When Decoupled Isn't Decoupled: Price Risk, Wealth Effects, and Behavioral Responses in a Nonseparable Household Model

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Abstract

We develop a nonseparable agricultural household model under output price risk to examine whether nominally decoupled income transfers are behaviorally neutral. In the presence of market imperfections and uncertainty, we show that such payments affect production decisions through endogenous wealth, risk, and technology channels. Using a dual certainty-equivalent representation, we derive analytical expressions that characterize how transfers propagate across production and consumption decisions. The framework identifies three mechanisms, an income channel, a wealth-risk channel, and a liquidity/technology channel, through which decoupled payments become partially recoupled. An empirical application to farm-level data from Greece quantifies these effects and shows that decoupled payments generate nontrivial responses in input use, labor allocation, and welfare. The results provide a unified explanation for the observed production effects of decoupled policies and inform the design of agricultural support programs.

Keywords: Decoupled payments; Nonseparable household models; Price risk; Behavioral coupling

JEL Codes: Q12; Q18; D81; D13; C51.

Introduction

A central question in agricultural economics is whether production and consumption decisions within rural households can be analyzed independently or whether they are fundamentally intertwined. The classical agricultural household (AH) model, originating from Singh et al. (1986), shows that under perfectly functioning markets, where households are price takers, face no transaction costs, and have frictionless access to labor, credit, and insurance, production and consumption decisions are separable. In such environments, the household behaves as if it were a profit-maximizing firm on the production side and a utility-maximizing consumer on the consumption side. Shadow wages coincide with market wages, leisure is chosen independently of production, and empirical analysis of supply and input demand can abstract from household preferences or demographic characteristics.

A large empirical literature, however, documents that these separability conditions rarely hold in rural economies. Labor market imperfections (e.g. Benjamin, 1992), credit and liquidity constraints (e.g. Udry, 1995), input transaction costs, and exposure to output-price risk jointly generate non-separable household structures (e.g. Key et al., 2000). When markets are incomplete, the shadow wage diverges from the market wage and labor-leisure choices become intrinsically linked to production intensity and technology. Income shocks and price volatility propagate across the production and consumption blocks, and household welfare and supply responses must be analyzed within a unified framework. Under these conditions, risk preferences and wealth constraints affect not only consumption behavior but also input use, crop mix, and the allocation of family labor between farm and off-farm activities.

The policy debate on decoupled payments fits naturally within this broader literature. Beginning with the U.S. FAIR Act of 1996 and successive reforms of the EU's Common Agricultural Policy (CAP), including Agenda 2000, the Fischler reform, and CAP 2013+, farm support shifted from tightly coupled, production-linked instruments toward nominally decoupled income transfers intended to minimize distortions. In a benchmark separable setting with complete markets, a fully decoupled payment should (i) not alter marginal production incentives, (ii) operate as a pure wealth transfer, and (iii) leave output, input use, and labor allocation unaffected except through standard income effects on consumption. In practice, however, these neutrality results inherit the same strong assumptions on market completeness and separability that are often violated in real agricultural environments.

An expanding empirical and theoretical literature challenges the view that decoupled payments are behaviorally neutral. Because such transfers raise household wealth, relax liquidity constraints, and modify effective exposure to risk, they may reduce absolute risk aversion, ease working-capital constraints, and change the opportunity cost of household labor. These mechanisms can generate *endogenous coupling*, whereby nominally decoupled transfers indirectly influence production behavior through wealth, risk, and technology channels, even when statutory rules no longer tie support directly to current output or input use (e.g. Just, 2011; Chang, 2024). Evidence from both the US and the EU suggests that farmers frequently allocate a non-trivial fraction of decoupled payments to variable inputs, on-farm investment, or labor reallocation, especially when credit constraints are binding or future policy reforms are anticipated.

This paper integrates these strands of research by developing a fully articulated nonseparable agricultural household model under output-price risk in which decoupled payments influence behavior through multiple channels. We distinguish between the *administratively decoupled* transfer defined by policy and the *behaviorally coupled* component that emerges endogenously through wealth effects, changes in risk preferences, and technological or liquidity-driven shifts in the mean shadow return to on-farm labor. On the production side, we derive a certainty-equivalent (CE) dual representation of the farm household's problem under price risk, showing how risk aversion and the variance of crop revenues jointly shape risk-adjusted netput responses. On the consumption side, we construct a CE money-metric indirect utility function in which full income and the shadow wage are jointly stochastic, and the associated risk premia depend on both the variance of income and its covariance with the shadow return to on-farm labor.

The CE representations allow us to characterize analytically how decoupled payments propagate across the interconnected production and consumption blocks. Building on these dual structures, we show that a given transfer payment affects household welfare and behavior through three distinct channels: (i) an *autonomous income channel*, whereby the truly decoupled share augments full income on the consumption side (Weber and Key, 2012); (ii) a *wealth/risk channel*, whereby the coupled share enters effective initial wealth and alters the producer's Arrow-Pratt risk aversion in the CE profit problem (Femenia et al., 2010); and (iii) a *technology/liquidity channel*, whereby the coupled share relaxes working-capital or technological constraints and shifts the mean shadow return to on-farm labor (Chambers and Voica, 2017). We derive closed-form envelope expressions for the total CE welfare effect of transfer payments, which provide a theoretically consistent metric for assessing the extent to which payments remain truly decoupled once price risk, shadow-wage feedback, and liquidity effects are taken into account.

To make the framework operational, we adopt flexible Normalized Quadratic (NQ) functional forms for both the production and consumption CE duals, which preserve the curvature and homogeneity properties of the underlying risk-adjusted problems. We then implement the model using detailed survey data for multi-output cereal farms in Central Macedonia (Greece), combining information on crop outputs, variable inputs, on- and off-farm labor, household income, wealth, and decoupled CAP payments. The behavioral coupling parameter is identified through a logit specification that depends on structural and financial characteristics that are exogenous to the CE systems. The resulting estimates allow us to quantify the degree of endogenous coupling and to decompose the welfare impact of decoupled payments into the three structural channels highlighted by the theory.

A Nonseparable Agricultural Household Model under Price Risk

Production Decisions

Let the farm crop technology for a rural household be represented by the closed and nonempty production possibilities set

$$T \equiv \left\{ \left(x^v, x^f, y, d \right) : \left(x^v, x^f \right) \text{can produce } y \right\}$$

where $x^v \in \Re^J_+$ is a vector of variable inputs used in farm production, $y \in \Re^M_+$ is a vector of crops produced, and $x^f \in \Re_{++}$ denotes on-farm labor supply by household members, assumed homogeneous for simplicity.[1] Because farm labor supply is predetermined by household members, it is treated as a quasi-fixed factor of production.

We assume that long-run maximal crop technology exhibits constant returns-to-scale in all variable inputs and farm labor, that is, :

$$F\left(\mu x^v, \mu x^f, \mu y\right) = \mu F\left(x^v, x^f, y\right) \quad \mu > 0$$

where $F\left(x^v, x^f, y\right)$ is a well defined quasi-convex transformation function representing maximal crop combinations obtainable from variable and quasi-fixed input use given farm-specific characteristics.

Rural households face random prices for the m crops they produce denoted by the random vector $\tilde{p}^y \in \Re^{\Omega \times M}_{++}$:

$$\tilde{p}^y = \bar{p}^y + \tilde{\epsilon}^y, \qquad \mathbb{E}[\tilde{\epsilon}^y] = 0, \qquad \text{Var}(\tilde{\epsilon}^y) = V^p \in \Re^{M \times M}. \tag{1}$$

where $\bar{p}^y$ denotes the vector of mean crop prices, $\Re^\Omega$ the random variable space formed by mapping the underlying random states, Ω, to reals, and $\tilde{\epsilon}^y$ the vector of mean-zero price shocks exogenous to household decisions. The covariance matrix V^p has diagonal elements $V^p_{mm} = \sigma^2_{p_m}$ and off-diagonal elements $V^p_{mh} = \text{Cov}\left(\tilde{\epsilon}^y_m, \tilde{\epsilon}^y_h\right)$.

Given these assumptions, the household maximizes its expected utility of total crop income subject to technological and policy constraints. The solution defines a *statewise* indirect utility

[1] The household does not employ nonfamily farm labor; the extension to hired labor is straightforward.

function representing utility derived from short-run farm profits under stochastic output prices:

$$\begin{aligned}\tilde{v}^p\left(W_0, D, \tilde{p}^y, w^v, x^f\right) &= \max_{x^v, y} \tilde{u}^p\left\{W_0 + \theta D + \tilde{p}^{y\top} y - w^{v\top} x^v : F\left(x^v, x^f, y; \theta D\right) \leq 0\right\} \\ &= \tilde{u}^p\left\{W_0 + \theta D + \tilde{\pi}\left(\tilde{p}^y, w^v, x^f; \theta D\right)\right\}\end{aligned} \tag{2}$$

where $w^v \in \Re^J_{++}$ is the vector of variable-input prices, $W_0 \in \Re_+$ is the nonrandom initial farm wealth (*e.g.*, value of farm assets owned by household members) which does not affect optimal input choice and $\theta D \in \Re_+$ is the share $0 \leq \theta \leq 1$ of decoupled payments that remains implicitly linked to production activities. The restricted profit function $\tilde{\pi}\left(\tilde{p}^y, w^v, x^f; \theta D\right)$ is well behaved: it is sublinear (positively linearly homogeneous and convex) in $(\tilde{p}^y, w^v)$, nondecreasing in $\tilde{p}^y$, and nonincreasing in w^v. It also satisfies *Hotelling's* Lemma.

