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Data description
households in developing countries are ill-equipped to face shocks, mostly covariant shocks that make risk sharing agreements only partially effective

empirical evidence on use of livestock as a buffer asset to smooth consumption is not conclusive: yet concern of losing productive assets may inhibit distress sales of livestock (Fafchamps et al. 1998, Carter-Zimmerman 2003)

households in anticipation of such outcomes may choose less risky technologies and portfolios to avoid permanent damage (Dercon-Christiaensen, 2007)

under subsistence and liquidity constraints optimal portfolio strategies can bifurcate: wealthier agents may opt for high return-risk activities, whilst poor ones are stuck in low return-risk portfolios (Rosenzweig-Wolpin 1993, Dercon 1998)
risk induced poverty traps may emerge (Carter-Zimmerman, 2003)

empirical evidence from both direct elicitation and observed production behaviour suggests that on average farmers exhibit DARA risk preferences (Dillon-Scandizzo 1978, Binswanger 1980, Chavas-Holt 1990)

incomplete markets break down separability between production and consumption decision (Fafchamps-Kurosaky, 2002)
Relevant literature

- risk and insurance (Townsend 1994, Udry 1995)
- vintage capital approach (Akyiama-Trivedi 1987, Weaver 1989)
- investment decisions under uncertainty and adjustment costs (Dixit-Pindyck 1994, Hill 2006)
Objectives

▶ investigate the determinants of crops portfolio and investment decisions by farmers in a resource-poor environment, under price and yield risk, where markets for credit and insurance are either incomplete or missing

▶ assess how risk-coping strategies affect farm households, heterogeneous in the ability of bearing risk, in choosing the composition of their crops portfolio and in undertaking risky investment

▶ set up a model of production choices from which structural estimates of implicit risk and time preference parameters are derived

▶ verify whether there is a latent demand for crop insurance and credit

▶ account for the perennial nature of tree crops, embedding an investment problem into the model
Objectives

- address the non-separability of production and consumption choices by jointly estimating a supply and demand system for large and small producers
- fit the model to longitudinal data from a sample of coffee producers in Ethiopia
- simulate the effects on welfare of alternative policies affecting the realization of shocks
Approach and limitations

- expected utility framework
- no explicit treatment of downside risk and precautionary saving, focus on first two moments (Kimball, 1990)
- no disentangling of risk aversion and elasticity of intertemporal substitution (Epstein-Zin, 1989)
Assumptions

- labour market is not modeled: off-farm employment is rare and occurs mainly through labour sharing agreements
- no treatment of households’ labour supply
- land market is neglected as land is state owned and transactions are prohibited by law; yet, perceived land rights are shown to be an important factor in investment decisions (Dercon et al., 2007)
- formal insurance and credit markets are absent except for working capital inputs under government guarantees
Objective function

\[ V_t = E_t \sum_{t=0}^{T} \beta^t u(c_t, z^h) \quad t = 0, 1, \ldots, T \]  

Welfare is defined over a finite time horizon \( T \), as the expected value of an intertemporally additive utility function in the consumption of a basket of goods \( (c_t) \), which may include staple crops, cash crops, animal and other non-food products, conditional on a vector of household characteristics \( z^h \).

Instantaneous utility \( u(.) \) is well behaved, with \( u'(.) > 0 \) and \( u''(.) < 0 \). Households discount future utilities over time according to the discount factor \( \beta = 1/(1 + \delta) \), where \( \delta \) is the time preference rate.
Household income

Total household income ($\pi_t$) is given by farm profits, either from cropping ($\pi^a_t$) or livestock rearing ($\pi^b_t$), as well as from other revenues ($\pi^w_t$) assumed to be exogenous, such as wage from off-farm work, profits from self-employment and remittances

$$\pi_t = \pi^a_t + \pi^b_t + \pi^w_t.$$ (2)

