduction in their mean consumption. However, examples abound when rather than trading variation for mean consumption, agents trade risk between consumption and health. Prevalent examples from agriculture include pesticide application and the introduction of genetically engineered crops.

In developing countries, alternatives to agriculture, such as mining, reduce the variation in consumption at the expense of negative health outcomes. Mining wages stabilize the household consumption, compensating for the agricultural risk, but increase the health risk. Developed countries are not spared. In the US, the Salinas Valley seems to provide a paradox: workers who harvest the produce cannot afford to buy and consume it. Effectively, these agricultural workers, mainly immigrants, trade future health outcomes for stable wages.

A well-known example in agriculture is the application of pesticides. Applying pesticides decreases the variation in crops yield at the expense of potential negative effects on health due to higher concentration of chemicals. Pesticide application acts as a crop insurance because it affects only the "pest" states of Nature where it mitigates the yield losses. If one of the "pest" states is selected by Nature, the farmer benefits from pesticide protection. However, independent of the pest infestation, once pesticides are applied, the farmer also "buys" into a health lottery, where in some states of Nature the health outcomes decrease. Hence a tradeoff is apparent, where risk in crop production is substituted for risk in health outcomes.

This paper explores the tradeoff between consumption risk and health risk in the case of pesticide application. To this end, we propose a two-period state contingent model where a rational agent, the farmer, maximizes utility over consumption and health. The first period is nonstochastic, while the second period is governed by uncertainty. Uncertainty is modeled by a finite state space, where each element, referred to as a state of Nature, is an exhaustive and mutually exclusive description of the world. Uncertainty is resolved by an unbiased entity, Nature. However, the state choice is revealed only after the farmer makes all relevant consumption and production decisions.

In the first period, the farmer chooses the optimal level of current consumption, second period consumption and health outcomes by making the appropriate agricultural and health production decisions. The farmer uses a stochastic technology and the agricultural output and health outcomes are not separable in production. For example, labor will affect both how much agricultural output is produced and how much health is generated. Similarly, pesticide application will mitigate the fall in yield in the "pest" states, but it will decrease the health outcomes in some states of Nature.

Independent of risk preferences, the gains in agricultural revenue from a positive application of pesticide must cover both the cost of applying the pesticide and must compensate for the potential loss in health. However, the extent of pesticide applications depends on the ratio between the consumption and health stochastic discounts factors derived from the farmers' risk preferences.

2 The Model

A rational agent, identified as a farmer, optimizes consumption, health and production behavior over two periods. The first period, 0, is nonstochastic, while the second period, 1, is governed by uncertainty. Uncertainty is modeled by a finite state space, a set Ω, where each element of Ω, referred to as a state of Nature, is an exhaustive and mutually exclusive description of the world [1]. For example, in a two states rep-

[1]The theoretical framework used here is known as state-contingent approach to uncertainty. A classical treatment is due to Debreu (1959). An accessible treatment to the state-contingent approach is Chambers and Quiggin (2000).

resentation of the world, a state could be "pest" and another could be "no pest". Uncertainty is resolved by an unbiased entity, Nature, choosing from Ω. However, the state choice is revealed after the farmer makes all the relevant consumption and production decisions.

The first period consumption is denoted by $q_0 \in \mathbb{R}_{++}$, while the second period consumption-health bundle is denoted by (q, h), where $q \in \mathbb{R}^{\Lambda}_{++}$ represents consumption resulting from productive activities (e.g. agricultural production) and $h \in \mathbb{R}^{\Theta}_{++}$ represents stochastic health outcomes. With this notation, $\Omega \equiv \Lambda \times \Theta$ and the *ex post* realization of the second period consumption in state s is (q_i, h_j), for $i \in \Lambda$, $j \in \Theta$ and with a slight abuse of notation s is a one to one function from Ω to the natural numbers. Preferences over first and second period consumption, $q_0 \in \mathbb{R}_{++}$, $q \in \mathbb{R}^{\Lambda}_{++}$, $h \in \mathbb{R}^{\Theta}_{++}$, are represented by a concave and strictly increasing utility function $W(q_0, q_1, h)$.