Although, in principle, income support is intended to be fully decoupled from current production choices, empirical evidence suggests that liquidity constraints, expectations about future policy reforms, and behavioral inertia lead farm households to allocate part of these payments to production-related expenses. This coupled component θD has two distinct economic effects. First, it raises the producer's effective wealth, thereby lowering absolute risk aversion in the CE producer problem and reducing the magnitude of the risk premium. Second, the same coupled funds expand the farm's working capital and relax technological or liquidity constraints. When incorporated into the restricted profit function, θD acts as an exogenous production shifter, analogous to an input subsidy or investment grant, increasing mean restricted profits. This interpretation follows the analytical reasoning of Just (2011) and, Chambers and Voica (2017) who showed that even nominally decoupled transfers may induce production responses through wealth and risk channels when markets are incomplete or preferences are non-separable. Hence, even though the policy is administratively decoupled, the endogenously coupled component θD influences both the farmer's effective risk environment and the technological capacity of farm production.

Under constant returns-to-scale, the restricted short-run profit function is also linear homogeneous in x^f. Thus, under a smooth farm technology, the *Clark-Wicksteed* product-exhaustion theorem applies, and quasi-rent to the fixed input endowment is fully exhausted (Diewert, 1973):

$$\tilde{\pi}\left(\tilde{p}^y, w^v, x^f; \theta D\right) = x^f \tilde{\pi}^f\left(\tilde{p}^y, w^v; \theta D\right) \tag{3}$$

where $\tilde{\pi}^f(\cdot)$ represents the *shadow price* of on-farm labor. The product of its shadow price with its use in crop production completely exhaust quasi-rent from farming. Using (3) and setting $W_0^D = W_0 + \theta D$, we may write the producer's *statewise* indirect utility in (2) as:

$$\tilde{v}^p\left(W_0^D, \tilde{p}^y, w^v, x^f, D\right) = \tilde{u}^p\left\{W_0^D + x^f \tilde{\pi}^f\left(\tilde{p}^y, w^v; \theta D\right)\right\} \tag{4}$$

where total farm income is given by $\tilde{W} = W_0^D + x^f\,\tilde{\pi}^{\,f}$, with mean $\bar{W} = W_0^D + x^f\,\bar{\pi}^{\,f}$ and variance $\sigma_w^2 = \mathrm{Var}(\tilde{W})$.

Assuming small risk (or joint normality), a second-order *Arrow-Pratt* expansion of expected utility around $\bar{W}$ yields (Sandmo, 1971):

$$\mathbb{E}\left[u^p(\tilde{W})\right] \simeq u_w^p(\bar{W}) + 0.5u_{ww}^p(\bar{W})\,\sigma_w^2 \quad \text{since} \quad \mathbb{E}[\tilde{W} - \bar{W}] = 0,$$

where u_w^p and u_{ww}^p are first- and second-order partial derivatives of the utility function with respect to wealth, evaluated at $\bar{W}$. Linearizing the utility function around $\bar{W}$ gives

$$u^p(\mathrm{CE}) \simeq u^p(\bar{W}) + u_w^p(\bar{W})\,\left[\mathrm{CE} - \bar{W}\right]$$

Equating the two expressions defines the *certainty-equivalent* (CE) version of (4):

$$\tilde{v}^{\,p}\left(W_0^D, \bar{p}^{\,y}, w^v, x^f, D, \sigma_w^2\right) = W_0^D + x^f\,\bar{\pi}^f - 0.5\,r^w\sigma_w^2 \tag{5}$$

where $r^w = \tilde{u}_{ww}^p/\tilde{u}_w^p$ is the *Arrow-Pratt* measure of absolute risk aversion.[2] The certainty equivalent farm income in (5) is strictly increasing in its mean component $\bar{W}$ and decreasing in the variance term σ_w^2 under risk aversion ($r^w > 0$) (Appelbaum and Ullah, 1997).[3] Intuitively, the CE transformation shifts the producer's objective from expected profits to a risk-adjusted measure of wealth. The *Arrow-Pratt* coefficient scales the variance of profits into a welfare-equivalent loss, reflecting the curvature of preferences over wealth. The negative marginal effect of price variance $\left(-0.5\,r^w\sigma_w^2\right)$ represents the implicit risk premium the household requires to remain indifferent to stochastic returns. As a result, risk-averse producers behave as if facing lower effective prices, generating a downward shift in the supply response relative to the risk-neutral case.

A final remark concerns the variance of total farm income σ_w^2. Since crop prices are the only random variable in the model, it is simply the variance of revenues realized from farm production. Given assumptions in (1), a first-order linearization of restricted profits around $\bar{p}^{\,y}$ gives $\tilde{\pi}^{\,f} \approx \bar{\pi}^{\,f} + y^\top\varepsilon$, where $y = \partial\bar{\pi}^{(\cdot)}\big/\partial p^y\Big|_{p^y=\bar{p}^y}$ is the optimal netput vector at $(\bar{p}^{\,y}, w^v, s)$. Hence,

$$\sigma_w^2 = \mathrm{Var}\left(W_0^D + x^f\tilde{\pi}^{\,f}\right) \simeq (x^f)^2\,y^\top V^p y, \tag{6}$$

and the variance term in (5) is determined by the (mean) netput response and the price variance-

[2]Under small risk, it can be proved that under CRRA $r^w = \frac{\rho}{W}$, whereas under CARA with exponential utility it is constant, $r^w = \alpha$. The intuition is simple: Under CRRA, risk premium falls with wealth resulting to more flattered indifference curves, whereas under CARA, risk premium is constant resulting to parallel curves across wealth levels.

[3]In fact, producer preferences defined in (5) are a special case of the translation invariant class preferences axiomatized by Quiggin and Chambers (2004).

covariance matrix.

The dual representation of the CE *statewise* indirect utility function follows the general properties of benefit and distance functions in Chambers et al. (1996), who show that risk adjustments preserve convexity and linear homogeneity in the dual space. Its exact properties are summarized in the following proposition.

Proposition 1 *Let $\tilde{v}^{\,p}\left(W_0^D, \bar{p}^{\,y}, w^v, x^f, D, \sigma_w^2\right)$ denote the CE value function of the production problem defined in (5). Then under competitive farm production with constant returns-to-scale and stochastic output prices, the function $\tilde{v}^p(\cdot)$ satisfies the following properties:*[4]

(i) ***Homogeneity:*** *If preferences exhibit CRRA then*

$$\tilde{v}^{\,p}\left(\lambda W_0^D, \lambda\bar{p}^{\,y}, \lambda w^v, x_f, D, \lambda^2\sigma_w^2\right) = \lambda\,\tilde{v}^{\,p}\left(W_0^D, \bar{p}^{\,y}, w^v, x^f, D, \sigma_w^2\right) \quad \lambda > 0,$$

so $\tilde{v}^{\,p}$ is linear homogeneous in all monetary arguments. Under CARA, $r_w(\bar{W}) = a$ is constant, and $\tilde{v}^p$ is instead translation–equivariant: $\tilde{v}^{\,p}\left(W_0^D + k, \dots\right) = \tilde{v}^{\,p}(\cdot) + k$.

(ii) ***Envelope derivatives:*** *Let y_m denote optimal outputs, x_j^v variable inputs, and $\bar{\pi}^{\,f}$ mean restricted profits. Applying the envelope theorem to $\tilde{v}^{\,p}(\cdot)$, holding the risk primitives fixed at their first-stage (mean-solution) values, yields:*

$$\frac{\partial\tilde{v}^{\,p}(\cdot)}{\partial\bar{p}_m^y} = y_m\Big(1 - 0.5 r_{\bar{W}}^w\,\sigma_w^2\Big) \qquad \frac{\partial\tilde{v}^{\,p}(\cdot)}{\partial w_j^v} = -x_j^v\Big(1 - 0.5 r_{\bar{W}}^w\,\sigma_w^2\Big)$$

$$\frac{\partial\tilde{v}^{\,p}(\cdot)}{\partial W_0^D} = 1 - 0.5 r_{\bar{W}}^w\,\sigma_w^2 \qquad \frac{\partial\tilde{v}^{\,p}(\cdot)}{\partial\sigma_w^2} = -0.5\,\left(r_\sigma^w\sigma_w^2 + r^w\right)$$

$$\frac{\partial\tilde{v}^{\,p}(\cdot)}{\partial x^f} = \bar{\pi}^{\,f}\Big(1 - 0.5 r_{\bar{W}}^w\,\sigma_w^2\Big)$$

where $r_{\bar{W}}^w$ and r_σ^w are the first-order partial derivatives of r^w with respect to wealth, evaluated at $\bar{W}$, and its variance. Dividing the first two expressions by the third gives risk-adjusted (compensated) supply and demand responses.

