Dynamic Financial Constraints: Distinguishing Mechanism Design from Exogenously Incomplete Regimes

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Literature on financial constraints: consumers vs. firms dichotomy

- **Consumption smoothing literature** – various models with risk aversion
  - permanent income, buffer stock, full insurance
  - private information (Phelan, 94, Ligon 98) or limited commitment (Thomas and Worrall, 90; Ligon et al., 05; Dubois et al., 08)
- **Investment literature** – firms modeled mostly as risk neutral
  - adjustment costs: Abel and Blanchard, 83; Bond and Meghir, 94
  - IO (including structural): Hopenhayn, 92; Ericson & Pakes, 95, Cooley & Quadrini, 01; Albuquerque & Hopenhayn, 04; Clementi & Hopenhayn, 06; Schmid, 09
  - empirical: e.g., Fazzari et al, 88 – unclear what the nature of financial constraints is (Kaplan and Zingales, 00 critique); Samphantharak and Townsend, 10; Alem and Townsend, 10; Kinnan and Townsend, 11

Literature (cont.)

- **Macro literature with micro foundations**
  - largely assumes exogenously missing markets – Cagetti & De Nardi, 06; Covas, 06; Angeletos and Calvet, 07; Heaton and Lucas, 00; Castro Clementi and Macdonald 09, Greenwood, Sanchez and Weage 10a,b

- **Comparing/testing across models of financial constraints** – Meh and Quadrini 06; Paulson et al. 06; Jappelli and Pistaferri 06; Kocherlakota and Pistaferri 07; Attanasio and Pavoni 08; Kinnan 09; Krueger and Perri 10; Krueger, Lustig and Perri 08 (asset pricing implications)

Objectives

- how good an approximation are the various models of financial markets access and constraints across the different literatures?

- what would be a reasonable assumption for the financial regime if it were taken to the data as well?
  - many ways in which markets can be incomplete
  - financial constraints affect investment and consumption jointly (no separation with incomplete markets)
  - it matters $what$ the exact source and nature of the constraints are
  - can we distinguish and based on what and how much data?

Contributions

- we solve dynamic models of incomplete markets – hard, but captures the full implications of financial constraints

- we can handle any number of regimes with different frictions and any preferences and technologies (no problems with non-convexities)

- using MLE we can estimate all structural parameters as opposed to only a subset available using other methods (e.g., Euler equations)

- using MLE we capture in principle more (all) dimensions of the data (joint distribution of consumption, output, investment) as opposed to only particular dimensions (e.g. consumption-output comovement; Euler equations)

- structural approach allows computing counterfactuals, policy and welfare evaluations

What we do

- formulate and solve a wide range of *dynamic* models/regimes of financial markets sharing common preferences and technology
  - **exogenously incomplete** markets regimes – financial constraints assumed / exogenously given (autarky, A; saving only, S; borrowing or lending in a single risk-free asset, B)
  - **mechanism-design** (endogenously incomplete markets) regimes – financial constraints arise endogenously due to asymmetric information (moral hazard, MH; limited commitment, LC; hidden output; unobserved investment)
  - complete markets (full information, FI)

What we do

- develop methods based on mechanism design, dynamic programming, linear programming, and maximum likelihood to
  - **compute** (Prescott and Townsend, 84; Phelan and Townsend, 91; Doepke and Townsend, 06)
  - **estimate** via maximum likelihood
  - **statistically test** the alternative models (Vuong, 89)
- apply these methods to simulated data and actual data from Thailand
- conduct numerous robustness checks
- get inside the 'black box' of the MLE – stylized facts, predictions on data not used in estimation, other metrics for model selection

Main findings

- we use consumption, income, and productive assets/capital data for small household-run enterprises
- using joint consumption, income and investment data improves ability to distinguish the regimes relative to using consumption/income or investment/income data alone
- the saving and/or borrowing/lending regimes fit Thai rural data best overall (but some evidence for moral hazard if using consumption and income data for households in networks)

Main findings

- moral hazard fits best in urban areas
- the autarky, full information (complete markets) and limited commitment regimes are rejected overall
- our results are robust to many alternative specifications – two-year panels, alternative grids, no measurement error, risk neutrality, adjustment costs.

The common theoretical framework

- **preferences:** $u(c, z)$ over consumption, c, and effort, z
- **technology:** $P(q|z, k)$ – probability of obtaining output level q from effort z and capital k
- household can contract with a risk-neutral competitive **financial intermediary** with outside rate of return R
  - dynamic optimal contracting problem $(T = \infty)$
  - the contract specifies probability distribution over consumption, output, investment, debt or transfers allocations
  - two interpretations: (i) single agent and probabilistic allocations or (ii) continuum of agents and fractions over allocations

Timing

- initial state: k or (k, w) or (k, b) depending on the model regime (w is promised utility, b is debt/savings)

- capital, k and effort, z used in production

- output, q realized, financial contract terms implemented (transfers, τ or new debt/savings, b')

- consumption, c and investment, $i \equiv k' - (1-\delta)k$ decided/implemented,

- go to next period state: k', (k', w') or (k', b') depending on regime

The linear programming (LP) approach

- we compute all models using linear programming
- write each model as dynamic linear program; all state and policy variables belong to finite grids, Z, K, W, T, Q, B, e.g. $K = [0, .1, .5, 1]$
- the choice variables are *probabilities* over all possible allocations (Prescott and Townsend, 84), e.g. $\pi(q, z, k', w') \in [0, 1]$
- extremely general formulation
  - by construction, no non-convexities for *any* preferences or technology (can be critical for MH, LC models)
  - very suitable for MLE – direct mapping to probabilities
  - contrast with the "first order approach" – need additional restrictive assumptions (Rogerson, 85; Jewitt, 88) or to verify solutions numerically (Abraham and Pavoni, 08)

Example with the autarky problem

- "standard" formulation

$$v(k) = \max_{z,\{k_i'\}_{i=1}^{\#Q}} \sum_{q_i \in Q} P(q_i|k, z)[u(q_i + (1-\delta)k - k_i',\ z) + \beta v(k_i')]$$

- linear programming formulation

$$v(k) = \max_{\pi(q,z,k'|k) \geq 0} \sum_{QxZxK'} \pi(q, z, k'|k)[u(q + (1-\delta)k - k',\ z) + \beta v(k')]$$

s.t. $\sum_{K'} \pi(\bar{q}, \bar{z}, k'|k) = P(\bar{q}|\bar{z}, k) \sum_{Q \times K} \pi(q, \bar{z}, k'|k)$ for all $(\bar{q}, \bar{z}) \in Q \times Z$

$$\sum_{QxZxK'} \pi(q, z, k'|k) = 1$$

Exogenously incomplete markets models (B, S, A)

- no information asymmetries; no default

- The agent's problem:

$$v(k,b) = \max_{\pi(q,z,k',b'|k,b)} \sum_{QxZxK'xB'} \pi(q,z,k',b'|k,b)[U(q+b'-Rb+(1-\delta)k-k',z)+\beta v(k',b')]$$

subject to Bayes-rule consistency and adding-up:

$$\sum_{K'xB'} \pi(\bar{q},\bar{z},k',b'|k,b) = P(\bar{q}|\bar{z},k) \sum_{Q\times K'xB'} \pi(q,\bar{z},k',b'|k,b) \text{ for all } (\bar{q},\bar{z}) \in Q\times Z$$

$$\sum_{QxZxK'\times B'} \pi(q,z,k',b'|k,b) = 1$$

and s.t. $\pi(q,z,k',b'|k,b) \geq 0, \;\; \forall (q,z,k',b') \in Q \times Z \times K' \times B'$

- *autarky*: set $B' = \{0\}$; *saving only*: set $b_{\max} = 0$; *debt*: allow $b_{\max} > 0$

Mechanism design models (FI, MH, LC)

- allow state- and history-contingent transfers, τ
- dynamic optimal contracting problem between a risk-neutral lender and the household

$$V(w,k) = \max_{\{\pi(\tau,q,z,k',w'|k,w)\}} \sum_{T\times Q\times Z\times K'\times W'} \pi(\tau,q,z,k',w'|k,w)[q-\tau+(1/R)V(w',k')]$$

s.t. *promise-keeping:*

$$\sum_{T\times Q\times Z\times K'\times W'} \pi(\tau,q,z,k',w'|k,w)[U(\tau+(1-\delta)k-k',z)+\beta w'] = w,$$

and s.t. Bayes-rule consistency, adding-up, and non-negativity as before.

Moral hazard

- additional constraints – *incentive-compatibility*, $\forall(\bar{z}, \hat{z}) \in Z \times Z$

$$\sum_{T\times Q\times K'\times W'} \pi(\tau, q, \bar{z}, k', w'|k, w)[U(\tau + (1-\delta)k - k', \bar{z}) + \beta w'] \geq$$

$$\geq \sum_{T\times Q\times K'\times W'} \pi(\tau, q, \bar{z}, k', w'|k, w)\frac{P(q|\hat{z}, k)}{P(q|\bar{z}, k)}[U(\tau + (1-\delta)k - k', \hat{z}) + \beta w']$$

- we also compute a moral hazard model with unobserved k and k' (UI) – adds dynamic adverse selection as source of financial constraints

Limited commitment

- additional constraints – *limited commitment*, for all $(\bar{q}, \bar{z}) \in Q \times Z$

$$\sum_{T \times K' \times W'} \pi(\tau, \bar{q}, \bar{z}, k', w' | k, w)[u(\tau + (1-\delta)k - k', \bar{z}) + \beta w'] \geq \Omega(k, \bar{q}, \bar{z})$$

where $\Omega(k, q, z)$ is the present value of the agent going to autarky with his current output at hand q and capital k, which is defined as:

$$\Omega(k, q, z) \equiv \max_{k' \in K'} \{u(q + (1-\delta)k - k', z) + \beta v^{aut}(k')\}$$

where $v^{aut}(k)$ is the autarky-forever value (from the A regime).

Hidden output/income model

As MH or LC above, but instead subject to *truth-telling constraints* (true output is $\bar{q}$ but considering announcing $\hat{q}$), $\forall$ $(\bar{z}, \bar{q}, \hat{q} \neq \bar{q})$:

$$\sum_{T\times K'\times W'} \pi(\tau, \bar{q}, \bar{z}, k', w'|k, w)[U(\bar{q} + \tau + (1-\delta)k - k', \bar{z}) + \beta w'] \geq$$

$$\geq \quad \sum_{T\times K'\times W'} \pi(\tau, \hat{q}, \bar{z}, k', w'|k, w)[U(\bar{q} + \tau + (1-\delta)k - k', \bar{z}) + \beta w']$$

Functional forms and baseline parameters

- **preferences:**

$$u(c,z)=\frac{c^{1-\sigma}}{1-\sigma}-\xi z^{\theta}$$

- **technology:** calibrated from data (robustness check with parametric/estimated), the matrix $P(q|z,k)$ for all $q,z,k\in Q\times Z\times K$

- **fixed parameters**: $\beta=.95,\ \delta=.05,\ R=1.053,\ \xi=1$ (the rest are estimated in the MLE; we also do robustness checks)

Table 1 - Problem Dimensionality

Number of: Model:	linear programs solved per iteration	variables per linear program	constraints per linear program
Autarky (A)	5	75	16
Saving / Borrowing (S, B)	25	375	16
Full information (FI)	25	11,625	17
Moral hazard (MH)	25	11,625	23
Limited commitment (LC)	25	11,625	32
Hidden output (HO)	25	11,625	77
Unobserved investment (UI), stage 1	250	1,650	122
Unobserved investment (UI), stage 2	550	8,370	2,507
Unobserved investment (UI), total	137,500	n.a.	n.a.