Livestock rearing:

$$\pi^b_t = p^b_t q^b_t - w^b_t L^b_t$$ (3)

where $q^b_t = F^b(B_t)$ is the quantity of livestock products, $B_t$ is the herding stock expressed in tropical livestock units at the beginning of period $t$, $w^b_t L^b_t$ are all livestock herding costs.
Crop cultivation:

$$\pi_t^a = \sum_{j=1}^{S} p_j^aq_j^t - w_tL_t^a - \sum_{j=1}^{S} p_t^x x_j^t$$  \hspace{1cm} (4)$$

where

$$q_j^t = \begin{cases} 
F_j(T_{j-1}^j, K_{t-1}^{jp}, x_{t-1}^j; z^q_t, \epsilon_t) & \forall j \in [1, s] \\
F_j(T_{j-1}^j, B_{t-1}, x_{t-1}^j; z^q_t, \epsilon_t) & \forall j \in (s + 1, S]
\end{cases}$$

and

$$K_{t-1}^{jp} = \sum_{v} \delta_v \theta_{t-1}^{jv} K_{t-1}^j$$  \hspace{1cm} (5)$$
Perennial crop modeling

Perennial crops exhibit a series of features which make the traditional framework unsuitable to modelling supply response, namely:

- the existence of a biological gestation lag between planting and obtaining yield during which supply conditions may change
- the bearing of significant adjustment costs related to the removal and planting of trees
- productivity of the trees varies systematically with age
- the heterogeneous nature of the tree stock, since age-yield profile and productive life depend on technical change and hence are not invariant with respect to the date (*vintage*) of the investment
staple crops in developing countries are always cultivated by small farmers to achieve food self-sufficiency (Fafchamps, 1992)

in fact, food markets are often thin and isolated, resulting in prices which are volatile and highly correlated with farmers’ own production patterns

cash crops provide a means to relax the household’s liquidity constraint because formal credit markets are absent

we may divide the crops into five categories: 1) coffee ($\theta^1_t$), the main cash crop; 2) cereals ($\theta^2_t$), such as wheat or teff, usually sold for cash; 3) enset ($\theta^3_t$), the main staple crop; 4) fruit and other trees ($\theta^4_t$); 5) other staples ($\theta^5_t$), usually not traded
## Crop portfolio

### Crop shares by land quantiles (Adado)

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<th>coffee</th>
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*Source: ERHS (round 4)*
Aggregation issues

- in addition to species homogeneity, aggregation of crops into categories is based on cross correlations of returns
- a cointegration analysis using regional producer prices provides guidance in the aggregation by looking at the covariant component of returns
- suitable consumption aggregates are identified using observed households expenditure shares
- the treatment of zero occurrences deserves special attention (use of homogeneous subsample, MSL estimation)
Figure: Monthly producer prices for food and cash crops (SSNPR region)
Land constraint:

\[ \sum_{j=1}^{S} T_t^j = \bar{T}_t \quad \text{or} \quad \sum_{j=1}^{S} \theta_t^j = 1 \]  

(6)

where \( \theta_t^j \) is the share of cultivated land allocated to the \( j^{th} \) crop category.

- we assume that livestock does not compete with agricultural cultivations for land
- land is available in limited amount and, for perennial crops, investment in new capacity \( k_t^j \) occurs mainly by uprooting the old stock and replanting new trees or substituting other cultivations
- a current, though declining, flow of income has therefore to be foregone against future higher revenues
Technology constraint:

\[ g(\theta^i_t, \alpha) = 0 \] (7)

where \( g(.) \) describes the agronomic interactions between agricultural activities. It is non-increasing in the arguments and concave.

Annual budget constraint:

\[ p^r_t c_t = y_t - p^b_t b_t - p^x_t x_t - p^k_t k_t \] (8)

Liquidity constraint:

\[ p^r_t c_t \leq \omega A_t - p^x_t x_t - p^k_t k_t \quad \forall r \in P \] (9)

where \( A_t = y_t + p^b_t B_t \) is the value of all liquidable assets, including livestock, \( \omega = 1 \) and \( P \) are purchased goods.
Perennial tree stock dynamics:

\[ K_{t+1}^{jp} = K_t^{jp} + k_t^j \quad \forall j \in [1, s] \quad (10) \]

with \(-k_t^j \leq K_t^j\). Livestock law of motion:

\[ B_{t+1} = (1 + n)B_t + b_t \quad (11) \]

where \(n\) is an exogenous growth rate and \(b_t\) are net purchases of livestock in the period, with \(-b_t \leq B_t\).
Timing of economic decisions