(iii) ***Curvature:*** *Under constant returns-to-scale, for any feasible (y, x^v) the objective*

$$\bar{W} + \bar{p}^{\,y\top} y - w^{v\top} x^v - 0.5\, r^w\,\sigma_w^2$$

is affine in $(\bar{p}^{\,y}, w^v)$, holding risk primitives fixed, and the variance penalty does not depend on price levels. Therefore $\tilde{v}^{\,p}(\cdot)$ -the supremum of affine functions in prices- is convex in

[4] The proof is presented in Appendix A.

$(\bar{p}^{y}, w^{v})$. *The Hessian with respect to prices is positive semidefinite, satisfying the Hatta (1980) curvature conditions.*

(iv) ***Weak separability and reciprocity:*** *Price effects operate through the aggregates* $(\bar{\pi}^{f}, \sigma_{w}^{2})$, *yielding conditional weak separability (holding risk primitives fixed) between* $(\bar{p}^{y}, w^{v})$ *and* (W_0^D, σ_w^2). *Mixed partial derivatives are symmetric,*

$$\frac{\partial^2 \tilde{v}^{p}(\cdot)}{\partial \bar{p}_m^y \partial w_j^v} = \frac{\partial^2 \tilde{v}^{p}(\cdot)}{\partial w_j^v \partial \bar{p}_m^y},$$

ensuring the usual reciprocity (Slutsky-type) conditions in the dual representation.

Consumption Decisions

On the consumption side, the representative rural household derives utility from an agrgegate consumption good $c \in \Re_{+}$ and leisure, $\ell \in \Re_{+}$.[5] Household is endowed with T^H units of time which can be consumed as leisure (ℓ), supplied to the market as labor $(x^o \in \Re_{+})$, or used in farm operation $\left(x^f \in \Re_{+}\right)$. Following Lopez (1984), we further assume that household members confront different disutilities from working on- and off-farm, or in other words, farm and nonfarm labor is not homogeneous. This assumption is consistent with the empirical and theoretical findings of Benjamin (1992), who demonstrated that nonseparability between production and consumption decisions arises precisely when household labor types (or supplied skills) are not perfect substitutes across sectors.[6]

Given that $\tilde{\pi}^{f}$ represents the shadow wage for on-farm work time and assuming perfect markets and no savings for household members, the standard household budget $p^{c}c = \tilde{\pi}^{f}x^{f} + w^{o}x^{o} + I_0 + (1-\theta)\,D$ can be written in the following stochastic full-income form:

$$\tilde{Z} \;=\; p^{c}c + \tilde{\pi}^{f}\ell^{f} + w_{o}\ell^{o}, \qquad \tilde{Z} \equiv I_0 + (1-\theta)\,D + T^{H}\left(\tilde{\pi}^{f} + w^{o}\right)$$

where $\ell^{f} = T^H - x^f$ and $\ell^{o} = T^H - x^o$ is the total leisure consumed by household members, $p^{c} \in \Re_{++}$ is the price of the consumption good, $w^o \in \Re_{++}$ is the off-farm wage rate, $I_0 \in \Re_{+}$ is the exogenous non-labor income, and $(1-\theta)\,D \in \Re_{+}$ is the fraction of policy transfer that are indeed decoupled, directed to household consumption.

Therefore, household's money-metric utility function, under stochastic crop prices, is derived

[5] Leisure is assumed to be a normal good.

[6] Market imperfections such as transaction costs and heterogeneity in labor markets imply that a household's production and consumption choices become non-separable, even when the household participates in input and output markets (Henning and Henningsen, 2007).

from the following optimization problem:

$$\tilde{v}^{\,c}\left(p^{\,c}, w^{o}, \tilde{\pi}^{\,f}, \tilde{Z}\right) = \max_{c,\ell^{\,f},\ell^{\,o}} \left\{u^{\,c}\left(c, \ell^{\,f}, \ell^{\,o}\right) : \ \tilde{Z} = p^{\,c}c + \tilde{\pi}^{\,f}\,\ell^{\,f} + w^{o}\,\ell^{\,o}\right\} \tag{7}$$

where, $u^{\,c}\left(c, \ell^{\,f}, \ell^{\,o}\right)$ is a monotonically non-decreasing quasi concave utility function. The optimization problem features a linear budget constraint defined over non-negative prices and positive income. We assume an interior solution such that the time-allocation constraint is not binding, implying that the household consumes some leisure at any feasible combination of off-farm wage rate, short-run profits, and crop prices. The problem is defined on the nonnegative orthant of $\left(c, \ell^{\,f}, \ell^{\,o}\right)$ which ensures continuity of the indirect utility function. Therefore, standard duality results apply, and the solution of the above problem defines the indirect utility function in a straightforward way, mapping observable prices and income into the household's welfare level.

Under risk, the indirect utility function above can be expressed in terms of the household's preferences over the moments of the probability distribution of the random variable defining its CE. In the traditional univariate case, where only income is random (and not due to stochastic crop prices), the indirect utility reduces to the familiar objective function defined solely over income. Nevertheless, since the prices of farm outputs are unknown at the time employment decisions are made, even when consumption-leisure choices are flexible, the joint distribution of income and the shadow on-farm wage rate is likely to influence the final allocation. In the conventional sense, the *Arrow-Pratt* risk premium quantifies the maximum income reduction the household is willing to accept to eliminate risk, holding all other factors constant. It converts the curvature of preferences into a monetary measure of risk compensation. However, if only crop prices are stochastic while income itself is stabilized, then the *Arrow-Pratt* risk premium does not necessarily capture the household's willingness to pay for insurance in terms of real income. In such a context, the risk premium instead measures the household's willingness to pay to avoid labor-income risk arising from random output prices (Finkelshtain and Chalfant, 1991).[7]

To define the certainty equivalent of the money metric utility function, we need first to simplify things. Holding (p^c, w^o) fixed, we may express money-metric utility potential as

$$\tilde{g}\left(\tilde{\pi}, \tilde{Z}\right) = \tilde{v}^{\,c}\left(p^{c}, w^{o}, \tilde{\pi}^{\,f}, \tilde{Z}\right)$$

for which the following *Lemma* applies:

Lemma 1 *Assume $g(\cdot)$ is twice continuously differentiable, strictly increasing and strictly concave in its money-metric argument, and that a second-order (small-risk / joint-normal) approximation*

[7]Similar moment-based decompositions of expected utility can be found in Gollier (2001), who provides a unified treatment of risk premia and certainty equivalents under small-risk approximations.

holds around $(\bar{\pi}_f, \bar{Z})$. *Define the Arrow-Pratt and mixed money-metric indices* $r^z = g_{zz}/g_z$ *and* $r^{z\pi} = g_{z\pi}/g_z$. *Then the (money-metric) certainty-equivalent value of the money-metric utility is*

$$\tilde{v}^{\,c}(p^{\,c}, w^o, \bar{\pi}^{\,f}, \bar{Z}, \sigma_z^2, \sigma_{z\pi}) \;=\; \bar{Z} \;-0.5\, r^z\, \sigma_z^2 \;-\; r^{z\pi}\, \sigma_{z\pi}, \tag{8}$$

where $\sigma_z^2 = \mathrm{Var}(\tilde{Z})$ *and* $\sigma_{z\pi} = \mathrm{Cov}(\tilde{Z}, \tilde{\pi}^{\,f})$.