Note: This table assumes the following grid sizes that used in the estimation: #Q=5, #K=5, #Z=3, #B=5, #T=31; #W=5; and #**W**=50 and #**W**m=110 for the UI model

Table 2 - Variable Grids Used in the Estimation

Variable	grid size (number of points)	grid range
income/cash flow, Q	5	[.04,1.75] from data percentiles
business assets, K	5	[0, 1] from data percentiles
effort, Z	3	[.01, 1]
savings/debt, B	5 (6 for B regime)	S: [-2, 0], B: [-2, .82]
transfers/consumption, C	31 for MH/FI/LC, endog. for B/S/A	[.001, 0.9]
promised utility, W	5	endogenous

Computation

- compute each model using policy function iteration (Judd 98)
- in general, let the initial state s be distributed $D_0(s)$ over the grid $\mathbf{S}$ (in the estimations we use the k distribution from the data)
  - use the LP solutions, $\pi^*(.|s)$ to create the state transition matrix, $M(s,s')$ with elements $\{m_{ss'}\}_{s,s'\in S}$
  - for example, for MH $s=(w,k)$ and thus

$$m_{ss'} \equiv prob(w',k'|w,k) = \sum_{T\times Q\times Z} \pi^*(\tau,q,z,k',w'|w,k)$$

  the state distribution at time t is thus $D_t(s) = (M')^t D_0(s)$

- use $D(s)$, $M(s,s')$ and $\pi^*(.|s)$ to generate cross-sectional distributions, time series or panels of any model variables

Structural estimation

- Given:
  - structural parameters, ϕ^s (to be estimated),
  - discretized over the grid K (observable state) distribution $H(k)$
  - the unobservable state (b or w) distribution – parameterized by ϕ^d and estimated

- compute the conditional probability, $g_1^m(y|k, \phi^s, \phi^d)$ of any $y = (c, q)$ or $y = (k, i, q)$ or $y = (c, q, i, k)$ implied by the solution $\pi^*(.)$ of model regime, m (m is A through FI), integrating over unobservable state variables.

Structural estimation

- allow for measurement error in k (Normal with stdev γ_{me} assumed in baseline)

- use a histogram function over the state grid K to generate the model joint probability distribution $f^m(y|H(\hat{k}), \phi^s, \phi^d, \gamma_{me})$ given the state distribution $H(k)$.

- estimated parameters determining the likelihood, $\phi \equiv (\phi^s, \phi^d, \gamma_{me})$

The likelihood function

Illustration:

- consider the case of $y \equiv (c, q)$, i.e., cross-sectional data $\{\hat{c}_j, \hat{q}_j\}_{j=1}^n$. The $C \times Q$ grid used in the LP consists of the points $\{c_h, q_l\}_{h=1,l=1}^{\#K,\ \#Q}$.

- from above,

$$f^m(c_h, q_l | H(k), \phi)$$

are the model m solution probabilities (obtained from the π's and allowing measurement error in k) at each grid point $\{c_h, q_l\}$ given parameters ϕ^s, ϕ^d and initial observed state distribution $H(\hat{k})$. By construction, $\sum_{h,l} f^m(c_h, q_l | H(k), \phi) = 1$.

- suppose $\hat{c}_j = c_j^* + \varepsilon_j^c$ and $\hat{q}_j = q_j^* + \varepsilon_j^q$ where ε^c and ε^q are independent Normal random variables with mean zero and normalized standard deviations σ_c and σ_q (i.e., $\sigma_c = \gamma_{me}(c_{\max} - c_{\min})$ and similarly for q). Let $\Phi(.|\mu, \sigma^2)$ denote the Normal pdf.

The likelihood function (cont.)

- ...then, the likelihood of data point $(\hat{c}_j, \hat{q}_j)$ relative to any given grid point $(c, q) \in C \times Q$ given $\phi, H(k)$ is:

$$\Phi(\hat{c}_j|c, \sigma_c^2)\Phi(\hat{q}_j|q, \sigma_q^2)$$

- the likelihood of data point $(\hat{c}_j, \hat{q}_j)$ relative to the whole LP grid $C \times Q$ is, adding over all grid points $\{c_h, q_l\}$ with their probability weights f^m implied by model m:

$$F^m(\hat{c}_j, \hat{q}_j|\phi, H(k)) = \sum_h \sum_l f^m(c_h, q_l|H(k), \phi)\Phi(\hat{c}_j|c_h, \sigma_c^2)\Phi(\hat{q}_j|q_l, \sigma_q^2)$$

The likelihood function (cont.)

- therefore, the log-likelihood of the data $\{\hat{c}_j, \hat{q}_j\}_{j=1}^n$ in model m given ϕ and $H(k)$ and allowing for measurement error in k, c, q is:

$$\Lambda^m(\phi) = \sum_{j=1}^{n} \ln F^m(\hat{c}_j, \hat{q}_j | \phi, H(k))$$

- in the runs with real data we use $H(k) = H(\hat{k})$ – the discretized distribution of actual capital stock data $\{\hat{k}_j\}_{j=1}^n$.

Structural estimation (cont.)

- Note, we allow for:
  - **measurement error** in the data $\hat{y}$ with standard deviation γ_{me} (estimated)
  - **unobserved heterogeneity**: the marginal distribution over the unobserved state variables b or w (estimated as $N(\mu_{b/w}, \gamma_{b/w})$)

- in robustness checks we also allow for **heterogeneity in productivity or risk-aversion**.

Testing

- Vuong's (1989) modified likelihood ratio test
  - neither model has to be correctly specified
  - the null hypothesis is that the compared models are 'equally close' in KLIC sense to the data
  - the test statistic is distributed $N(0,1)$ under the null

Application to Thai data

- Townsend Thai Surveys (16 villages in four provinces, Northeast and Central regions)
  - balanced panel of 531 rural households observed 1999-2005 (seven years of data)
  - balanced panel of 475 urban households observed 2005-2009

- data series used in estimation and testing
  - **consumption expenditure** (c) – household-level, includes owner-produced consumption (fish, rice, etc.)
  - **assets** (k) – used in production; include business and farm equipment, exclude livestock and household durables
  - **income** (q) – measured on accrual basis (Samphantharak and Townsend, 09)
  - **investment** (i) – constructed from assets data, $i \equiv k' - (1 - \delta)k$