Time is divided into discrete intervals during which shocks occur and decisions are taken by households:

- at the beginning of the crop year $t$ income from harvested crop production, cattle rearing and other activities is observed, as well as consumption prices
- total income plus liquid assets determine household’s cash in hand ($y_t$) which can be: 1) spent on consumption ($c_t$); 2) saved in the form of livestock purchases ($b_t$); 3) used to maintain or expand production capacity through investments in capital stock ($k_t^i$)
- available land ($\bar{T}_t$) is allocated to $S$ competing crops
- households observe the prices of variable inputs (fertilizers, pesticides) and choose the amount to use in production ($x_t^i$)
Bellman equation

The model comprises the following control variables \((\theta^j_t, k^j_t, x^j_t, b_t)\) and state variables \((y_t, B_t, K^{jp}_t, p_t, \epsilon_t)\).

\[
V_t(y_t, B_t, K^{jp}_t, p_t, \epsilon_t) = \max_{\theta^j, k, b, x} \left\{ v(y_t, b_t, x^j_t, k^j_t, p_t) + \beta E_t V_{t+1}(y_{t+1}, B_{t+1}, K^{jp}_{t+1}, p_{t+1}, \epsilon_{t+1}) \right\}
\]

for \(t < T\), subject to (7), (9), the non-negativity constraints \(\theta^j_t, x^j_t, B_t, K^{jp}_t \geq 0\) and the transversality conditions

\[
B_{T+1} = 0 \quad K^{jp}_{T+1} = 0.
\]
Euler conditions

Since $v(.)$ and $V(.)$ are twice continuously differentiable, exploiting the Envelope Theorem, we differentiate the Bellman equation to get

\[
\frac{\partial V_t}{\partial \theta_t^j} : \beta E_t \left[ \frac{\partial V_{t+1}}{\partial y_{t+1}} p_{t+1}^j \frac{\partial F^j}{\partial \theta_t^j} \right] + \mu_{jt} - \lambda_t \frac{\partial g}{\partial \theta_t^j} = 0 \quad \forall j
\]

\[
\frac{\partial V_t}{\partial b_t} : - p_b^t \frac{\partial v_t}{\partial b_t} + \beta E_t \left[ \frac{\partial V_{t+1}}{\partial y_{t+1}} p_{t+1}^b \frac{\partial F^b}{\partial B_{t+1}} \right] + \eta_t p_b^t = 0
\]

\[
\frac{\partial V_t}{\partial x_t^j} : - p_x^t \frac{\partial v_t}{\partial x_t^j} + \beta E_t \left[ \frac{\partial V_{t+1}}{\partial y_{t+1}} p_{t+1}^j \frac{\partial F^j}{\partial x_t^j} \right] + \eta_t p_x^t = 0 \quad \forall j
\]

\[
\frac{\partial V_t}{\partial k_t^j} : - p_{jk}^t \frac{\partial v_t}{\partial k_t^j} + \beta E_t \left[ \frac{\partial V_{t+1}}{\partial y_{t+1}} p_{t+1}^j \frac{\partial F^j}{\partial K_{t+1}^j} \right] + \eta_t p_{jk}^t = 0 \quad \forall j \in [1, s]
\]

along with the non-negativity conditions $\theta_t^j, x_t^j, B_t, K_{t+1}^j \geq 0.$
Solution steps

- choice of suitable functional forms for utility and production
- linearization of Euler equations
- appropriate specification for the risk structure, namely the stochastic processes for prices, other covariant and idiosyncratic shocks (yields): agents form beliefs on joint distributions of covariant shocks based on predictions of marginal distributions
- ML estimation of the structural system for the whole sample, conditioning the risk aversion parameter on household characteristics
- ML estimation of the structural system by wealth quantiles
no investment decisions concerning livestock holding and the tree stock of perennial crops are taken

- capital stock for perennial crops is neglected, assuming that homogeneously planted land is a good proxy for it

- adoption of a Leontieff production function, where variable inputs are optimally set to $x_t^* = \sum_{s=1}^{S} \kappa_j \theta^j_t \overline{T}_t$ where $\kappa_j$ is a fixed input-output coefficient

- the liquidity constraint is not considered
The basic model: Bellman equation

Net revenues from cropping can thus be expressed as

$$\pi^{a}_{t+1} = \sum_{j=1}^{S} (p^{j}_{t+1} \xi^{j}_{t+1} - p^{x}_{t} \kappa_{j}) \theta^{j}_{t} T_{t} - w_{t} L^{a}_{t}$$

(12)

where $\xi^{j}_{t+1}$ are random yields per hectare of cultivated land.