In the first period, the farmer starts with the initial wealth and health endowments $\omega_0 > 0$ and $h_0 > 0$. The farmer is competitive and takes the input prices, $w \in \mathbb{R}^{N}_{++}$, and state-contingent outputs prices, $p \in \mathbb{R}^{\Lambda}_{++}$, as given. In period 0, the farmer selects the optimal levels of state contingent period 1 output $z \in \mathbb{R}^{\Lambda}_{+}$, where the *ex post* realization of output is z_i for $i \in \Lambda$, and pesticide $\delta \in \mathbb{R}_{+}$. Also, in this period, the farmer decides the level of first and second period consumption and health, q_0, q_1 and h, by making the appropriate agricultural and health production decisions. Production is characterized by a stochastic technology. More formally, the technology is represented by an input correspondence $X : \mathbb{R}^{\Omega}_{+} \to R^{N}_{+}$ which maps state-contingent outputs and health outcomes into inputs sets capable of producing them. Specifically, the technology is defined as

$$X(z, h) = \left\{ x \in R^{N}_{+} | x \text{ can produce } (z, h) \in \mathbb{R}^{\Omega}_{+} \right\}$$

An implicit assumption is that z and h are not separable in production. For example, labor will affect both how much z is produced and how much h is generated. Similarly, pesticide application will mitigate the fall in yield in the "pest" states, but will decrease the health outcomes in same states of Nature.

On this note, with probability π_1, the Nature selects the state where the pest affects the agricultural yields. [2] *Ex ante* the farmer can choose to apply pesticide $\delta \in \mathbb{R}_+$ in order to protect against the yield loss in these states of Nature. Applying pesticide has two effects. First, δ increases the yield in the pest state by $f(\delta, z_1)$ for a state contingent output equal to $z_1 f(\delta, z_1)$, where z_1 is the state contingent agricultural output when $\delta = 0$ and $f(\delta, z_1)$ is a production function of δ and z_1. The pesticide application has no effect on the output in the no pest state(s). Second, the pesticide δ will reduce the health with probability $\tilde{\pi}_1$ resulting in a state contingent health output of $h_1 g(\delta)$, where h_1 is the state contingent realization of the health outcome for $\delta = 0$ and $g(\delta)$ is a damage function of δ. The pesticides application does not affect the health outcome with probability $1 - \tilde{\pi}_1$. In this case, the state contingent health outcome is h_2. No correlation is assumed between the agricultural and health outcomes. For example, for a positive application of pesticides $\delta > 0$, the probability to obtain the agricultural - health outcomes $(z_1 f(\delta, z_1), h_2)$ is $\pi_1(1 - \tilde{\pi}_1)$ and the probability to obtain the agricultural - health outcomes $(z_1 f(\delta, z_1), h_1 g(\delta))$ is $\pi_1 \tilde{\pi}_1$.

The application of pesticide, $\delta > 0$, suggests the presence of technological constraints which prevent the farmer from achieving certain state-contingent output combination in their absence, $\delta = 0$. To this extent, for each feasible output combination (z_1, z_2), we assume that $z_1 \leq z_2/k$, where $k > 1$ is a constant denoting the extent of the technological constraint. The maximum amount of agricultural output that can be produced in the "pest" state equals the amount of agricultural output produced in the "no pest" state scaled down by the technological constraint k. In

[2] To simply the presentation, I assume that q and h are two dimensional vectors (i.e. $|\Lambda| = 2$ and $|\Theta| = 2$, hence $|\Omega| = 4$). Later drafts would revert to the general case $|\Lambda| > 2$ and $|\Theta| > 2$.

other words, for $k > 1$, the farmer can not produce on the bisector (the locus of points where $z_1 = z_2$). Hence, the technological constraint prevents the farmer from eliminating production risk in the absence of pesticide. The closest the farmer can be to the bisector is by producing on the ray from the origin with slope k. A second constraint imposed on the technology is $z_1 f(\delta, z_1) \leq z_2$, which, given the first constraint, is equivalent to $f(\delta, z_1) \leq k$. The pesticide application allows the farmer to reach the bisector and eliminate the production risk.