Figure 1: Thai data − income, consumption, investment comovement

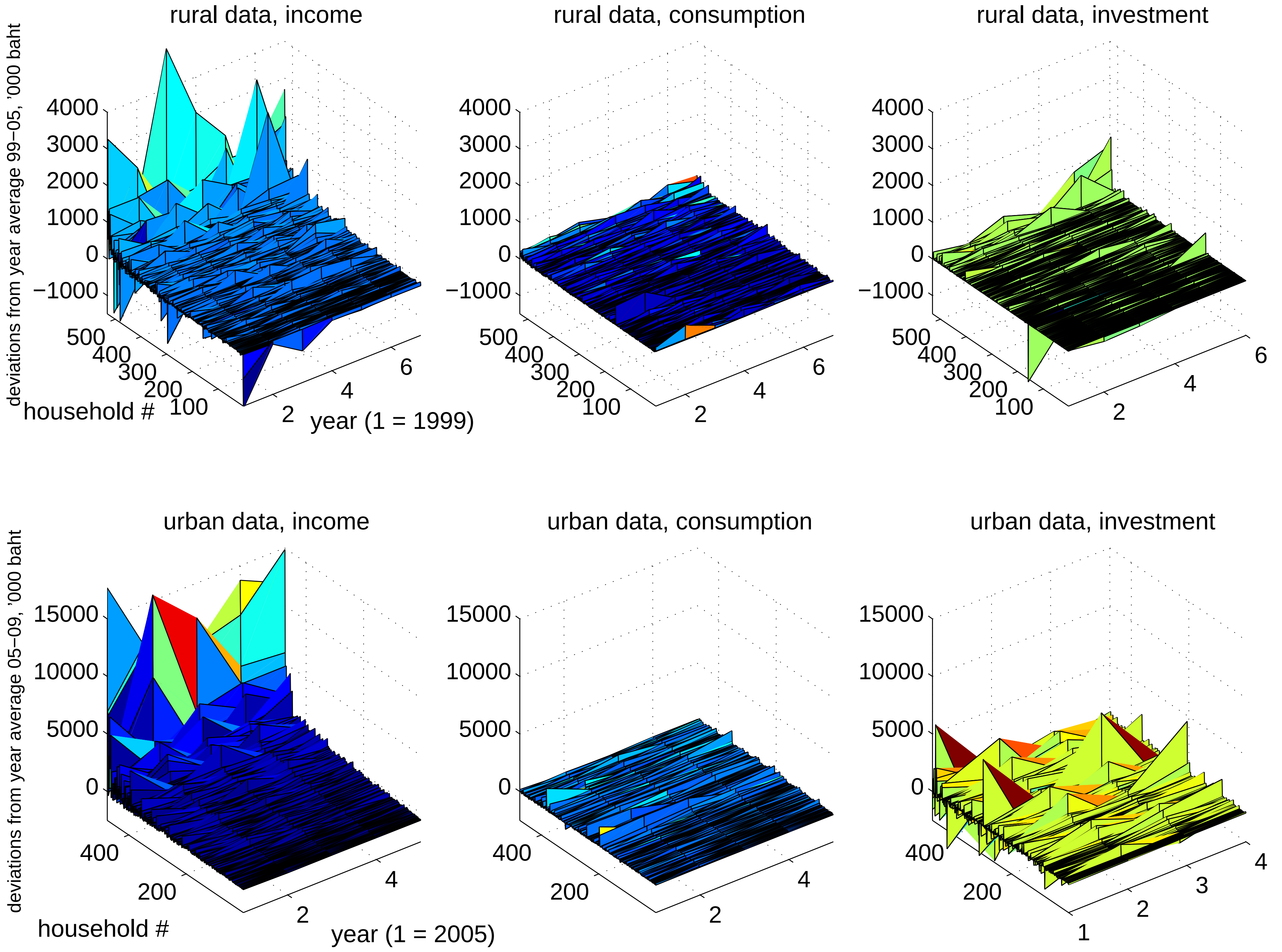


Figure 2: Thai data − income, consumption, assets changes

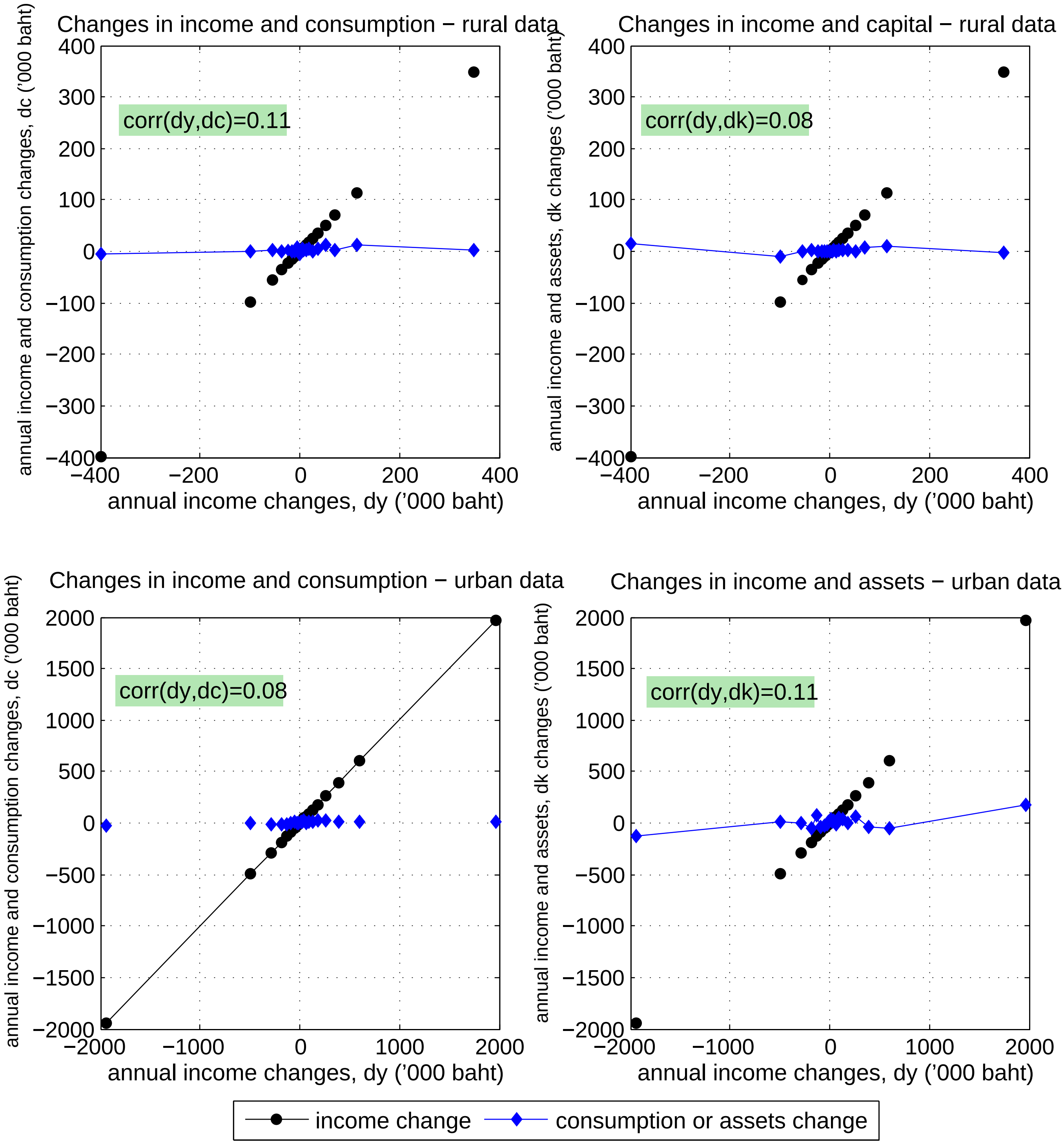


Table 3 - Thai data summary statistics

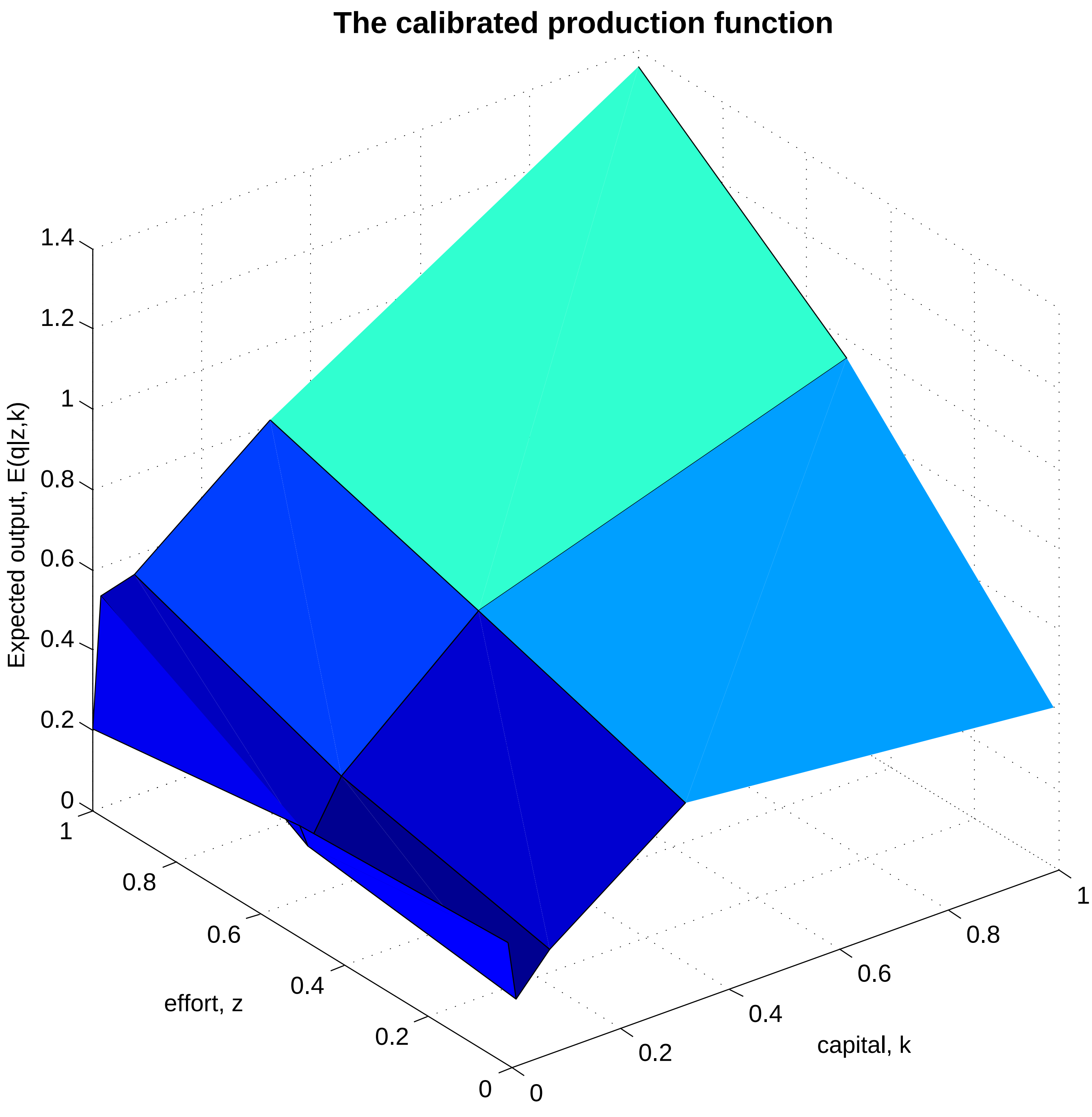
	Rural data, 1999-2005	Urban data, 2005-2009
Consumption expenditure, c		
mean	64.172	148.330
standard deviation	53.284	131.710
median	47.868	115.171
Income, q		
mean	128.705	635.166
standard deviation	240.630	1170.400
median	65.016	361.000
Business assets, k		
mean	80.298	228.583
standard deviation	312.008	505.352
median	13.688	57.000
Investment, i		
mean	6.249	17.980
standard deviation	57.622	496.034
median	0.020	1.713

1. Sample size in the rural data is 531 households observed over seven consecutive years (1999-2005).
2. Sample size in the urban data is 475 households observed over five consecutive years (2005-2009).
3. All summary statistics in the Table are computed from the pooled data. Units are '000s Thai baht.

Calibrated production function from the data

- use data on labor, output and capital stock $\{\hat{q}_{jt}, \hat{z}_{jt}, \hat{k}_{jt}\}$ for a sub-sample of Thai households $(n = 296)$ to calibrate the production function $P(q|k, z)$
  - use a histogram function to discretize (normalized) output, capital and labor data onto the model grids K, Q, Z
  - labor data is normalized setting $z_{\max}$ equal to the 80th percentile of the labor data $\{z_{it}\}$

- the result is an 'empirical' version of the production function: $P(q|k, z)$ for any $q \in Q$ and $k, z \in K \times Z$.


The calibrated production function
Expected output, E(q|z,k)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
effort, z
1
0.8
0.6
0.4
0.2
0
capital, k
0
0.2
0.4
0.6
0.8
1

Application to Thai data (cont.)

- **mapping to the model**
  - convert data into 'model units' – divide all nominal values by the 90% asset percentile
  - draw initial unobserved states (w, b) from $N(\mu_{w/b}, \gamma_{w/b})$; initial assets k are taken from the data
  - allow for additive measurement error in k, i, c, q (standard deviation, γ_{me} estimated)
- **estimate and test** pairwise the MH, LC, FI, B, S, A models with the Thai data

Thai data – results

- the exogenously incomplete markets S and B regimes fit the rural Thai data best overall (Table 5)
  - independent of type of data used (only exception is 1999 c, q data)
  - consistent with other evidence for imperfect risk-sharing and investment sensitivity to cash flow/income

- using joint consumption, income and investment data pins down the best fitting regimes more sharply than consumption/income or investment/income data alone

- the full information (FI), moral hazard (MH) and limited commitment (LC) regimes are rejected using investment/capital stock data

- the autarky (A) (no access to financial markets) regime is rejected with all types of data

Table 4 - Parameter Estimates using 1999-00 Thai Rural Data *UPDATED*

Business assets, investment and income, (k,i,q) data

Model	γ_{me}	σ	θ	$\mu_{w/b}$[1]	$\gamma_{w/b}$	LL Value[2]
Moral hazard - MH	0.1632	0.0465	1.3202	0.4761	0.0574	**-3.1081**
	(0.0125)	*(0.0000)*	*(0.0000)*	*(0.0139)*	*(0.0005)*	
Full information - FI	0.1625	0.0323	1.1928	0.4749	0.0591	**-3.1100**
	(0.0132)	*(0.0060)*	*(0.0770)*	*(0.0351)*	*(0.0138)*	
Limited commitment - LC	0.1606	0.4390	1.2039	0.7010	0.0609	**-3.0994**
	(0.0115)	*(0.0001)*	*(0.0053)*	*(0.0456)*	*(0.0432)*	
Borrowing & Lending - B	0.0950	4.2990	0.1091	0.8883	0.0065	**-2.5992**
	(0.0059)	*(0.0880)*	*(0.0000)*	*(0.0269)*	*(0.0153)*	
Saving only - S *	0.0894	5.7202	9.2400	0.9569	0.0101	**-2.5266**
	(0.0068)	*(0.0000)*	*(0.0000)*	*(0.0087)*	*(0.0075)*	
Autarky - A	0.1203	3.1809	9.2000	n.a.	n.a.	**-2.7475**
	(0.0046)	*(0.6454)*	*(0.0000)*	n.a.	n.a.	