To prove this we first take the second-order *Taylor* expansion of $g(\cdot)$ around $\left(\bar{\pi}^{\,f}, \bar{Z}\right)$ assuming that $\left(\tilde{\pi}^{\,f}, \tilde{Z}\right)$ are jointly normal:

$$\begin{aligned}\mathbb{E}\left[g\left(\tilde{\pi}^{\,f}, \tilde{Z}\right)\right] \approx g\left(\bar{\pi}^{\,f}, \bar{Z}\right) + g_z\left(\bar{\pi}^{\,f}, \bar{Z}\right)\,\mathbb{E}\left[\tilde{Z} - \bar{Z}\right] + g_\pi\left(\bar{\pi}^{\,f}, \bar{Z}\right)\,\mathbb{E}\left[\tilde{\pi}^{\,f} - \bar{\pi}^{\,f}\right] \\ + 0.5 g_{zz}\left(\bar{\pi}^{\,f}, \bar{Z}\right)\mathrm{Var}\left(\tilde{Z}\right) + g_{z\pi}\left(\bar{\pi}^{\,f}, \bar{Z}\right)\mathrm{Cov}\left(\tilde{Z}, \tilde{\pi}^{\,f}\right) + 0.5 g_{\pi\pi}\left(\bar{\pi}^{\,f}, \bar{Z}\right)\mathrm{Var}\left(\tilde{\pi}^{\,f}\right)\end{aligned}$$

Since $\mathbb{E}\big[\tilde{Z} - \bar{Z}\big] = \mathbb{E}\left[\tilde{\pi}^{\,f} - \bar{\pi}^{\,f}\right] = 0$, the linear terms above vanish. In addition, the term $g_{\pi\pi}$ is omitted as its effect enters σ_z^2 and $\sigma_{z\pi}$ through the linear dependence of $\tilde{Z}$ on $\tilde{\pi}^{\,f}$.[8] Hence, the above results in the following

$$\mathbb{E}\left[g\left(\tilde{\pi}^{\,f}, \tilde{Z}\right)\right] \approx g\left(\bar{\pi}^{\,f}, \bar{Z}\right) + 0.5 g_{zz}\,\sigma_z^2 + g_{z\pi}\,\sigma_{z\pi} \tag{9}$$

Linearizing $g(\cdot)$ around $\bar{Z}$, $g(CE) \approx g\left(\bar{\pi}^{\,f}, \bar{Z}\right) + g_z\left(\bar{\pi}^{\,f}, \bar{Z}\right)\left(Z_{CE} - \bar{Z}\right)$ and equating with the expected value in (9) yields:

$$CE - \bar{Z} \approx \frac{1}{g_z}\left(0.5 g_{zz}\,\sigma_z^2 + g_{z\pi}\,\sigma_{z\pi}\right).$$

Define the *Arrow-Pratt* type curvature indices for $g(\cdot)$: $r^z\left(\bar{Z}\right) = -\frac{g_{zz}}{g_z}$ and $r^{z\pi}\left(\bar{Z}, \bar{\pi}^{\,f}\right) = -\frac{g_{z\pi}}{g_z}$. Substituting these into the previous expression gives the money-metric certainty equivalent in (8). Hence, the household's expected indirect utility can be represented by the certainty-equivalent full income

$$\tilde{v}^{\,c}\left(p^{\,c}, w^o, \bar{\pi}^{\,f}, \bar{Z}, \sigma_z^2, \sigma_{z\pi}\right) = \bar{Z} - 0.5 r^z \sigma_z^2 - r^{z\pi}\sigma_{z\pi} \tag{10}$$

where $0.5 r^z \sigma_z^2$ is the pure income–risk premium (absolute risk aversion in indirect utility space) that measures concavity of money-metric utility in income and $r^{z\pi}\sigma_{z\pi}$ is the cross-risk premium measuring cross-sensitivity of marginal utility to changes in on-farm shadow wage rate (in effect links consumption and production risks). Under a first-order linearization of $\tilde{\pi}^{\,f}$ in crop prices, it turns that $\sigma_z^2 = (\ell^{\,f})^2\, y^\top V^p y$ and $\sigma_{z\pi} = \ell^{\,f} y^\top V^p y$, with y being the mean netput vector from the producer problem and V^p the crop-price variance-covariance matrix.[9]

[8] See Appendix B for the proof.

[9] Using definitions in (1) and linearizing short-run profits we get $\tilde{\pi}^{\,f} \approx \bar{\pi}^{\,f} + y^\top \epsilon^y$. Since $\tilde{Z} = p^{\,c} c + \tilde{\pi}^{\,f} \ell^{\,f} + w^o \ell^o$,

Relation (10) establishes that the two second moments driving the consumption-side risk premia, σ_z^2 and $\sigma_{z\pi}$, are affine in the common primitive $y^\top V^p y$, the scalar measuring overall price-risk exposure on the production side. Both moments are scaled by on-farm leisure ℓ^f, so the extent of the household's time commitment to farming amplifies the magnitude of the risk-adjustment terms in the consumption value function. The first term, σ_z^2, represents the pure variance of full income, proportional to the square of on-farm exposure ℓ^f, while the second, $\sigma_{z\pi}$, measures the covariance between full income and the shadow wage, proportional to ℓ^f itself. Consequently, both premia inherit the same directional sensitivity to output-price uncertainty but with distinct scaling exponents.[10]

Economically, these mappings imply two transmission channels from production to consumption decisions: *(i) shadow-wage channel* as the expected short-run profits $\bar{\pi}^f$ affect full income $\bar{Z}$ directly through the deterministic full-income constraint $Z = p^c c + \pi^f \ell^f + w_o \ell^o$, and *(ii)* the *risk-premium channel* as the price-variance primitive $y^\top V^p y$ enters the CE penalties via $(\sigma_z^2, \sigma_{z\pi})$, modifying the marginal value of income and thereby the slopes of the *Hicksian* and *Marshallian* demand surfaces for (c, ℓ^f, ℓ^o). Because both channels depend on ℓ^f, on-farm labor (or leisure) decisions jointly determine not only the shadow wage but also the magnitude of the risk adjustment. This creates cross-price effects between production and consumption even under complete markets, reinforcing the non-separability of the agricultural household model. The analytical properties of household's expected indirect utility are presented in the following proposition.[11]

Proposition 2 *Let $\tilde{v}^c(\cdot)$ be given by (10). Suppose the preference index is either CRRA or CARA in its money-metric argument and let c, ℓ^f, ℓ^o denote Marshallian demands. Then expected indirect utility satisfies the following properties:*

(i) ***Homogeneity:*** *If household preferences exhibit CRRA, then it holds that $r^z(\lambda\bar{Z}, \lambda^2\sigma_z^2) = \lambda^{-1} r^z(\bar{Z}, \sigma_z^2)$ and $r^{z\pi}(\lambda\bar{Z}, \lambda\bar{\pi}^f, \lambda^2\sigma_{z\pi}) = \lambda^{-1} r^{z\pi}(\bar{Z}, \bar{\pi}^f, \sigma_{z\pi})$, $\forall\lambda > 0$. Hence, it holds*

$$\tilde{v}^c(\lambda p^c, \lambda w^o, \lambda\bar{\pi}^f, \lambda\bar{Z}, \lambda^2\sigma_z^2, \lambda^2\sigma_{z\pi}) = \lambda\tilde{v}^c(p^c, w^o, \bar{\pi}^f, \bar{Z}, \sigma_z^2, \sigma_{z\pi}).$$

Under CARA, $r^z \equiv a$ and $r^{z\pi} \equiv b$ are constants, so it holds that $\tilde{v}^c(\bar{Z}+k, \cdots) = \tilde{v}^c(\bar{Z}, \cdots) + k$.

(ii) ***Envelope derivatives:*** *Let $r_z^z = \partial r^z(\cdot)/\partial\bar{Z}$, $r_z^{z\pi} = \partial r^{z\pi}(\cdot)/\partial\bar{Z}$, $r_\pi^{z\pi} = \partial r^{z\pi}(\cdot)/\partial\bar{\pi}^f$, $r_\sigma^z = \partial r^z(\cdot)/\partial\sigma_z^2$, and $r_\sigma^{z\pi} = \partial r^{z\pi}(\cdot)/\partial\sigma_{z\pi}$. Then the following the envelope theorem it holds (hold-*

the sole randomness is $\ell^f(y^\top \epsilon^y)$.

[10] This mechanism is consistent with recent empirical findings by Singhal and Tarp (2025), who shows that exposure to output-price volatility has significant welfare effects on small producers, shaping both their income stability and subjective well-being. Such results support the interpretation of the risk premium in indirect utility function as a welfare-equivalent measure of price-induced uncertainty transmitted from production to consumption.