In general, unless facing trivially stochastic output prices, farmers are concerns with choosing the optimal level of state-contingent revenue, $r = pz \in \mathbb{R}_+^\Lambda$, rather than state-contingent outcomes $z \in \mathbb{R}_+^\Lambda$, where the *ex-post* realization of the revenues is $r_i = p_i z_i \in \mathbb{R}_+^\Lambda$ for $i \in \Lambda$. The period 0 revenue -health cost of producing r and h is $c(w, r, h, p)$, where

$$c(w, r, h, p) = \min_x \{wx : x \in X(z, h), pz \geq r\}$$

The revenue-health cost function is assumed convex in both z and h.Chambers and Quiggin (2000, 2001) provided a detail discussion of the properties of the revenue-cost function.

In addition to the stochastic technology, farmers can access off-farm production opportunities. This would characterized farmers in developed countries. To simplify the discussion, assume that these opportunities take the form of incomplete financial markets. Specifically, the farmer can purchase and sell assets in financial markets. These markets allow rational agents to trade financial assets at a period 0 price $v_A \in \mathbb{R}_{++}^M$ and promise an *ex ante* stochastic period 1 payoff given by the $\Lambda \times M$ matrix A. For example, the m-th financial asset trades at period 0 price $v_{Am} \in \mathbb{R}_{++}$ and delivers the stochastic period 1 payoff $A_m \in \mathbb{R}^\Lambda$ (the m-th column of the payoff matrix A), where the period 1 payoff in state s is $A_{ms} \in \mathbb{R}$. The number of units of this asset purchased in period 0 is denoted $l_m \in \mathbb{R}$, while the entire financial market portfolio is denoted by $l \in \mathbb{R}^M$. Without loss of generality, the payoff matrix A is assumed to have full column rank M (i.e. the column vectors are linearly independent) and $M < |\Lambda|$ (i.e. financial markets are incomplete).

3 Equilibrium Conditions

First, we consider a farmer with no access to off-farm opportunities. In the first period, the farmer chooses $q_0 \in \mathbb{R}_{++}$, $q = (q_1, q_2) \in \mathbb{R}^2_{++}$, $r = (r_1, r_2) \in \mathbb{R}^2_{++}$, $h = (h_1, h_2) \in \mathbb{R}^2_{++}$, $\delta \in \mathbb{R}_+$ to[3]

$$\max \Big\{ W\Big(q_0, q_1, q_2, h_1 g(\delta), h_2\Big) : \tag{1}$$
$$\frac{r_2}{p_2 k} - \frac{r_1}{p_1} \geq 0,$$
$$f\Big(\delta, \frac{r_1}{p_1}\Big) \leq k,$$
$$q_0 \leq \omega_0 - c(w, r_1, r_2, h_1, h_2, p; h_0) - v\delta,$$
$$q_1 \leq r_1 f\Big(\delta, \frac{r_1}{p_1}\Big),$$
$$q_2 \leq r_2 \Big\}$$

where $f(0, r_1/p_1) = g(0) = 1$, $\partial f/\partial\delta > 0$ and $dg/d\delta < 0$.

There are five constraints to this optimization problem. The first two are the technology constraints discussed earlier, and the last three are budget constraints. In first period consumption, q_0, must be covered by the difference between the initial wealth endowment, ω_0, and the cost of producing the revenue-health bundle (r, h) and the cost of purchasing the pesticide, $v\delta$. The available consumption in each state of the second period is limited by the state-contingent returns, $r_1 f(\delta, r_1/p_1)$ and r_2,

[3]Alternative specifications are available. For example, $r_1 + f(\delta, r_1/p_1)$ instead of $r_1 f(\delta, r_1/p_1)$, and $h_1 - g(\delta)$ instead of $h_1 g(\delta)$. However, the pesticide literature subscribes to a multiplicative function representation of the damage. For consistency with previous work, we decided to adopt this specification.

respectively.

The budget constraints are binding because the utility is strictly increasing in consumption and health. Hence, (1) can be written as

$$\max_{r_1,r_2,h_1,h_2,\delta} \Big\{ W\Big(\omega_0 - c(w, r_1, r_2, h_1, h_2, p; h_0) - v\delta, r_1 f\Big(\delta, \frac{r_1}{p_1}\Big), r_2, h_1 g(\delta), h_2\Big) \quad (2)$$

$$+ \mu_1\Big(\frac{r_2}{p_2 k} - \frac{r_1}{p_1}\Big) + \mu_2\Big(k - f\Big(\delta, \frac{r_1}{p_1}\Big)\Big)\Big\}$$