Consumption and income, (c,q) data

Model	γ_{me}	σ	θ	$\mu_{w/b}$	$\gamma_{w/b}$	LL Value
Moral hazard - MH *	0.1240	1.0260	1.6057	0.7933	0.0480	**-0.8869**
	(0.0086)	*(0.0046)*	*(0.0584)*	*(0.0053)*	*(0.0007)*	
Full information - FI	0.1242	0.9345	1.9407	0.7938	0.0464	**-0.9008**
	(0.0082)	*(0.0002)*	*(0.0000)*	*(0.0055)*	*(0.0000)*	
Limited commitment - LC	0.1337	1.0358	7.7343	0.0188	0.0672	**-0.9116**
	(0.0109)	*(0.0076)*	*(0.5142)*	*(0.0070)*	*(0.0000)*	
Borrowing & Lending - B	0.1346	4.3322	1.8706	0.8397	0.0311	**-1.0558**
	(0.0130)	*(0.0197)*	*(0.0000)*	*(0.0045)*	*(0.0004)*	
Saving only - S *	0.1354	2.9590	0.0947	0.9944	0.0516	**-1.0033**
	(0.0074)	*(0.0343)*	*(0.8556)*	*(0.0133)*	*(0.0180)*	
Autarky - A	0.1769	1.2000	1.2000	n.a.	n.a.	**-1.1797**
	(0.0087)	*(0.0000)*	*(4.2164)*	n.a.	n.a.	

Business assets, consumption, investment, and income, (c,q,i,k) data

Model	γ_{me}	σ	θ	$\mu_{w/b}$	$\gamma_{w/b}$	LL Value
Moral hazard - MH	0.1581	0.0342	0.9366	0.3599	0.0156	**-2.8182**
	(0.0073)	*(0.0000)*	*(0.0000)*	*(0.0013)*	*(0.0010)*	
Full information - FI	0.1434	0.1435	1.0509	0.5608	0.1244	**-2.8119**
	(0.0083)	*(0.0018)*	*(0.0009)*	*(0.0112)*	*(0.0105)*	
Limited commitment - LC	0.1626	0.8035	1.0179	0.0142	0.0630	**-2.8178**
	(0.0075)	*(0.0102)*	*(0.0147)*	*(0.0074)*	*(0.0003)*	
Borrowing & Lending - B	0.1397	1.0831	8.1879	0.9571	0.0398	**-2.5582**
	(0.0071)	*(0.1102)*	*(0.2536)*	*(0.0359)*	*(0.0267)*	
Saving only - S *	0.1245	5.6697	0.1114	0.9839	0.0823	**-2.3825**
	(0.0077)	*(0.0225)*	*(0.0744)*	*(0.0248)*	*(0.0432)*	
Autarky - A	0.1394	1.6922	9.2000	n.a.	n.a.	**-2.6296**
	(0.0050)	*(0.3157)*	*(0.0000)*	n.a.	n.a.	

1. $\mu_{w/b}$ and $\gamma_{w/b}$ (the mean and standard deviation of the w or b initial distribution) are reported relative to the variables' grid range

2. Normalized (divided by n) log-likelihood values;

3. Bootstrap standard errors are in parentheses below each parameter estimate.

* denotes the best fitting regime (including ties)

Table 5 - Model Comparisons[1,2] using Thai Rural Data - Baseline Vuong Test Results (**UPDATED**)

Comparison	MH v FI	MH v LC	MH v B	MH v S	MH v A	FI v LC	FI v B	FI v S	FI v A	LC v B	LC v S	LC v A	B v S	B v A	S v A	Best Fit
1. Using (k,i,q) data																
1.1 years: 1999-00	MH*	LC**	B***	S***	A***	LC***	B***	S***	A***	B***	S***	A***	S***	B***	S***	S
1.2 years: 2004-05	FI***	MH***	B***	S***	A***	tie	B***	S***	A***	B***	S***	A***	tie	B***	S***	B,S
2. Using (c,q) data																
2.1 year: 1999	MH**	tie	MH***	MH***	MH***	tie	FI***	FI**	FI***	LC***	LC**	LC***	S***	B***	S***	MH,FI,LC
2.2 year: 2005	tie	tie	tie	tie	tie	LC***	tie	S***	tie	tie	tie	LC*	S**	tie	S***	S,LC,MH
3. Using (c,q,i,k) data																
3.1 years: 1999-00	tie	tie	B***	S***	A**	tie	B***	S***	A**	B***	S***	A**	S***	tie	S***	S
3.2 years: 2004-05	FI***	MH***	B***	S***	A***	FI***	B***	S***	A**	B***	S***	A***	S***	tie	S**	S
4. Two-year panel																
4.1 (c,q) data, years: 1099 and 00	MH***	LC***	B***	S***	MH**	LC***	B***	S***	tie	LC*	tie	LC***	tie	B***	S***	LC,S
4.2 (c,q) data, years: 1999 and 05	MH***	MH***	tie	tie	MH***	FI***	B***	S***	tie	B***	S***	A***	tie	B***	S***	B,S,MH
5. Dynamics																
5.1 99 k distribution & 04-05 (c,q,i,k)	FI***	MH***	B***	tie	tie	FI***	B***	tie	FI*	B***	S***	A***	B***	B***	S**	B
5.2 99 k distribution & 05 (c,q)	tie	MH***	tie	tie	MH***	FI***	tie	tie	FI***	B***	S***	A**	tie	B***	S***	S,B,FI,MH
5.3 99 k distribution & 04-05 (k,i,q)	FI***	LC*	B***	S**	MH**	FI***	B***	S*	FI**	B***	S*	LC**	B***	B***	S***	B

Notes: 1. *** = 1%, ** = 5%, * = 10% two-sided significance level, the better fitting model abbreviation is displayed; 2. Vuong statistic cutoffs: >2.575 = ***; >1.96 = **; >1.645 = *; <1.645 = "tie"

Thai data – results

- Networks (Table 6), by blood/kinship or loan/gift – evidence for high degree of smoothing in c, q data

Table 6 - Model Comparisons[1] using Thai Rural Data - Networks (UPDATED**)**

Comparison	MH v FI	MH v LC	MH v B	MH v S	MH v A	FI v LC	FI v B	FI v S	FI v A	LC v B	LC v S	LC v A	B v S	B v A	S v A	Best Fit
1. Networks by friend or relative																
1.1 (c,q) data, in network, n=391	FI**	tie	MH***	MH*	MH***	FI***	FI***	FI***	FI***	LC***	tie	LC***	S***	B***	S***	FI
1.2 (k,i,q) data, in network	tie	tie	B***	S***	A***	tie	B***	S***	A***	B***	S***	A***	S**	B**	S***	S
1.3 (c,q,i,k) data,in network	tie	tie	B***	S***	A**	tie	B***	S***	A***	B***	S***	A**	S***	tie	S**	S
1.4 (c,q) data, not in network, n=140	tie	tie	tie	tie	tie	LC**	tie	tie	tie	LC**	LC*	LC**	tie	B*	tie	LC,MH
1.5 (c,q,i,k) data, not in network	tie	MH***	tie	S***	tie	FI***	tie	S***	A**	B**	S***	A***	S***	tie	S*	S
2. Networks by gift or loan																
2.1 (c,q) data, in network, n=357	FI**	tie	MH**	tie	MH***	tie	FI***	FI**	FI***	LC***	tie	LC***	S***	B***	S***	FI,LC
2.2 (k,i,q) data, in network	tie	tie	B***	S***	A***	tie	B***	S***	A***	B***	S***	A***	S**	B**	S***	S
2.3 (c,q,i,k) data, in network	tie	MH***	B***	S***	A**	FI***	B***	S***	A**	B***	S***	A***	S***	tie	S**	S
2.4 (c,q) data, not in network, n=174	tie	tie	tie	tie	MH**	LC*	tie	tie	FI*	tie	tie	LC**	tie	B**	S***	S,LC,MH,FI,B
2.5 (c,q,i,k) data, not in network	tie	tie	B***	S***	tie	tie	B***	S***	tie	B***	S***	tie	S**	B*	S***	S

Notes: 1. *** = 1%, ** = 5%, * = 10% two-sided significance level, the better fitting model abbreviation is displayed; 2. Vuong statistic cutoffs: >2.575 = ***; >1.96 = **; >1.645 = *; <1.645 = "tie"

Thai data – results

- Thai urban data (Table 7) – evidence for moral hazard in c, q and c, q, i, k data

Table 7 - Model Comparisons[1,2] using Thai Urban Data - Vuong Test Results (UPDATED**)**

Comparison	MH v FI	MH v LC	MH v B	MH v S	MH v A	FI v LC	FI v B	FI v S	FI v A	LC v B	LC v S	LC v A	B v S	B v A	S v A	Best Fit
1. Using (c,q,i,k) data																
1.1. years: 2005-06	MH***	MH***	MH***	MH***	MH***	LC***	B***	S***	FI*	tie	S***	LC***	S***	B***	S***	MH
1.2. years: 2008-09	MH***	MH***	MH***	MH***	MH***	LC***	B***	S***	tie	LC**	tie	LC***	S***	B***	S***	MH
2. Using (c,q) data																
2.1. year: 2005	tie	MH**	MH***	MH***	MH***	tie	FI***	FI**	FI***	LC***	LC**	LC***	S***	B***	S***	MH,FI
2.2. year: 2009	MH*	MH***	tie	MH*	MH***	FI***	tie	tie	FI***	B***	S***	LC***	tie	B***	S***	MH,B
3. Using (k,i,q) data																
3.1. years: 2005-06	tie	MH*	tie	S***	tie	tie	tie	S***	tie	tie	S***	tie	S***	tie	S**	S
3.2. years: 2008-09	FI*	tie	B***	S***	A***	FI*	B***	S***	tie	B***	S***	A**	tie	tie	S*	S,B
4. Two-year panel																
4.1. (c,q) data, years: 2005 and 06	tie	MH***	MH***	tie	MH***	FI***	FI***	tie	FI***	tie	S***	LC**	S***	B**	S***	S,MH,FI
4.2. (c,q) data, years: 2005 and 09	MH***	MH***	MH***	MH***	MH***	FI***	FI***	FI***	FI***	B***	S***	tie	S***	B***	S***	MH

Notes: 1. *** = 1%, ** = 5%, * = 10% two-sided significance level, the better fitting model abbreviation is displayed; 2. Vuong statistic cutoffs: >2.575 = ***; >1.96 = **; >1.645 = *; <1.645 = "tie"

Thai data – robustness

- estimated production function (Table 8)

- for $q \in \{q_{\min}, ..., q_{\#Q}\} \equiv Q$

$$
\begin{aligned}
Prob(q &= q_{\min}) = 1 - (\frac{k^\rho + z^\rho}{2})^{1/\rho} \\
Prob(q &= q_i,\ i \neq \min) = \frac{1}{\#Q - 1}(\frac{k^\rho + z^\rho}{2})^{1/\rho}
\end{aligned}
$$

$\rho = 0$ is perfect substitutes; $\rho \to -\infty$ is Leontieff; $\rho \to 0$ is Cobb-Douglas

Table 8 - Model Comparisons[1,2] using parametric production function (**UPDATED**)