[11] The proof is presented in Appendix C.

ing risk-primitives fixed to ensure consistency with the certainty-equivalent representation):

$$\frac{\partial \tilde{v}^{c}(\cdot)}{\partial \bar{Z}} = 1 - 0.5\left(r^{z}_{z}\sigma^{2}_{z} + r^{z\pi}_{z}\sigma_{z\pi}\right) \qquad \frac{\partial \tilde{v}^{c}(\cdot)}{\partial p^{c}} = -c\left[1 - 0.5\left(r^{z}_{z}\sigma^{2}_{z} + r^{z\pi}_{z}\sigma_{z\pi}\right)\right]$$

$$\frac{\partial \tilde{v}^{c}(\cdot)}{\partial w^{o}} = -\ell^{o}\left[1 - 0.5\left(r^{z}_{z}\sigma^{2}_{z} + r^{z\pi}_{z}\sigma_{z\pi}\right)\right] \qquad \frac{\partial \tilde{v}^{c}(\cdot)}{\partial \bar{\pi}^{f}} = -\ell^{f}\left[1 - 0.5\left(r^{z}_{z}\sigma^{2}_{z} + r^{z\pi}_{z}\sigma_{z\pi}\right)\right] - r^{z\pi}_{\pi}\sigma_{z\pi}$$

$$\frac{\partial \tilde{v}^{c}(\cdot)}{\partial \sigma^{2}_{z}} = -0.5\left(r^{z} + r^{z}_{\sigma}\sigma^{2}_{z}\right) - r^{z\pi}_{\sigma}\sigma_{z\pi}$$

(iii) ***Curvature and separability:*** *If $u^{c}(\cdot)$ exhibits DARA, then $\tilde{v}^{c}\left(p^{c}, w^{o}, \bar{\pi}^{f}, \bar{Z}\right)$ is quasi-convex in its arguments and weakly separable between the* price block (p^{c}, w^{o}) *and the income-risk block $\left(\bar{\pi}^{f}, \bar{Z}\sigma^{2}_{z}, \sigma_{z\pi}\right)$. Since $\tilde{v}^{c}(\cdot)$ is a potential from a smooth maximization, Young's symmetry holds and reciprocity conditions apply.*

Proposition 2 characterises the fundamental envelope derivatives of the consumption-side CE problem, namely the marginal value of full income and the marginal effect of the shadow return on welfare. These results hold for any process that perturbs $\bar{Z}$ or $\bar{\pi}^{f}$ and are independent of the specific mechanism through which the policy variable D enters the economic environment. In the model developed here, however, the decoupled payment D influences the farm household through multiple channels: it contributes autonomously to full income, raises the producer's effective wealth and thus alters risk preferences, and modifies the mean shadow return to on-farm labour. Proposition 3 next combines the envelope derivatives established in Proposition 2 with these structural channels to obtain the complete welfare effect of D.[12]

Proposition 3 *Building on the envelope derivatives established in Propositions 1 and 2, consider the case where the decoupled payment D affects the household through three channels: (i) as autonomous income on the consumption side, (ii) through the production-side wealth term $W^{D}_{0} = W_{0} + \theta D$ entering producer risk preferences r^{w}, and (iii) through the coupled component θD that shifts the mean shadow return $\bar{\pi}^{f}(\cdot)$ in the production block. Let*

$$\tilde{V}(\cdot) \equiv \tilde{v}^{p}(\cdot) + \tilde{v}^{c}(\cdot)$$

denote the household's total CE welfare. Using the marginal valuation of full household income and initial farm wealth,

$$\frac{\partial \tilde{v}^{c}(\cdot)}{\partial \bar{Z}} = 1 - 0.5\left(r^{z}_{z}\sigma^{2}_{z} + r^{z\pi}_{z}\sigma_{z\pi}\right), \qquad \frac{\partial \tilde{v}^{p}(\cdot)}{\partial \bar{W}^{d}_{0}} = 1 - 0.5 r^{w}\sigma^{2}_{w},$$

[12]The proof is presented in Appendix D.

and the envelope derivative with respect to the shadow return,

$$\frac{\partial \tilde{v}^{\,c}(\cdot)}{\partial \bar{\pi}^f} = -\,\ell^{\,f}\frac{\partial \tilde{v}^{\,c}(\cdot)}{\partial \bar{Z}} - r_{\pi}^{z\pi}\sigma_{z\pi}, \qquad \ell^{\,f} = T^H - x^f,$$

then, holding all risk primitives fixed, the total welfare impact of D is given by

$$\frac{d\tilde{V}(\cdot)}{dD} = \underbrace{\theta\Big(1 - 0.5\, r^w \sigma_w^2\Big)}_{\textit{production wealth/risk channel}} + \underbrace{(1-\theta)\,\frac{\partial \tilde{v}^{\,c}(\cdot)}{\partial \bar{Z}}}_{\textit{autonomous income}} + \underbrace{\Big[x^f\,\frac{\partial \tilde{v}^{\,c}(\cdot)}{\partial \bar{Z}} - r_{\pi}^{z\pi}\sigma_{z\pi}\Big]\,\frac{\partial \bar{\pi}^{\,f}}{\partial D}}_{\textit{technology/liquidity channel}}$$

The above expression summarises the full welfare impact of D when the coupled portion θD simultaneously alters producer risk preferences and the production technology, thereby influencing both the deterministic and risky components of household income.

Although decoupled payments D are administratively designed to be production-neutral, in a non-separable agricultural household setting they affect behavior and welfare through three distinct channels. First, the non-productive share $(1-\theta)D$ enters full income directly and therefore generates a pure income effect on consumption and labor-leisure choices. Second, the coupled share θD augments effective initial wealth W_0, reducing the household's absolute risk aversion in the producer's CE problem and thus attenuating the magnitude of the risk premium. Third, the same coupled component θD acts as a technological or liquidity shifter in the production block, relaxing working-capital constraints or enhancing productive capacity, thereby modifying the mean shadow return to on-farm labor. The interaction of these three channels implies that even nominally decoupled transfers may have nontrivial and nonlinear effects on household decisions and welfare.

The Practical Problem

Functional Representations

To make the non-separable agricultural household model operational, we need to impose a specific parametric specification for the certainty-equivalent functions in (5) and (10). In this respect, we rely on the *Normalized Quadratic* (NQ) flexible functional form introduced by Diewert and Wales (1987) as a globally regular flexible form consistent with duality theory. Its consistency make it particularly suitable for empirical systems derived from the certainty-equivalent representation of expected utility, since the same quadratic structure applies to both mean and variance terms (Coyle, 1992, 1999). Considering first, household's production decisions, under CRRA the mean (risk-neutral) NQ profit per unit per unit of on-farm labour takes the following general form:

$$\bar{\pi}^f(p^y, w^v, \theta D) = \beta_0 + \sum_{m=1}^{M}\left(\beta_m^y + 0.5\sum_{h=1}^{M}\beta_{mh}^{yy}p_h^y + \sum_{j=1}^{J-1}\beta_{mj}^{yv}w_j^v + \beta_m^{yd}\theta D\right)p_m^y + \sum_{j=1}^{J-1}\left(\beta_j^v + 0.5\sum_{l=1}^{J-1}\beta_{jl}^{vv}w_l^v + \beta_j^{vd}\theta D\right)w_j^v \tag{11}$$

Symmetry and reciprocity property imply that $\beta_{mh}^{yy} = \beta_{hm}^{yy}$ and $\beta_{jl}^{vv} = \beta_{lj}^{vv}$.

For the risk aversion function we follow the simple standard CRRA-based mean-variance duality framework (Coyle, 1992, 1999):

$$r^w = \frac{\xi^w}{\bar{W}}, \quad \bar{W} = W_0^D + x^f\bar{\pi}^f \quad \text{and} \quad W_0^D = W_0 + \theta D \tag{12}$$

where W_0^D is effective initial wealth including policy transfers. Under this specification, the *Arrow-Pratt* coefficient declines proportionally with wealth, ensuring that the certainty-equivalent value function remains linearly homogeneous in all monetary arguments. Then using relations (11) and (12), the producer's (indirect) money-metric certainty-equivalent value function can be expressed from:

$$\tilde{v}^p\left(p^y, w^v, d; x^f, W_0, D\right) = W_0^D + x^f\bar{\pi}^f(p^y, w^v, \theta D) - 0.5\, r^w\left(\bar{W}\right)\sigma_w^2 \tag{13}$$

where $\sigma_w^2 = \left(x^f\right)^2\sum_m\sum_h y_m(\cdot)\,V_{mh}^p\,y_h(\cdot)$ with $y(\cdot)$ being the optimal supply crop quantities implied by the mean (risk-neutral) NQ profit function.[13] Applying the envelope theorem to $\tilde{v}^p(\cdot)$ yields the derivatives of Proposition 1 per unit of on-farm labour:

$$\frac{y_m}{x^f} = \left[\beta_m^y + \sum_{h=1}^{M}\beta_{mh}^{yy}p_h^y + \sum_{j=1}^{J-1}\beta_{mj}^{yv}w_j^v + \beta_m^{yd}\theta D - r^w x^f\sum_{h=1}^{M}\sum_{k=1}^{M}\beta_{hm}^{yy}\,V_{hk}^p\,y_k\right] \times R_W^{-1} \tag{14}$$

$$-\frac{x_j^v}{x^f} = \left[\beta_j^v + \sum_{m=1}^{M}\beta_{mj}^{yv}p_m^y + \sum_{l=1}^{J-1}\beta_{jl}^{vv}w_l^v + \beta_j^{vd}\theta D - r^w\, x^f\sum_{h=1}^{M}\sum_{k=1}^{M}\beta_{hj}^{yv}\,V_{hk}^p\,y_h\right] \times R_W^{-1} \tag{15}$$