The Bellman equation reduces to

$$V_{t}(y_{t}, p_{t}, \epsilon_{t}) = \max_{\theta^{j}} \{v(y_{t}, p_{t})$$

$$+ \beta E_{t} V_{t+1}(\sum_{j=1}^{S} (p^{j}_{t+1} \xi^{j}_{t+1} - p^{x}_{t} \kappa_{j}) \theta^{j}_{t} T_{t} - w_{t} L^{a}_{t} + \pi^{b}_{t+1} + \pi^{w}_{t+1})$$

(13)

for $t < T$, subject to (7) and the non-negativity constraints $\theta^{j}_{t} \geq 0$. 
Differentiating with respect to the crop shares we get the first order conditions

\[ \beta E_t \left[ \frac{\partial V}{\partial y} (p^j_{t+1} \xi^j_{t+1} - p^x_{t} \kappa^j_t) \bar{T}_t \right] - \lambda_t \frac{\partial g_t}{\partial \theta^j_t} = 0 \quad \text{for } j \in [1, S] \quad (14) \]

and combining the above FOCs we have

\[ E_t \left[ V_y \left( \pi_{jt} - \frac{g^j_{jt}}{g^j_{St}} \pi_{St} \right) \right] = 0 \quad \text{for } j \in [1, S - 1] \quad (15) \]

where \( V_y \equiv \frac{\partial V}{\partial y} \), while \( \pi_{jt} \) and \( g_{jt} \) denote the partial derivatives of \( \pi_t \) and \( g(\theta^j_t, \alpha) \) with respect to \( \theta^j_t \), respectively.
The basic model: local approximation

In spite of its local validity, we take a first order approximation of $\partial V/\partial y$ around the expected values of income $\bar{y}$ and prices $\bar{p}$, as in Fafchamps (1992)

$$V_y \approx \bar{V}_y + \sum_{r=1}^{R} \bar{V}_{yp} (p^r - \bar{p}^r) + \bar{V}_{yy} (y - \bar{y})$$

(16)

where $\bar{V}_y$ stands for $V_y(\bar{y}, \bar{p})$. After taking expectations and rearranging, equation (15) can be rewritten as

$$\bar{V}_y \left[ E_t[\pi_{jt}] - \frac{g_{jt}}{g_{St}} E_t[\pi_{St}] + \sum_{r=1}^{R} \frac{\bar{V}_{yp}^r}{\bar{V}_y} E_t \left[ (p^r - \bar{p}^r) \left( \pi_{jt} - \frac{g_{jt}}{g_{St}} \pi_{St} \right) \right] \right] + \frac{\bar{V}_{yy}}{\bar{V}_y} E_t \left[ (y - \bar{y}) \left( \pi_{jt} - \frac{g_{jt}}{g_{St}} \pi_{St} \right) \right] = 0 \quad \text{for } j \in [1, S - 1].$$

(17)
The basic model: functional forms

As in Fafchamps-Kurosaky (2002), to make (17) empirically tractable we assign $V$ the following power form

$$V(y_t, p_t^r) = \frac{1}{1 - \psi_t} \left[ \frac{y_t - \sum_{r=1}^R p_t^r \gamma_r}{\prod_{r=1}^R (p_t^r)^{\beta_r}} \right]^{1 - \psi_t}$$

(18)

where $\psi_t$ is a relative risk aversion coefficient with respect to income after necessary consumption $\sum_r \gamma_r$ has been satisfied.