Comparison	MH v FI	MH v LC	MH v B	MH v S	MH v A	FI v LC	FI v B	FI v S	FI v A	LC v B	LC v S	LC v A	B v S	B v A	S v A	Best Fit
1. Rural data																
1.1 (k,i,q), years: 1999-00	FI**	LC***	B***	S***	A***	LC***	B***	S***	A***	B***	S***	A***	tie	B***	S***	S,B
1.2 (k,i,q), years: 2004-05	MH***	MH***	B***	S***	A***	FI***	B***	S***	A***	B***	S***	A***	S***	tie	S**	S
1.3 (c,q), year: 1999	MH***	MH***	tie	tie	MH***	FI***	B***	S***	FI*	B***	S***	tie	tie	B***	S***	B,S,MH
1.4 (c,q), year: 2005	MH**	MH**	B***	S***	tie	tie	B***	S***	A**	B***	S***	A***	B**	B**	tie	B
1.5 (c,q,i,k), years: 1999-00	tie	LC***	B***	S***	A***	LC***	B***	S***	A***	B***	S***	tie	tie	B***	S***	B,S
1.6 (c,q,i,k), years: 2004-05	MH***	LC***	B***	S***	A***	LC***	B***	S***	A***	B***	S***	A***	S*	B**	S***	S
1.7 (c,q) panel, years: 1999 and 00	MH***	tie	tie	S**	MH***	LC***	B***	S***	FI***	B*	S***	LC***	tie	B***	S***	S,B
1.8 (c,q) panel, years: 1999 and 05	MH*	tie	tie	tie	MH***	LC**	tie	tie	FI***	tie	tie	LC***	tie	B***	S***	LC,B,MH,S
2. Urban data																
2.1 (c,q,i,k), years: 2005-06	tie	tie	MH**	MH***	MH***	tie	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	FI,MH,LC
2.2 (c,q), year: 2005	tie	tie	MH***	MH***	MH***	tie	FI***	FI*	FI***	LC***	tie	LC***	S***	B***	S***	MH,FI,LC
2.3 (k,i,q), years: 2005-06	tie	LC**	tie	S**	tie	LC**	tie	S***	tie	tie	S**	tie	S***	tie	tie	S,A

Notes: 1. *** = 1%, ** = 5%, * = 10% two-sided significance level, the better fitting model abbreviation is displayed; 2. Vuong statistic cutoffs: >2.575 = ***; >1.96 = **; >1.645 = *; <1.645 = "tie"

Thai data – robustness

- More robustness checks (Table 9)
- risk neutrality
- fixed measurement error variance
- allowing quadratic adjustment costs in investment
- different grids and samples (alternative definitions of assets; region, household and time fixed effects removed)
- hidden output and unobserved investment regimes

Table 9 - Model Comparisons[1] using Thai Data - Robustness Runs (**UPDATED**)

Comparison	MH v FI	MH v LC	MH v B	MH v S	MH v A	FI v LC	FI v B	FI v S	FI v A	LC v B	LC v S	LC v A	B v S	B v A	S v A	Best Fit
1. Risk neutrality																
1.1 (c,q) data	MH***	LC***	B***	S***	A***	LC***	B***	S***	A***	B***	S***	A***	S***	B**	S***	S
1.2 (k,i,q) data	tie	tie	B***	S***	A***	tie	B***	S***	A***	B***	S***	A***	B***	B***	A***	B
1.3 (c,q,i,k) data	MH***	tie	B***	S***	A***	LC***	B***	S***	A***	B***	S***	A***	S**	tie	S***	S
2. Fixed measurement error variance																
2.1 (c,q) data	tie	tie	MH***	MH***	MH***	tie	FI***	FI***	FI***	LC***	LC**	LC***	S***	B***	S***	MH,FI,LC
2.2 (k,i,q) data	tie	MH***	B***	S***	A***	FI***	B***	S***	A***	B***	S***	A***	S***	B***	S***	S
2.3 (c,q,i,k) data	FI***	tie	B***	S***	A***	FI***	B***	S***	A*	B***	S***	A***	S***	tie	S***	S
3. Investment adjustment costs																
3.1. (c,q) data	MH**	tie	tie	MH*	MH***	tie	tie	tie	FI***	tie	tie	LC***	B*	B***	S***	MH,B,LC
3.2 (k,i,q) data	tie	LC**	B***	S***	A***	LC**	B***	S***	A***	B***	S***	A***	S*	A*	tie	S,A
3.3 (c,q,i,k) data	tie	MH***	tie	S**	MH**	FI***	tie	tie	FI***	B***	S***	A***	S**	B***	S***	S,FI
4. Removed fixed effects																
4.1 removed year fixed effects, cqik	tie	tie	B***	S***	A***	tie	B***	S***	A***	B***	S***	A*	S*	tie	S*	S
4.2 removed fixed effects (yr+hh), kiq	tie	tie	B*	S***	A***	tie	B*	S***	A***	B*	S***	A***	S***	A***	S*	S
4.3 removed fixed effects (yr+hh), cq	MH*	MH***	MH***	MH***	MH***	tie	FI***	FI**	FI***	LC***	LC***	LC***	S***	B***	S***	MH
4.4 removed fixed effects (yr+hh), cqik	MH***	tie	MH***	MH***	MH***	LC***	FI***	FI***	FI***	LC***	LC***	LC***	S***	B***	S***	LC,MH
4.5 removed fixed effects, param. pr. f-n	FI**	LC***	tie	tie	MH***	LC***	tie	tie	FI***	LC***	LC***	LC***	tie	B***	S***	LC
5. Other robustness runs (with 1999-00 c,q,i,k data unless otherwise indicated)																
5.1 alternative assets definition	tie	MH***	MH**	S***	tie	FI***	FI**	S***	tie	B***	S***	A***	S***	A***	tie	S,A
5.2 alternative income definition	MH***	MH***	tie	S*	tie	FI***	B**	S***	A***	B***	S***	A***	S***	tie	S***	S
5.3 alternative interest rate, R=1.1	tie	tie	B***	S***	A*	tie	B***	S***	A*	B***	S***	A**	tie	B***	S***	S,B
5.4 alternative depreciation rate, δ=0.1	FI***	LC***	B***	S***	A***	FI*	B***	S***	A**	B***	S***	A***	tie	B*	S***	S,B
5.5 coarser grids	MH***	MH***	B***	S***	A***	FI***	B***	S***	A***	B***	S***	A***	B**	B***	S***	B
5.6 denser grids	MH***	LC***	B***	S***	A***	LC***	B***	S***	A***	B***	S***	A***	tie	B***	S***	B,S
5.7 generalized effort disutility form	FI***	tie	B***	S***	A*	tie	B***	S***	tie	B***	S***	tie	S***	B***	S***	S
5.8 mixture of normals b,w distributions	MH***	MH***	B***	S***	tie	FI***	B***	S***	A*	B***	S***	A***	S***	tie	S***	S

6. Runs with hidden output (HO) and unobserved investment (UI) models[2]

	Rural data							Urban data						
	v MH	v FI	v B	v S	v A	v LC	Best fit	v MH	v FI	v B	v S	v A	v LC	Best fit
6.1 hidden output model, cqik	tie	tie	B***	S***	A***	LC**	B,S	HO***	HO***	HO***	HO***	HO***	HO***	HO
6.2 unobserved investment model, cqik	UI***	UI***	B***	S***	tie	UI***	B	UI***	UI***	UI***	UI***	UI***	LC*	LC

1. *** = 1%, ** = 5%, * = 10% Vuong (1989) test two-sided significance level. Listed is the better fitting model or "tie" if the models are tied. Sample size is n=531; data are for 1999-00 unless noted otherwise.
2. For computational reasons (incompatibility between the k, q estimation grids and the non-parametric production funcion) the HO model is computed with the parametric production function (read with table 8); the UI model is computed with coarser grids (read with line 5.5 above).

Estimation runs with simulated data

- **Generating simulated data** – use the MH regime as baseline
  - fix baseline grids and parameters, ϕ^{base} (Table 10)
  - generate initial state distribution $D(k, w)$: here we set $H(k)$ to have equal number of data points at each element of K and, for each k, draw w from $N(\mu_w, \gamma_w^2)$ (can use mixtures of normals)
  - solve the MH dynamic program and generate simulated data for c, q, i, k; sample size $n = 1000$
  - allow measurement error in all variables, $\varepsilon \sim N(0, \gamma_{me}^2)$ (apply to simulated data)
  - two specifications: "low measurement error" with $\gamma_{me} = .1$ of each variable's grid span and "high measurement error" with $\gamma_{me} = .2$ of grid span

Table 10 - Parameter Estimates using Simulated Data from the Moral Hazard (MH) Model

Assets, investment and income, (k,i,q) data

Model	γ_{me}	σ	θ	ρ	$\mu_{w/b}$ [1]	$\gamma_{w/b}$	LL Value[2]
Moral hazard - MH *	0.0935	0.6557	0.1000	0.2212	0.8289	0.0778	**-1.0695**
	(0.0019)	*(0.0144)*	*(0.0001)*	*(0.0079)*	*(0.0008)*	*(0.0029)*	
Full information - FI *	0.0937	0.5495	0.1000	0.2720	0.8111	0.1078	**-1.0692**
	(0.0019)	*(0.0648)*	*(0.0011)*	*(0.0291)*	*(0.0081)*	*(0.0105)*	
Limited commitment - LC	0.1053	1.3509	1.1087	-4.2141	0.4483	0.5468	**-1.2410**
	(0.0032)	*(0.0916)*	*(0.0037)*	*(11.645)*	*(0.0408)*	*(0.0003)*	
Borrowing & Lending - B	0.1011	1.0940	1.0811	-1.5783	0.0096	0.9995	**-1.1821**
	(0.0021)	*(0.0782)*	*(0.1352)*	*(2.6279)*	*(0.0003)*	*(0.0683)*	
Saving only - S	0.0972	0.5000	1.2043	-1.8369	0.5184	0.1697	**-1.1407**
	(0.0025)	*(0.0000)*	*(0.0000)*	*(0.0000)*	*(0.0104)*	*(0.0076)*	
Autarky - A	0.2927	0.0000	2.0000	2.2117	n.a.	n.a.	**-2.5390**
	(0.0046)	*(0.1431)*	*(0.5000)*	*(1.4179)*	n.a.	n.a.	
baseline parameters	*0.1000*	*0.5000*	*2.0000*	*0.0000*	*0.5000*	*0.3500*	

Consumption and income, (c,q) data

Model	γ_{me}	σ	θ	ρ	$\mu_{w/b}$	$\gamma_{w/b}$	LL Value
Moral hazard - MH *	0.1041	0.4851	2.7887	-0.2338	0.4780	0.2867	**-0.1462**
	(0.0022)	*(0.0188)*	*(0.0742)*	*(0.6062)*	*(0.0098)*	*(0.0117)*	
Full information - FI	0.1102	0.4462	0.0934	-1.2892	0.5056	0.2644	**-0.1784**
	(0.0027)	*(0.0000)*	*(0.0001)*	*(11.694)*	*(0.0108)*	*(0.0180)*	
Limited commitment - LC	0.1157	1.1782	1.2024	-10.9857	0.2276	0.6321	**-0.2185**
	(0.0019)	*(0.0032)*	*(0.0334)*	*(1.6645)*	*(0.0279)*	*(0.0375)*	
Borrowing & Lending - B	0.1160	0.6007	0.1544	-1.5090	0.5202	0.3489	**-0.2182**
	(0.0023)	*(0.0000)*	*(0.0043)*	*(0.0170)*	*(0.0178)*	*(0.0312)*	
Saving only - S	0.1077	0.0000	1.9849	3.0075	0.4204	0.4527	**-0.1842**
	(0.0020)	*(0.0000)*	*(0.4816)*	*(0.0445)*	*(0.0278)*	*(0.0272)*	
Autarky - A	0.1868	0.0276	0.9828	0.2036	n.a.	n.a.	**-0.7443**
	(0.0122)	*(0.0124)*	*(0.0004)*	*(0.0271)*	n.a.	n.a.	
baseline parameters	*0.1000*	*0.5000*	*2.0000*	*0.0000*	*0.5000*	*0.3500*	