[13] Applying the envelope theorem we differentiate the certainty-equivalent conditional profit function with respect to the exogenous crop price. We can hold the optimal choices constant, except where those choices enter through the direct dependence of the objective on them as it happens with the variance term σ_w^2. However, there's no need to re-optimize under risk, because the certainty-equivalent adjustment is applied ex post to the mean solution (Just and Pope, 1979).

$$\bar{\pi}^f = \left[\beta_0 + \sum_{m=1}^{M}\left(\beta_m^y + 0.5\sum_{h=1}^{M}\beta_{mh}^{yy}p_h^y + \sum_{j=1}^{J-1}\beta_{mj}^{yv}w_j^v + \beta_m^{yd}\theta D\right)p_m^y \right. \\ \left. + \sum_{j=1}^{J-1}\left(\beta_j^v + 0.5\sum_{l=1}^{J-1}\beta_{jl}^{vv}w_l^v + \beta_j^{vd}\theta D\right)w_j^v - r^w x^f \sum_{h=1}^{M}\sum_{k=1}^{M}\beta_{hm}^{yy}V_{hk}^p y_k\right] \times R_W^{-1} \tag{16}$$

where $R_W \equiv \dfrac{\partial \tilde{v}^p(\cdot)}{\partial W_0^D} = \left(1 + 0.5\dfrac{\xi^w}{\bar{W}^2}\sigma_w^2\right)$ is the envelope derivative with respect to W_0^D. Linear homogeneity is imposed by dividing all prices above with the price of the last variable input used as numeraire. Thus, only $J-1$ equations from variable inputs demands are used in the econometric estimation. The parameters of the last equation are recovered from the parameter restrictions due to linear homogeneity.

Turning now to the consumption side of farm households, the risk-neutral normalized quadratic indirect utility function takes the following form:

$$\bar{v}^c(p^c, w^o, \bar{\pi}^f) = \delta_0 + \delta_w w^o + \delta_\pi \bar{\pi}^f + \delta_c p^c + 0.5\left[\delta_{ww}(w^o)^2 + \delta_{\pi\pi}(\bar{\pi}^f)^2 + \delta_{cc}(p^c)^2\right] \\ + \delta_{w\pi} w^o \bar{\pi}^f + \delta_{wc} w^o p^c + \delta_{\pi c}\bar{\pi}^f p^c \tag{17}$$

Again, we adopt the simple CRRA mean variance duality framework to proxy the two risk aversion function appearing in the consumption side of rural households:

$$r^z = \frac{\xi^z}{\bar{Z}}, \quad r^{z\pi} = \frac{\xi^{z\pi}}{\bar{Z}} \quad \text{and} \quad \bar{Z} = I_0 + (1-\theta)\,D + T^H\left(\bar{\pi}^f + w^o\right) \tag{18}$$

Finally, using (17) and (18), the full income certainty equivalent indirect utility function can be expressed from the following relation:

$$\tilde{v}^c(p^c, w^o, \bar{\pi}^f; Z, \sigma_z^2, \sigma_{z\pi}) = \bar{Z} + \bar{v}^c\left(p^c, w^o, \bar{\pi}^f; Z\right) - 0.5\, r^z\left(\bar{Z}\right)\sigma_z^2 - r^{z\pi}\left(\bar{Z}\right)\sigma_{z\pi} \tag{19}$$

where $\sigma_z^2 = (\ell^f)^2 \sum_m \sum_h y_m(\cdot)\, V_{mh}^p\, y_h(\cdot)$ and $\sigma_{z\pi} = \ell^f \sum_m \sum_h y_m(\cdot)\, V_{mh}^p\, y_h(\cdot)$ following the linearization of $\tilde{\pi}_f$ in prices and the full-income identity in (18).

Applying the *Roy's* identity, the on- and off-farm labour supply and household income equations are given from:

$$-\left(T^H - x^o\right) = \left(\delta_w + \delta_{wc}p^c + \delta_{ww}w^o + \delta_{w\pi}\bar{\pi}^f\right) \times R_Z^{-1} \tag{20}$$

$$-\left(T^H - x^f\right) = \left(\delta_\pi + \delta_{\pi c}p^c + \delta_{\pi w}w^o + \delta_{\pi\pi}\bar{\pi}^f\right) \times R_Z^{-1} \tag{21}$$

$$c = -\left(\delta_c + \delta_{cc}p^c + \delta_{cw}w^o + \delta_{c\pi}\bar{\pi}^f\right) \times R_Z^{-1} \tag{22}$$

with

$$R_Z \equiv \frac{\partial \tilde{v}^c(\cdot)}{\partial \bar{Z}} = 1 + 0.5\left(\frac{\xi^z}{\bar{Z}^2}\sigma_z^2 + \frac{\xi^{z\pi}}{\bar{Z}^2}\sigma_{z\pi}\right) \tag{23}$$

Symmetry restrictions imply that $\delta_{\pi w} = \delta_{w\pi}$, $\delta_{cw} = \delta_{wc}$ and $\delta_{c\pi} = \delta_{\pi c}$. To impose linear homogeneity of the indirect utility in monetary arguments, all prices and full income are normalized by the aggregate-good price. The NQ indirect utility is estimated in the relative price vector and relative income. The parameters of the numeraire (consumption-good) equation are recovered from the homogeneity conditions.

Finally, to allow for heterogeneity in the behavioural coupling of payments across farms, θ_i is parameterised using a logit function that maps observable structural characteristics of the farm into the interval $(0, 1)$:

$$\theta = \left[1 + \exp\left(-\sum_{s=1}^{S} \zeta_s z_s\right)\right]^{-1} \tag{24}$$

where $z \in \Re_+^S$ is a vector of exogenous variables affecting households allocation of transfer payments. The above relation is plugged into equations (14)-(16) and (20)-(20) to obtain individual farm shares of decoupled payments that are linked to farm production activities.

The parameter θ_i should not be interpreted as an observed accounting share of the transfer mechanically spent on farm inputs. Rather, it represents a latent *behavioural coupling index* that measures the extent to which nominally decoupled support enters the production block through wealth, risk, and liquidity mechanisms implied by the agricultural household model. In the theoretical framework developed above, the payment D_i is allocated between two conceptually distinct channels. The component $\theta_i D_i$ augments effective farm wealth and therefore shifts the producer-side certainty-equivalent profit function through both wealth and risk-preference effects, while the remaining component $(1 - \theta_i)D_i$ enters household full income as autonomous income on the consumption side. Hence θ_i captures the behavioural fraction of the transfer that becomes economically coupled with production decisions.

Identification of θ_i follows from the joint restrictions imposed by the nonseparable household structure on the production and consumption systems. Because the payment D_i appears simultaneously in the producer wealth term, in the restricted profit function, and in the household full-income expression, the extent to which transfers affect input demand, labour allocation, and consumption choices provides information on the allocation of the payment between the two channels. In this sense, θ_i is not identified from a single reduced-form equation but from the cross-equation restrictions implied by the structural agricultural household model.

Farm Survey Data

All data were obtained through a primary survey within the context of the Research Program *Biovalue* financed by the *European Commission* during the 2021-25 period.[14] The stratified sample consists of 509 randomly selected multi-output farms located in the Greek NUTS II region of Central Macedonia for the 2020-21 cropping year. Using *Agricultural Census* and data from local *Extension Agencies*, farms in the area were stratified according to their size and specialization. Surveyed farmers were asked to recall key variables related to their farming operation in the same year (i.e., production patterns, input use, gross revenues, irrigation water use and cost, structural characteristics, assets, liabilities, production quotas and subsidies, including those connected with the application of CAP measures). All information was collected using questionnaire-based field interviews. All 509 rural holdings based exclusively on household members for their operation producing all crop outputs considered (*i.e.*, no hired labor). Further, all sample participants exhibit non-zero hours of work off-farm implying the absence of corner solutions either for outputs produced or for off-farm working hours.

We consider three crop outputs, *i.e.*, *wheat*, *cotton* and *corn*, for which arable CAP regime ensures different levels of area payments and three variable inputs, (*i.e.*, *seeds*, *chemical fertilizers* and *intermediate inputs*). Output includes quantities sold off the farm plus quantities consumed in farm households during the cropping year. The price of each crop is that obtained by the farmer at the date that farm production is sold to the market, subtracting indirect taxes. Farmers utilize a mixture of chemical fertilizers depending on the soil quality and specific needs of their trees. These include nitrate, phosphorous, and potassium fertilizers that are applied during the cropping season. The aggregate price of fertilizers was computed using a *Divisia index* with the cost shares of each one of the different fertilizers used as weights. Finally, the intermediate input consists of goods used in crop production during the cropping year, whether purchased from outside the farm or withdrawn from beginning inventories.These include fuel and electric power, storage expenses, and irrigation water, measured in Euros. Again the aggregate price of intermediate inputs was computed using *Divisia* methods.