For simplicity we restrict our attention to interior solutions. First order conditions for the case when the technological constraints are not binding are

$$\Big(\frac{\partial W}{\partial q_1}\Big/\frac{\partial W}{\partial q_0}\Big)\Big(f(\delta, \frac{r_1}{p_1}) + \frac{r_1}{p_1}\frac{\partial f}{\partial z_1}\Big) = \frac{\partial c}{\partial r_1} \quad (3)$$

$$\frac{\partial W}{\partial q_2}\Big/\frac{\partial W}{\partial q_0} = \frac{\partial c}{\partial r_2} \quad (4)$$

$$\Big(\frac{\partial W}{\partial h_1}\Big/\frac{\partial W}{\partial q_0}\Big)g(\delta) = \frac{\partial c}{\partial h_1} \quad (5)$$

$$\frac{\partial W}{\partial h_2}\Big/\frac{\partial W}{\partial q_0} = \frac{\partial c}{\partial h_2} \quad (6)$$

$$\Big(\frac{\partial W}{\partial q_1}\Big/\frac{\partial W}{\partial q_0}\Big)r_1\frac{\partial f}{\partial \delta} + \Big(\frac{\partial W}{\partial h_1}\Big/\frac{\partial W}{\partial q_0}\Big)h_1\frac{dg}{d\delta} = v \quad (7)$$

The first order conditions (3) to (6) reflect optimal consumption and health decisions. The marginal rate of substitution between the state-contingent consumption in the second period and consumption in the first period equals the marginal revenue-cost function of obtaining the state-contingent revenue. For the "pest" state, the marginal revenue is scaled by a factor $(f + r_1 f_{z_1})$ due to the pesticide application. Everything else constant, $(f + r_1 f_{z_1}) > 1$ suggests the optimal revenue r_1 is higher compared to the level it would attained in the absence of pesticide. Similarly, the marginal rate of substitution between state-contingent health outcomes and first period consumption equals the marginal revenue-health cost function of obtaining the state-contingent health outcomes. For a positive application of pesticide, the optimal health outcome h_1 is scaled down by the amount of damage, $g(\delta)$, incurred. The last first order condition describes the optimal pesticide choice. The marginal return from the pesticide application must equal the cost of pesticide plus the health damage incurred by the pesticide.

For an optimal amount of pesticide application $\delta > 0$, the technological constraints determine three cases depending on which constraint is binding. First, none of the two constraints is binding. This is consistent with the first order conditions discussed above. In this case, the pesticide is not used to mitigate production risk, but to decrease the production costs of q_1 at the expense of health outcome $h_1(1 - g(\delta))$.

Second, only the first constraint is binding, $z_1 = z_2/k$. Now, the pesticide is applied to reduced the production risk. Observe that even a risk neutral farmer can choose a positive amount of pesticide if this allows a movement to a higher fair-odds line.

Third, both constraints are binding. This is consistent with an absolutely risk averse farmer choosing to produce on the bisector, but even a risk neutral farmer can choose to produce at this point. Considering restrictions which prevents the farmer from choosing $z_1 > z_2$, any movement behind the bisector is technological impossible. However, behind this point a risk neutral, if possible, will choose a higher level of pesticide than a risk averse producer. Up to this point, the risk neutral pesticide usage was lower or equal to that of a risk averse farmer.

4 Off-farm Opportunities and Pesticide

In the presence of off-farm opportunities, the farmer chooses $q_0 \in \mathbb{R}_{++}$, $q = (q_1, q_2) \in \mathbb{R}^2_{++}$, $r = (r_1, r_2) \in \mathbb{R}^2_{++}$, $h = (h_1, h_2) \in \mathbb{R}^2_{++}$, $l \in \mathbb{R}$, and $\delta \in \mathbb{R}_+$ to

$$
\begin{aligned}
\max \Big\{ W\Big(q_0, q_1, q_2, h_1 g(\delta), h_2\Big) : \\
&\frac{r_2}{p_2 k} - \frac{r_1}{p_1} \geq 0, \\
&f\Big(\delta, \frac{r_1}{p_1}\Big) \leq k, \\
&q_0 = \omega_0 - c(w, r_1, r_2, h_1, h_2, p; h_0) - v_\delta \delta - v_A l, \\
&q_1 = r_1 f\Big(\delta, \frac{r_1}{p_1}\Big) + A_1 l, \\
&q_2 = r_2 + A_2 l \Big\}
\end{aligned} \tag{8}
$$