Assets, consumption, investment, and income, (c,q,i,k) data

Model	γ_{me}	σ	θ	ρ	$\mu_{w/b}$	$\gamma_{w/b}$	LL Value
Moral hazard - MH *	0.0952	0.5426	2.1951	0.2267	0.5005	0.3464	**-0.8952**
	(0.0020)	*(0.0079)*	*(0.0889)*	*(0.0162)*	*(0.0119)*	*(0.0097)*	
Full information - FI	0.1358	0.5436	0.0967	-6.4718	0.5567	0.2862	**-1.4184**
	(0.0029)	*(0.0167)*	*(0.0021)*	*(1.3883)*	*(0.0127)*	*(0.0082)*	
Limited commitment - LC	0.1381	1.2000	0.1239	-36.3392	0.2654	0.5952	**-1.4201**
	(0.0031)	*(0.0114)*	*(0.0009)*	*(2.7831)*	*(0.0212)*	*(0.0211)*	
Borrowing & Lending - B	0.1339	1.2000	7.7164	-3.0189	0.4048	0.3238	**-1.5624**
	(0.0036)	*(0.2416)*	*(0.0000)*	*(20.484)*	*(0.0135)*	*(0.0134)*	
Saving only - S	0.1678	0.0000	0.0727	-1.1738	0.3818	0.2771	**-1.7803**
	(0.0040)	*(0.0000)*	*(0.0004)*	*(0.0028)*	*(0.0212)*	*(0.0230)*	
Autarky - A	0.3302	1.2000	0.1000	0.4681	n.a.	n.a.	**-3.0631**
	(0.0042)	*(0.3634)*	*(0.2738)*	*(0.6550)*	n.a.	n.a.	
baseline parameters	*0.1000*	*0.5000*	*2.0000*	*0.0000*	*0.5000*	*0.3500*	

1. $\mu_{w/b}$ and $\gamma_{w/b}$ (the mean and standard deviation of the w or b initial distribution) are reported relative to the variables' grid range

2. Normalized (divided by n) log-likelihood values;

3. Bootstrap standard errors are in parentheses below each parameter estimate.

* denotes the best fitting regime (including tied)

All runs use data with sample size n=1000 generated from the MH model at the *baseline parameters*

Table 11 - Model Comparisons using Simulated Data[1] - Vuong Test Results

Comparison	MH v FI	MH v LC	MH v B	MH v S	MH v A	FI v LC	FI v B	FI v S	FI v A	LC v B	LC v S	LC v A	B v S	B v A	S v A	Best Fit
1. Using (k,i,q) data																
1.1 low measurement error	tie	MH***	MH***	MH***	MH***	FI***	FI***	FI***	FI***	LC***	LC***	LC***	S**	B***	S***	MH,FI
1.2 high measurement error	tie	tie	tie	tie	MH***	tie	B**	tie	FI***	tie	tie	LC***	tie	B***	S***	all but A
2. Using (c,q) data																
2.1 low measurement error	MH***	MH***	MH***	MH***	MH***	FI***	FI**	tie	FI***	tie	S*	LC***	S**	B***	S***	MH
2.2 high measurement error	FI***	tie	B*	MH*	MH***	tie	tie	FI***	FI***	tie	tie	LC***	B***	B***	S***	B,FI
3. Using (c,q,i,k) data																
3.1 low measurement error	MH***	MH***	MH***	MH***	MH***	tie	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	MH
3.2 high measurement error	tie	MH***	MH***	MH***	MH***	FI***	FI***	FI***	FI***	LC**	LC***	LC***	B***	B***	S***	MH,FI
4. Two-year (c,q) panel, t = 0, 1																
4.1 low measurement error	MH***	MH***	MH***	MH***	MH***	FI***	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	MH
4.2 high measurement error	tie	tie	MH***	MH***	MH***	tie	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	MH,FI,LC
5. Robustness runs with simulated data[2]																
5.1 sample size n = 200	MH***	MH***	MH***	MH***	MH***	tie	tie	FI***	FI***	tie	LC***	LC***	B***	B***	S***	MH
5.2 sample size n = 5000	MH***	MH***	MH***	MH***	MH***	tie	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	MH
5.3 coarser grids	MH***	MH***	MH***	MH***	MH***	FI***	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	MH
5.4 denser grids used to simulate data	MH***	MH***	MH***	MH***	MH***	FI**	FI***	FI***	FI***	LC***	LC***	LC***	B**	B***	S***	MH
5.5 (c,q) data long panel (t = 0, 50)	MH***	MH***	MH***	MH***	MH***	FI***	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	MH
5.6 (c,q) data from t = 1,000	MH**	MH***	MH***	MH***	MH***	FI**	FI***	FI***	FI***	LC***	LC***	LC***	S**	B***	S***	MH
5.7 zero meas. error in simulated data	MH***	MH***	MH***	MH***	MH***	FI***	tie	FI*	FI***	B*	tie	LC***	B***	B***	S***	MH
5.8 data simulated at MLE estimates	MH***	MH***	MH***	MH***	MH***	tie	tie	tie	FI***	LC*	LC***	LC***	tie	B***	S***	MH
5.9 sim. data from S, removed fixed effects	MH***	MH***	B***	S***	A***	FI***	B***	S***	A***	B***	S***	A***	tie	B***	S***	B,S
5.10 simulated data from the LC regime	FI***	LC***	MH***	MH***	MH***	LC***	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	LC
6. Runs with heterogeneity in the simulated data																
6.1 heterogeneous productivity	MH***	MH***	MH***	MH***	MH***	tie	tie	FI***	FI***	tie	LC***	LC***	B***	B***	S***	MH
6.2 heterogeneous risk aversion	MH***	MH***	MH***	MH***	MH***	FI**	FI***	FI***	FI***	LC***	LC***	LC***	B***	B***	S***	MH
6.3 heterogeneous interest rates	MH***	MH***	MH***	MH***	MH***	FI***	tie	FI***	FI***	tie	LC***	LC***	B***	B***	S***	MH

1. *** = 1%, ** = 5%, * = 10% two-sided significance level, the better fitting model regime's abbreviation is displayed. Data-generating model is MH and sample size is n = 1000 unless stated otherwise.
2. these runs use (c,q,i,k) data simulated from the MH model and low measurement error ($\gamma_{me} = 0.1$) unless stated otherwise

Runs with simulated data – robustness

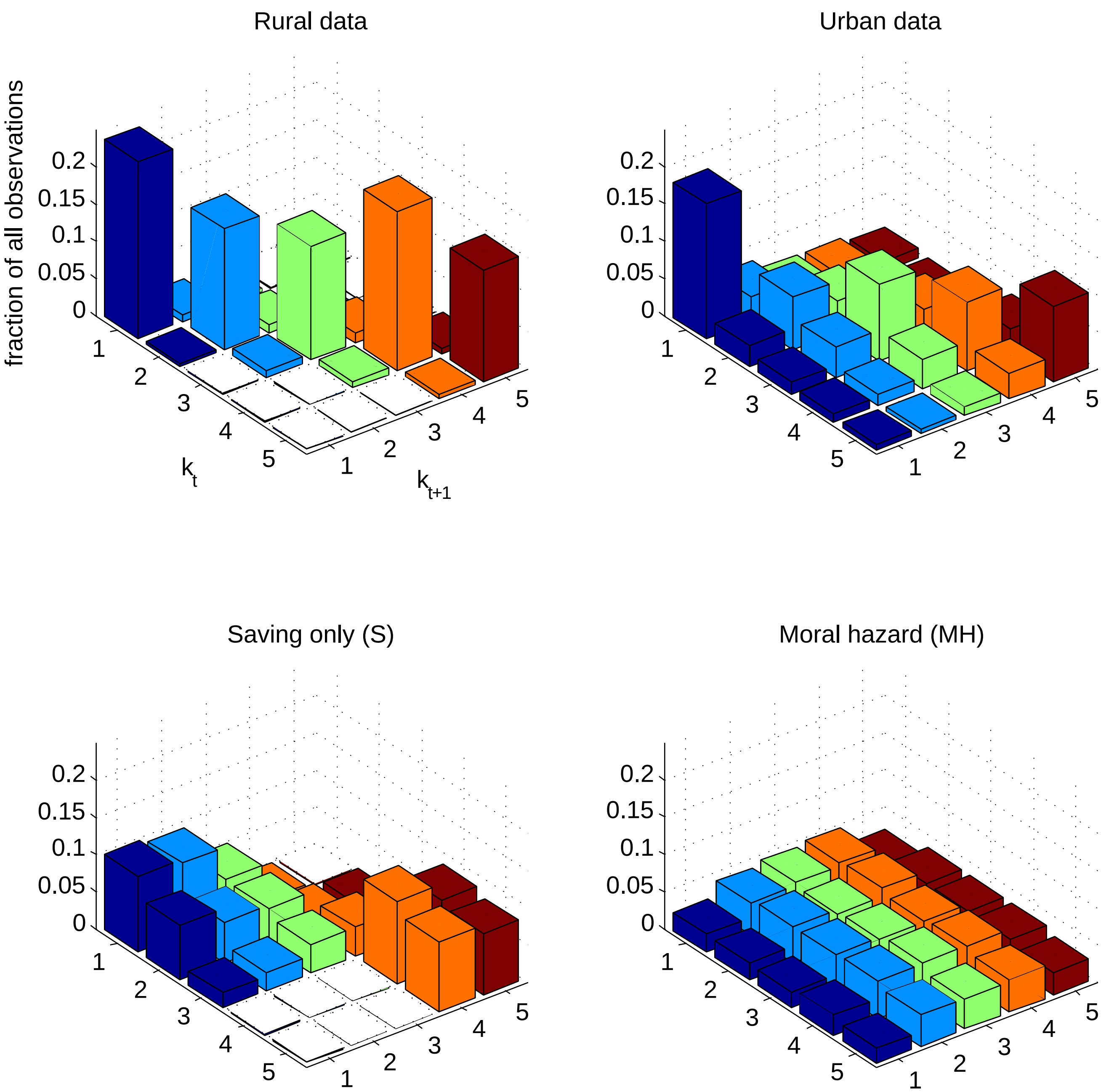
- smaller/larger sample or grid sizes, measurement error level; using estimated parameters

- **heterogeneity**: we also perform runs where we run the MH regime at different parameters or grids to generate a composite dataset with
  - *heterogeneity in productivity* (multiplying the Q grid by 10 factors on $[0.75, 1.25]$) or
  - *heterogeneity in risk aversion* (three values for σ based on Schulhofer-Wohl and Townsend estimates, 0.62, 0.78 and 1.4).