The survey also includes data on the number of hours of off-farm work for household members, the number of hours worked on-farm, the off-farm wage rate and, the household's non-labor income. Total short-run profits have been computed as the sum of total gross sales minus total variable costs divided by hours worked on-farm. Non-labor household income was measured as the asset income generated from off-farm investments, assuming a 6 percent rate of return. Household off-farm wage rate was calculated as the weighted average of individual wage rates (husband, wife and spouses)

[14] The Biovalue project (*Fork-to-farm agent-based simulation tool augmenting biodiversity in the agri-food value chain*) was financed within the H2020 Programme under Biodiversity in action: Across farmland and the value chain.

with hours of work off-farm used as weights. Initial farm wealth has been approximated by the value of farm equity also provided by the survey. For the price of aggregate marketed good, we use a regional-specific consumer price index published by the *Greek Statistical Service*. Finally, total decoupled payments are obtained from the survey which according to the current CAP regime are awarded to all farmers producing cereals oilseeds and protein crops. The payment varies by region and crop and is computed multiplying a fixed per ton amount by a regional historical yield and then by the acreage declared each year by farmers sowing eligible crops. In order to access full amount, the total land allocated to program crops cannot exceed a fixed national base acreage.

In order to generate the variance-covariance matrix for crop prices we used the adaptive expectation hypothesis of Chavas and Holt (1990, 1996). Specifically, the untruncated crop price at time t is defined as the market price of the previous year plus the sample mean of the past difference between observed prices and naive expected prices (*i.e.*, prices in the previous period) as:

$$E\left(p^y_{mit+1}\right) = p^y_{mit} + E\left(p^y_{mit} - p^y_{mit-1}\right)$$

Similarly untruncated price variance is computed by taking a weighted sum of the squared deviations of past prices from their expected prices as:

$$Var\left(p^y_{mit}\right) = \sum_{j=1}^{3} \gamma_j \left[p^y_{mit-j} - E_{t-j-1}\left(p^y_{mit-j}\right)\right]$$

where γ_j are the three lag weights defined as 0.50, 0.33 and 0.17.[15] Individual price covariances were estimated in a similar way. The above approach actually presumes that price risk is measured as the squared deviation of past prices from their expected values with declining weights.

Finally, to identify the farm-specific coupling share, the logit index is parameterized using structural and financial characteristics that are exogenous to the NQ production and consumption system, ensuring valid exclusion restrictions. Two structural variables are included. First, *farm size* measured as the total utilized agricultural area. Larger farms have greater scope for technological adjustment and are therefore more likely to divert part of the decoupled transfer toward productive uses. Second, the *liquidity ratio* defined as current assets over short term liabilities, with lower ratios indicating stronger internal liquidity constraints and therefore a greater marginal value of allocating part of the decoupled payment to production. Taken together, these two exogenous variables provide a theoretically consistent and empirically credible basis for explaining heterogeneity in behavioral coupling across farms.

[15]The same values have been used in all previous studies adopting Chavas and Holt (1990) approach assuming three lags for current price determination.

Empirical Results

Equations in (14)–(16) and (20)–(22) define a simultaneous system describing the joint production and consumption decisions of agricultural households. Intermediate input prices and the aggregate marketed good were used as numeraire prices in imposing linear homogeneity on the production and consumption systems, respectively. The resulting nonlinear system was estimated jointly using nonlinear least squares with bootstrap standard errors. The estimated household system satisfies the theoretical regularity conditions implied by the certainty-equivalent dual representation. The production-side profit function was conditionally convex in normalized prices, while the indirect utility function satisfied the corresponding quasi-convexity conditions. Overall, the estimated structural parameters reported in Table 1 display economically plausible signs and magnitudes, generating downward-sloping input demand schedules, positive own-price supply responses, and theoretically consistent labour-allocation behaviour.

The estimated *Arrow–Pratt* risk-aversion coefficients are positive and statistically significant across all specifications, providing strong empirical support for the certainty-equivalent representation adopted in the paper. As reported in Table 2, the average production-side relative risk-aversion coefficient is estimated at $r_w = 0.1138$, while the corresponding consumption-side coefficients are $r_z = 0.0057$ and $r_{z\pi} = 0.0023$. The estimates further indicate that production-side risk aversion declines monotonically across farm-size quartiles, from 0.1332 for the smallest farms to 0.0966 for the largest, consistent with greater risk-bearing capacity among larger holdings. These magnitudes imply economically meaningful responses to output-price uncertainty, indicating that farm households behave as risk-sensitive decision makers rather than risk-neutral profit maximizers.

The estimated *Marshallian* netput elasticities reveal economically plausible behavioural responses across both outputs and variable inputs (Table 3). Output supply elasticities with respect to own prices are positive and relatively large, ranging from 0.7606 for wheat to 0.7998 for cotton and 0.7970 for corn, while variable input demand elasticities with respect to own prices are negative, varying between −0.3999 for fertilizers and −0.4495 for intermediate inputs. Cross-price effects remain moderate in magnitude, suggesting limited substitution possibilities across production activities and variable inputs. The estimated *Morishima* elasticities of transformation range from −0.9022 to −0.9539, indicating that output reallocation across crop activities is relatively inelastic and that farm households face important technological constraints when adjusting production portfolios in response to changing price signals. Similarly, the estimated *Morishima* elasticities of substitution for variable inputs range between 0.3459 and 0.4339, implying moderate substitution possibilities across inputs.

The estimated conditional *Marshallian* elasticities for the consumption block also display economically plausible magnitudes (Table 4). Off-farm labour supply responds positively to increases in the off-farm wage rate, with an elasticity of 0.5036, while on-farm labour supply responds positively to increases in the shadow return to farm labour, with an elasticity of 0.6886. Cross-effects between farm and off-farm labour allocation margins are negative, indicating that labour reallocates across activities when relative returns change. The estimated aggregate marketed good demand elasticities with respect to both the off-farm wage and the shadow farm return are positive, at 0.1840 and 0.1961, respectively, while the estimated own-price elasticity of aggregate consumption is -1.7503. Economically, these findings imply that farm households allocate labour across farm and off-farm activities according to relative certainty-equivalent returns rather than observed market wages alone. Because the shadow return to on-farm labour embeds both expected profitability and output-price risk exposure, changes in crop-market conditions propagate directly into labour allocation and consumption behaviour.

The estimated full-income elasticities further indicate that increases in certainty-equivalent income primarily operate through reduced labour supply and increased marketed consumption. In particular, the estimated income elasticities are -0.7258 for off-farm labour, -0.6966 for on-farm labour, and 1.3661 for aggregate marketed consumption. These findings support the theoretical prediction that the full-income channel jointly affects marketed consumption and labour–leisure decisions within a nonseparable household setting. The compensated *Hicksian* elasticities further confirm the presence of a stable substitution structure within the household allocation system. After controlling for income effects, own compensated labour-supply elasticities remain positive, with values of 0.5762 for off-farm labour and 0.7583 for on-farm labour, while compensated cross-effects remain negative. Similarly, the compensated elasticity of aggregate consumption with respect to its own price remains strongly negative at -2.8432, whereas compensated responses to labour returns remain positive. These results indicate that substitution effects remain economically meaningful even after controlling for wealth effects generated through certainty-equivalent income adjustments.

The unconditional elasticities reveal the central mechanism underlying the endogenous coupling effects generated by the model. Changes in crop and variable input prices affect household labour allocation and consumption behaviour indirectly through their effects on the shadow return to on-farm labour and the associated full-income channel. In particular, increases in crop prices generate positive unconditional responses for aggregate consumption, with elasticities close to 0.63 across all crop prices, while on-farm labour responds positively and off-farm labour negatively. Conversely, increases in variable input prices reduce aggregate marketed consumption and on-farm labour supply while increasing off-farm labour allocation. Although decoupled payments are formally disconnected from contemporaneous production decisions, the estimated shadow-wage and risk-transmission mechanisms generate indirect behavioural responses through household labour allocation and certainty-equivalent wealth effects.

Finally, the welfare decomposition results highlight the central theoretical mechanism developed in the paper, namely that nominally decoupled payments affect household behaviour simultaneously through wealth, risk, and endogenous shadow-wage channels. As reported in Table 5, the autonomous income channel accounts for 47.1% of the total certainty-equivalent welfare effect of transfer payments, followed by the production-side wealth/risk channel at 39.8%, while the technology/liquidity channel operating through the endogenous shadow wage accounts for an additional 13.1%. The corresponding welfare effects are estimated at 0.5280, 0.4462, and 0.1469, respectively, yielding a total certainty-equivalent welfare effect of 1.1211. Increases in the effective wealth term $W_0^D = W_0 + \theta D$ reduce the magnitude of the producer-side risk premium by lowering the *Arrow–Pratt* measure of absolute risk aversion under the CRRA specification. Consequently, higher transfer payments attenuate the effective variance penalty in the certainty-equivalent producer problem and increase risk-adjusted farm profitability, thereby generating stronger production incentives even though the transfer is administratively decoupled from current production choices.