where the equality in the budget constraints is due to the monotonicity of the utility over consumption and health. Hence, for optimal values of second period consumption and revenue levels, q_1,q_2, r_1 and r_2, the optimal level of financial market participation is

$$
l = P\Big(q_1 - r_1 f\Big(\delta, \frac{r_1}{p_1}\Big), q_2 - r_2\Big) \tag{9}
$$

where $P = (A^T A)^{-1} A^T$. After substituting for l in (8) yields:

$$
\begin{aligned}
\max \Big\{ W\Big(\omega_0 - v_\delta^T P(q_1, q_2) + v_\delta^T P\Big(r_1 f\Big(\delta, \frac{r_1}{p_1}\Big), r_2\Big) - c(w, r_1, r_2, h_1, h_2, p; h_0) \\
- v_\delta \delta, q_1, q_2, h_1 g(\delta), h_2\Big)\Big\}
\end{aligned} \tag{10}
$$

when the technology constraints are not binding. Assuming the preference, the revenue-health cost function, pesticide production function and health damage are differentiable, the first order conditions for problem (10), at interior solutions, are:

$$
v_\delta^T P_1 \Big(f\Big(\delta, \frac{r_1}{p_1}\Big) + \frac{r_1}{p_1}\frac{\partial f}{\partial z_1}\Big) = \frac{\partial c}{\partial r_1} \tag{11}
$$

$$
v_\delta^T P_2 = \frac{\partial c}{\partial r_2} \tag{12}
$$

$$\left(\frac{\partial W}{\partial h_1}\Big/\frac{\partial W}{\partial q_0}\right)g(\delta) = \frac{\partial c}{\partial h_1} \tag{13}$$

$$\frac{\partial W}{\partial h_2}\Big/\frac{\partial W}{\partial q_0} = \frac{\partial c}{\partial h_2} \tag{14}$$

$$v_\delta^T P_1 r_1 \frac{\partial f}{\partial \delta} + \left(\frac{\partial W}{\partial h_1}\Big/\frac{\partial W}{\partial q_0}\right)h_1 \frac{dg}{d\delta} = v \tag{15}$$

Observe, that production decisions, (11) and (12), are not truly separated from consumption decisions, not shown, because the health and production are not separated in production. For example, if the output and health are substitutes in production, then the marginal cost of producing output will decrease with health.

If the first technology constraint is binding, $r_1/p_1 = r_2/(p_2 k)$, the interior first order conditions become

$$v_\delta^T P_1 \left(\frac{p_1}{p_2 k} f\left(\delta, \frac{r_1}{p_1}\right) + \frac{r_2 p_1}{p_2 k}\frac{\partial f}{\partial z_1}\right) + v_\delta^T P_2 = \frac{\partial c}{\partial r_1}\frac{p_1}{p_2 k} + \frac{\partial c}{\partial r_2} \tag{16}$$

and

$$v_\delta^T P_1 r_1 \left(\frac{p_1}{p_2 k} f\left(\delta, \frac{r_1}{p_1}\right) + \frac{r_2 p_1}{p_2 k}\frac{\partial f}{\partial z_1}\right) + \left(\frac{\partial W}{\partial h_1}\Big/\frac{\partial W}{\partial q_0}\right)h_1 \frac{dg}{d\delta} = v \tag{17}$$

where conditions (13) and (14) remain unchanged. Furthermore, if we assumed a banned on the usage of pesticide, $\delta = 0$, first order conditions become

$$v_\delta^T P\left(\frac{p_1}{p_2 k}, 1\right) = \bigtriangledown_r c\left(\frac{p_1}{p_2 k}, 1\right) \tag{18}$$

and

$$\frac{\bigtriangledown_h W}{W_0} = \bigtriangledown_h c \tag{19}$$

where $\bigtriangledown$ represents the gradient of the function with respect to the variable under consideration. *[FOC interpretation to be added.]*

5 Conclusion

Preliminary analysis suggests that technology constraints impose restrictions on the farmer's ability to replicate consumption even in the presence of incomplete financial markets. The addition of pesticide relaxes these constraints, but at the expense of health outcomes which must be analyze.

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