Into the MLE 'black box'

- Thai vs. simulated data – assets persistence (Fig. 3)
  - a data feature all models (S,B the least) struggle to match well is the extremely high persistence of capital k in the Thai rural data
  - urban data closer to MH regime
  - evidence for infrequent investment in the data (once every 30-40 months on average) – Samphantharak and Townsend, 09

Figure 3: Thai vs. simulated data; business assets transition matrix

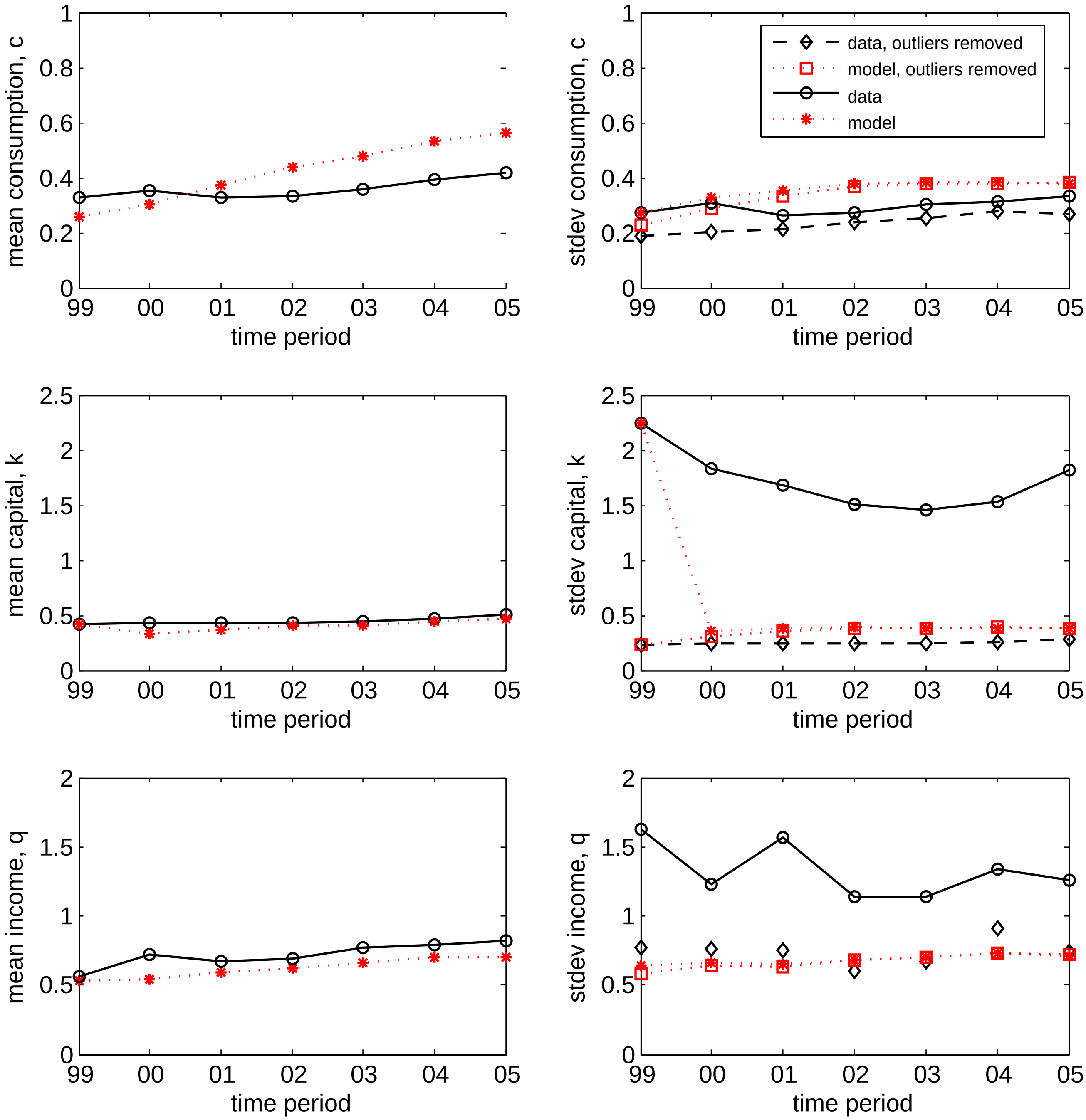


Note: axis labels corresponds to k percentiles; 1 is 10th, 5 is 90th; values larger than $4*10^{-3}$ plotted in color

Into the MLE 'black box'

- Thai vs. simulated data – time paths (Fig. 4)

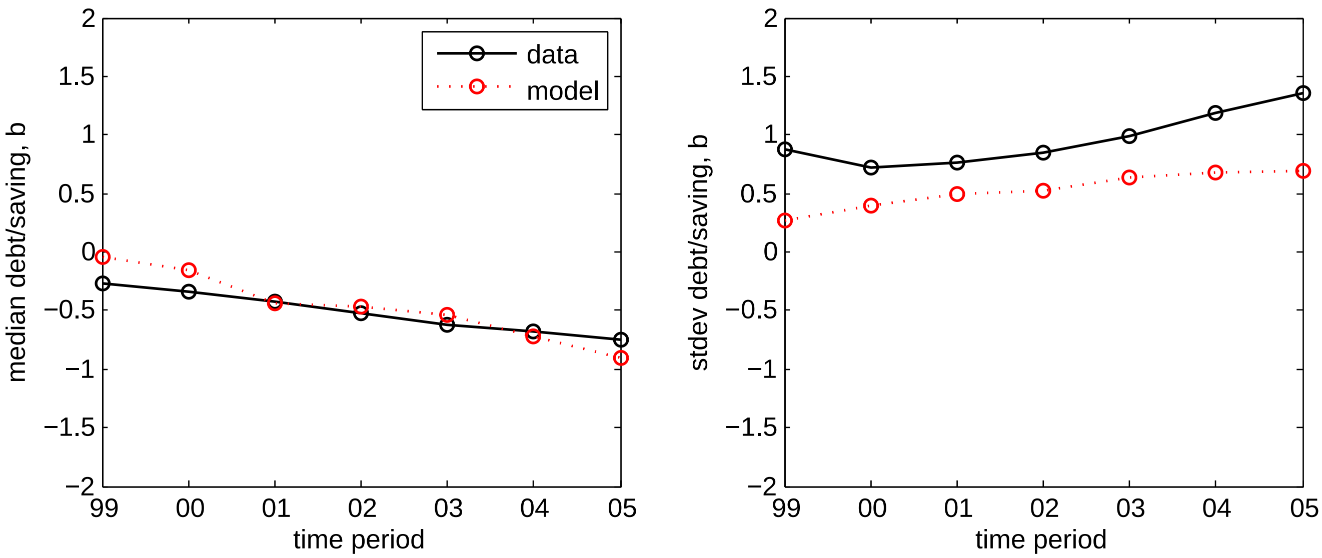
Figure 4: Thai vs. Simulated data − Time Paths



Into the MLE 'black box'

- Thai vs. simulated data – financial net worth (Fig. 5)

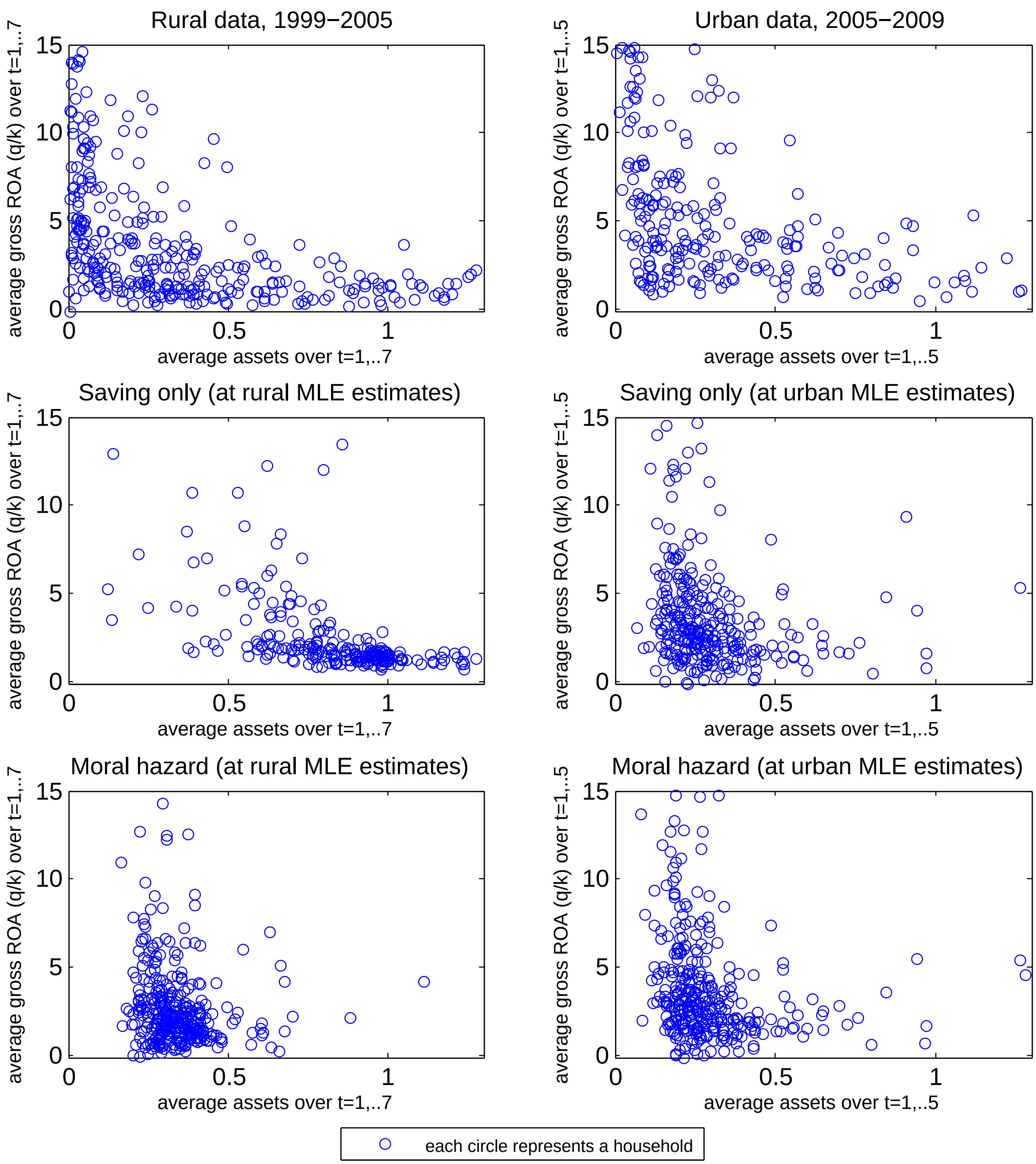
Figure 5: Thai vs. simulated data − savings



Into the MLE 'black box'

- Thai vs. simulated data – ROA (Fig. 6)

Figure 6 − Thai vs. simulated data − return on assets



Into the MLE 'black box'

- alternative measure of fit, $D^m = \sum_{j=1}^{\#s} \frac{(s_j^{data} - s_j^m)^2}{|s_J^{data}|}$ where s_j denote various moments of c, q, i, k (mean, median, stdev, skewness, correlations)

model, $m =$	**MH**	**FI**	**B**	**S**	**A**	**LC**
criterion value (rural), $D^m =$	321.1	395.4	38.5	**20.8**	28.1	6520
criterion value (urban), $D^m =$	36.8	**32.0**	36.4	35.3	35.4	236.7

Thai data – GMM robustness checks – consumption

- Based on Ligon (1998), run a consumption-based Euler equation GMM estimation (*this method uses c time-series data alone) to test:
  - the 'standard EE', $u'(c_t) = \beta R E u'(c_{t+1})$ in the B model vs.
  - the 'inverse EE', $\frac{1}{u'(c_t)} = \frac{1}{\beta R} E(\frac{1}{u'(c_{t+1})})$ in the MH model
  - assuming CRRA utility the sign of the GMM estimate of parameter b ($= -\sigma$ or σ depending on regime) in the moment equation $E_t(h(\xi_{it}^b, b)) = 0$ where $\xi_{it} = \frac{c_{i,t+1}}{c_{it}}$ is used to distinguish B vs. MH
  - additional pre-determined variables (income, capital, average consumption) can be used as instruments

- Result: further evidence favoring the exogenously incomplete regimes in the Thai rural data.