The empirical results further indicate that the autonomous income component $(1 - \theta)D$ exerts substantial effects on household consumption and labour allocation decisions through the full-income channel. Increases in certainty-equivalent household income raise aggregate marketed consumption while simultaneously reducing labour supply through leisure-income effects. Because the shadow wage enters both the deterministic full-income component and the covariance-based risk premium of the consumption-side certainty-equivalent function, changes in farm profitability propagate directly into labour allocation and consumption behaviour. The results therefore provide strong evidence in favour of the technology/liquidity channel emphasized in Proposition 3 and support the central argument of the paper that decoupled agricultural support remains partially behaviourally coupled once risk exposure, shadow labour returns, and certainty-equivalent wealth effects are jointly incorporated into the agricultural household framework.

Concluding Remarks

This paper developed and estimated a certainty-equivalent agricultural household model integrating production, labour allocation, and consumption decisions under output-price uncertainty. By combining a normalized quadratic certainty-equivalent profit function with a certainty-equivalent indirect utility representation, the analysis provided a unified framework linking production risk, endogenous shadow wages, and household welfare. The empirical results indicate that agricultural households behave as risk-sensitive decision makers and that uncertainty exerts economically meaningful effects on both production incentives and household allocation decisions. The estimated elasticities and welfare decompositions reveal that crop-price shocks propagate through the endogenous shadow return to on-farm labour, thereby affecting labour allocation, marketed consumption, and certainty-equivalent household welfare. In this setting, nominally decoupled transfers influence behaviour not only through direct wealth effects but also through endogenous adjustments in risk exposure and shadow labour returns.

More broadly, the findings provide empirical support for the argument that decoupled agricultural support may remain partially behaviourally coupled in the presence of uncertainty, nonseparability, and imperfect rural markets. The welfare decomposition results indicate that autonomous income effects, production-side wealth/risk effects, and technology/liquidity channels jointly shape the overall impact of transfer payments on household behaviour. In particular, the results suggest that decoupled support relaxes liquidity constraints, attenuates effective variance penalties, and modifies labour allocation incentives through changes in farm profitability. These findings have important policy implications, as they imply that the behavioural neutrality of decoupled payments critically depends on the extent of market completeness and the degree of household exposure to production risk. Future research could extend the framework by incorporating dynamic asset accumulation, multiple sources of uncertainty, or heterogeneous expectations in order to further examine the long-run interaction between agricultural policy, household welfare, and production behaviour under risk.

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Tables and Figures

Table 1: Parameter Estimates of the NQ Household Model

Crop Supply Equations								
	constant	p_{wh}	p_{ct}	p_{cr}	w_s	w_f	w_e	D
Wheat	0.9231	0.7836	-0.1451	-0.1609	-0.1961	-0.1675	-0.1141	0.0566
	(0.0527)	(0.0108)	(0.0385)	(0.0208)	(0.1011)	(0.0011)	-	(0.0113)
Cotton	0.8671	-	0.8236	-0.1578	-0.1641	-0.1784	-0.1782	0.0416
	(0.1027)	-	(0.0509)	(0.0008)	(0.0311)	(0.0111)	-	(0.0212)
Corn	0.8306	-	-	0.8208	-0.1391	-0.1482	-0.2147	0.0419
	(0.0427)	-	-	(0.0610)	(0.0211)	(0.0412)	-	(0.0044)
Input Demand Equations								
Seeds	-0.4593	-	-	-	0.4484	0.0426	0.0083	0.0827
	(0.0543)	-	-	-	(0.1023)	(0.0015)	-	(0.0125)
Fertilizers	-0.3618	-	-	-	-	0.4102	0.0412	0.0860
	(0.0740)	-	-	-	-	(0.0219)	-	(0.0225)
Intermediate	-0.7997	-	-	-	-	-	0.4575	0.1223
	-	-	-	-	-	-	-	(0.0194)
Labor Supply and Aggregate Good Demand Equations								
	constant	w_o	$\bar{\pi}^f$	p_c				
Off-farm labor	0.3206	0.8037	-0.1204	-0.6833				
	(0.0455)	(0.1004)	(0.0473)	-				
On-farm labor	0.3211	-	0.8033	-0.6830				
	(0.0311)	-	(0.0614)	-				
Agg. Good	0.3583	-	-	1.3662				
Risk Primitives				*Logit model*				
	ξ^w	ξ^z	$\xi^{z\pi}$		ζ_s	ζ_l		
	-2.2342	-5.1779	-6.0669		-0.1334	0.0297		
	(0.4289)	(0.2164)	(0.6234)		(0.0171)	(0.0106)		

where p_{wh} is the wheat price, p_{ct} is the cotton price, p_{cr} is the corn price, w_s is the price of seeds, w_f is the fertilizer price and w_e is the price of intermediate inputs. The corresponding standard errors in parentheses are obtained using non-parametric bootstrap.

Table 2: Estimated Relative Risk Aversion Coefficients

Farm size quartiles	r^w	r^z	$r^{z\pi}$
1st	0.1332	0.0058	0.0024
2nd	0.1175	0.0057	0.0023
3rd	0.1077	0.0057	0.0023
4th	0.0966	0.0056	0.0023
Average	0.1138	0.0057	0.0023

Table 3: Estimated Production Elasticities

	p_{wh}	p_{ct}	p_{cr}	w_s	w_f	w_e
Marshallian Crop Supply Elasticities						
Wheat	0.7606	-0.1414	-0.1569	-0.1912	-0.1632	-0.1112
Cotton	-0.1416	0.7998	-0.1539	-0.1601	-0.1740	-0.1737
Corn	-0.1571	-0.1540	0.7970	-0.1358	-0.1446	-0.2095
Marshallian Variable Input Demand Elasticities						
Seeds	0.1908	0.1629	0.1110	-0.4373	-0.0415	-0.0081
Fertilizers	0.1597	0.1735	0.1733	-0.0415	-0.3999	-0.0402
Intermediate	0.1367	0.1455	0.2108	-0.0081	-0.0405	-0.4495
Hicksian Variable Input Demand Elasticities						
Seeds	-	-	-	-0.2786	0.1139	0.1559
Fertilizers	-	-	-	0.1282	-0.2320	0.1125
Intermediate	-	-	-	0.1554	0.1219	-0.2786
Morishima Elasticities of Transformation						
	Wheat	Cotton	Corn			
Wheat	-	-0.9412	-0.9539			
Cotton	-0.9022	-	-0.9509			
Corn	-0.9177	-0.9538	-			
Morishima Elasticities of Substitution						
	Seeds	Fertilizers	Intermediate			
Seeds	-	0.3459	0.4245			
Fertilizers	0.4068	-	0.4111			
Intermediate	0.4339	0.3538	-			

where p_{wh} is the wheat price, p_{ct} is the cotton price, p_{cr} is the corn price, w_s is the price of seeds, w_f is the fertilizer price and w_e is the price of intermediate inputs. All risk primitives were held fixed in the calculation of elasticities.

Table 4: Estimated Consumption Elasticities

	w^o	π^f	p_c	Income
Marshallian Elasticities conditional on π^f				
Aggregate Good	0.1840	0.1961	-1.7503	1.3661
On-farm labor	-0.2475	0.6886	0.2575	-0.6966
Off-farm labor	0.5036	-0.3660	0.5832	-0.7258
Hicksian Elasticities conditional on π^f				
Aggregate Good	0.0473	0.0595	-2.8432	-
On-farm labor	-0.1778	0.7583	0.8148	-
Off-farm labor	0.5762	-0.2934	1.1638	-
Unconditional Marshallian Elasticities w.r.t. crop prices				
	p_{wh}	p_{ct}	p_{cr}	
Aggregate Good	0.6262	0.6257	0.6264	
On-farm labor	0.4163	0.4030	0.2329	
Off-farm labor	-0.4287	-0.4278	-0.4297	
Unconditional Marshallian Elasticities w.r.t. input prices				
	w_s	w_f	w_e	
Aggregate Good	-0.6168	-0.5973	-0.3489	
On-farm labor	-0.3384	-0.3311	-0.1852	
Off-farm labor	0.3123	0.3636	0.3435	

where w^o is the off-farm wage rate, π^f are farm unit profits, p_c is the price of aggregate marketed good, p_{wh} is the wheat price, p_{ct} is the cotton price, p_{cr} is the corn price, w_s is the price of seeds, w_f is the fertilizer price and w_e is the price of intermediate inputs. All risk primitives were held fixed in the calculation of elasticities.

Table 5: CE Welfare Effect of Decoupled Payments

Channel	WE	%
Wealth/Risk on production	0.4462	39.8
Autonomous income on consumption	0.5280	47.1
Technology/Liquidity via $\bar{\pi}^f$	0.1469	13.1
Total	1.1211	100.0