We assume that the concavity of $V$ depends on household’s ability to bear risk and thus we parameterize $\psi_t$ as

$$\psi_t = \psi_0 + \sum_{h} \psi_h Z_t^h$$

(19)

where $Z_t^h$ include household’s assets, such land and livestock owned, demographic characteristics and proxies for human capital.
The basic model: functional forms

The CPI in the indirect utility function is calculated as a geometric average, where $\beta^r$ is the expenditure share of the $r^{th}$ good in the Stone-Geary linear expenditure system

$$p_t^r c_t^r = p_t^r \gamma^r + \beta_t^r (y_t - \sum_{r=1}^R p_t^r \gamma^r) \quad \forall r \in [1, R]. \quad (20)$$

As in Chavas and Holt (1996), we assign a quadratic form to the technology constraint $g(\theta^j_t, \alpha)$ to take into account agronomic constraints among the $S-1$ free land shares, independent of past crop choices, such as crop complementarities and water requirements

$$\alpha_0 - \alpha_1 \theta_t^1 + \sum_{j=2}^{S-1} [\alpha_j \theta_t^j + \alpha_{j+S-2} (\theta_t^j)^2] = 0 \quad (21)$$
The basic model: structural system

The structural model comprises the first order conditions for land allocation \((17)\), the technology constraint \((21)\) and the demand equations \((20)\)

\[
E_t \left[ V_y \left( \pi_{jt} - \frac{g_{jt}}{g_{St}} \pi_{St} \right) \right] = v_t^j \quad \forall j \in [1, S - 1] \quad (22)
\]

\[
\alpha_0 - \alpha_1 \theta_t^1 + \sum_{j=2}^{S-1} \left[ \alpha_j \theta_t^j + \alpha_{j+S-2} (\theta_t^j)^2 \right] = v_t^S \quad (23)
\]

\[
-p_t^r c_t^r + p_t^r \gamma_t^r + \beta_t^r (y_t - \sum_{r=1}^{R} p_t^r \gamma_t^r) = v_t^{S+r} \quad \forall r \in [1, R - 1] \quad (24)
\]

Notice that one demand equation has been dropped because of the adding-up constraint.
The structural system is estimated by FIML. The disturbance vector $\nu^i_t$ is assumed jointly normal, with variance-covariance matrix $\Sigma$, hence the log-likelihood function for the system of $p$ equations is given by

$$
\ln L(\Omega|data) = \frac{pTN}{2} \ln(2\pi) - \frac{TN}{2} \ln |\Sigma| + \sum_{i=1}^{N} \sum_{t=1}^{T} \left( \ln |J_{i,t}| - \frac{1}{2} \nu^i_t \Sigma^{-1} \nu^i_t \right) \tag{25}
$$

where $\Omega \equiv \{ \alpha, \beta, \gamma, \Psi, \Sigma \}$ is the vector of parameters to be estimated, $N$ is the number of households in the sample, $T$ the time periods and $J_{i,t}$ is the Jacobian transform matrix.
Estimation procedure

- preliminary estimates (investment-yield equations, VAR-VECM price estimation)
- construction of moments
- block-wise estimation of the system
- estimation of the full system through MSL
Data description

- data used in the empirical study come from the Ethiopian Rural Household Survey (ERHS) carried out by IFPRI, the University of Oxford and the University of Addis Ababa.
- It is a longitudinal data set collected in six rounds from 1989 to 2004 covering 15 villages across the country and providing a sample of 1477 households.
- It is not representative of all rural Ethiopia but covers all different agro-ecological areas.
- Our selected sub-sample covers four villages of southern Ethiopia where coffee is produced.
## Summary statistics: Adado (1997)

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**Source:** ERHS (round 4)

* Tropical Livestock Units (FAO, Sub-Saharan Africa)
### Summary statistics: Adado (1997)

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</tr>
<tr>
<td>Coffee age profile</td>
<td>index</td>
<td>125</td>
<td>.568</td>
<td>.0973</td>
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<td>Enset age profile</td>
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<td>.501</td>
<td>.096</td>
</tr>
</tbody>
</table>

*Source: ERHS (round 4)*
Next steps and extensions

- identification and estimation of the time preference rate conditioning on household characteristics
- separate estimation of the system for small and large producers (by land/wealth quantiles)
- different construction of expectations
- test alternative non-nested specifications through Vuong’s tests