Table 13: Consumption Euler equation GMM test as in Ligon (1998), rural sample

Instruments	b	std. error	[95% conf.	interval]	J-test
---	-0.3358*	0.0602	-0.454	-0.218	n.a.
income	-0.3257*	0.0546	-0.433	-0.219	1.006
income, capital	-0.3365*	0.0499	-0.434	-0.239	2.389
income, capital, avg. consumption	-0.3269*	0.0492	-0.423	-0.231	2.793

Notes:
1. b is the estimate of the risk aversion coefficient; assuming households are risk-averse, a negative b suggests the correct model is B (standard EE); a positive b suggests MH (inverse EE)
2. the estimates are obtained using continuous updating GMM (Hansen, Heaton and Yaron, 1996). Matlab code adapted from K. Kyriakoulis, using HACC_B method with optimal bandwidth.

Thai data – GMM robustness checks – investment

- Based on Arellano and Bond (1991) and Bond and Meghir (1994), run GMM of the investment Euler equation (*this method uses k, i, q panel data)
  - under the null of no financial constraints besides quadratic adjustment costs in investment, the coefficient β_3 on income, q in the regression

$$\left(\frac{i}{k}\right)_{jt} = \beta_1 \left(\frac{i}{k}\right)_{jt-1} + \beta_2 \left(\frac{i}{k}\right)^2_{jt-1} + \beta_3 \left(\frac{q}{k}\right)_{jt-1} + d_t + \eta_j + \varepsilon_{jt}$$

    should be negative
  - We find $\hat{\beta}_3 > 0$ (albeit insignificantly different from zero), thus rejecting the null of no financing constraints.
  - Consistent with MLE kiq results with adjustment costs (S, A win).
- Caveat: this method does not allow to distinguish the exact source of financing constraints.

Table 14: Investment Euler equation GMM test as in Bond and Meghir (1994), rural sample

Dynamic panel-data estimation, one-step difference GMM using lags of 2 or more for instruments

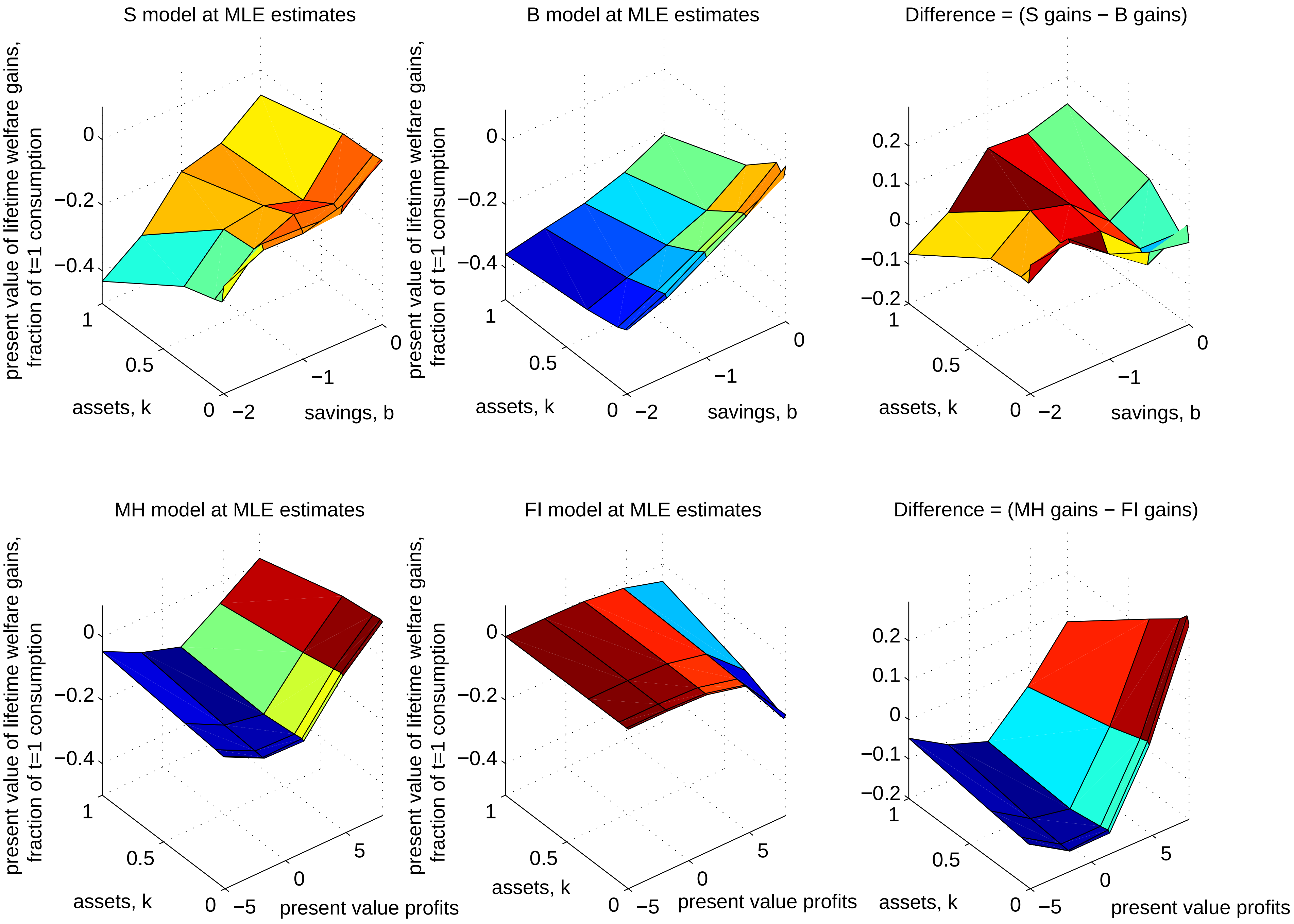
Group variable: household	Number of observations: 1552
Time variable : year	Number of groups: 388
Number of instruments = 24	Observations per group: 4

dependent variable = i_t / k_t	Coef	Robust st. err.	z	P > |z|	[95% conf. interval]	
i_{t-1} / k_{t-1}	0.3232775	0.0595142	5.43	0.000	0.2066317	0.43992
$(i_{t-1} / k_{t-1})^2$	-0.0965482	0.2777705	-0.35	0.728	-0.6409683	0.44787
q_{t-1} / k_{t-1}	0.0002172	0.0002812	0.77	0.440	-0.0003339	0.00077
year dummies	included					

Arellano-Bond test for AR(1) in first differences: z = -1.87 Pr > z = 0.061
Arellano-Bond test for AR(2) in first differences: z = -0.48 Pr > z = 0.628
Arellano-Bond test for AR(3) in first differences: z = 1.25 Pr > z = 0.211
Hansen test of overid. restrictions: chi2(17) = 22.29 Prob > chi2 = 0.174

Note: observations with zero assets (k) were excluded.

Figure 7: Policy experiment − reduction in the gross interest rate R from 1.05 to 1.025



Future work

- further work on the theory given our findings with the Thai data
  - multiple technologies, aggregate shocks, entrepreneurial ability, explicit adjustment costs
  - other regimes – costly state verification, limited enforcement
  - transitions between regimes

- data from other economies, e.g. Spain – more entry-exit, larger sample size (joint work with Ruano and Saurina)

- supply side – lenders' rules for access, regulatory distortions (Assuncao, Mityakov and Townsend, 09)

- computational methods – parallel processing; MPEC (Judd and Su, 09); NPL (Aguiregabirria and Mira; Kasahara and Shimotsu)

Moral hazard with unobserved investment (UI)

- **Structure**
  - unobserved: effort z; capital stock / investment k, i
  - observed: output q
  - dynamic moral hazard and adverse selection: both incentive and truth-telling constraints
  - the feasible promise functions set W is endogenously determined and iterated on together with V (Abreu, Pierce and Stacchetti, 1990)

- **LP formulation**
  - state variables: $k \in K$ and a vector of promises, $\mathbf{w} \equiv \{w(k_1), w(k_2), ...w(k_{\#K})\} \in \mathbf{W}$ (Fernandes and Phelan, 2000)
  - assume separable utility, $U(c, z) = u(c) - d(z)$ to divide the optimization problem into two sub-periods and reduce dimensionality; $\mathbf{w}_m$ – vector of interim promised utilities

Moral hazard with unobserved investment (UI) part 1

$$V(\mathbf{w},k) = \max_{\{\pi(q,z,\mathbf{w}_m|\mathbf{w},k)\}} \sum_{Q\times Z\times \mathbf{W}_m} \pi(q,z,\mathbf{w}_m|\mathbf{w},k)[q+V_m(\mathbf{w}_m,k)]$$

$$\text{s.t.} \quad \sum_{Q\times Z\times \mathbf{W}_m} \pi(q,z,\mathbf{w}_m|\mathbf{w},k)[-d(z)+w_m(k)] = w(k) \textit{ (promise keeping)}$$

s.t. *incentive-compatibility*, for all $\bar{z},\ \hat{z} \in Z$

$$\sum_{Q\times \mathbf{W}_m} \pi(q,\bar{z},\mathbf{w}_m|\mathbf{w},k)[-d(\bar{z})+w_m(k)] \geq \sum_{Q\times \mathbf{W}_m} \pi(q,\bar{z},\mathbf{w}_m|\mathbf{w},k)[-d(\hat{z})+w_m(k)]\frac{P(q|\hat{z},k)}{P(q|\bar{z},k)}$$

s.t. *truth-telling*, for all announced $\hat{k} \neq k \in K$, and all $\delta(z) : Z \to Z$

$$w(\hat{k}) \geq \sum_{Q\times Z\times \mathbf{W}_m} \pi(q,z,\mathbf{w}_m|\mathbf{w},k)[-d(\delta(z))+w_m(\hat{k})]\frac{P(q|\delta(z),\hat{k})}{P(q|z,k)}$$

and subject to Bayes consistency and adding-up

Moral hazard with unobserved investment (UI) part 2

$$V_m(\mathbf{w}_m, k) = \max_{\{\pi(\tau,k',\mathbf{w}'|\mathbf{w}_m,k)\},\{v(k,\hat{k},k',\tau)\}} \sum_{T\times K'\times \mathbf{W}'} \pi(\tau, k', \mathbf{w}'|\mathbf{w}_m, k)[-\tau + (1/R)V(k', \mathbf{w}')]$$

s.t., for all $\tau, k', \hat{k}', \hat{k} \neq k$, and $\hat{k}' \neq k'$

$$\sum_{\mathbf{W}'} \pi(\tau, k', \mathbf{w}'|\mathbf{w}_m, k)[u(\tau + (1-\delta)\hat{k} - \hat{k}') + \beta w'(\hat{k}')] \leq v(k, \hat{k}, k', \tau) \quad \textit{(utility bounds)}$$

$$\text{s.t.} \sum_{T\times K'} v(k, \hat{k}, k', \tau) \leq w_m(\hat{k}) \quad \textit{(threat keeping)}$$

$$\text{s.t. } w_m(k) = \sum_{T\times K\times \mathbf{W}'} \pi(\tau, k', \mathbf{w}'|\mathbf{w}_m, k)[u(\tau+(1-\delta)k-k')+\beta w'(k')] \quad \textit{(interim promise-keeping)}$$

and subject to Bayes consistency and adding-up.