Theoretical Production Restrictions and Measures of Technical Change in U.S. Agriculture

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Applied Production Analysis

Simple functional forms fully consistent with economic theory

Vs.

Flexible functional forms not fully consistent with economic theory

Recent example: Andersen, Alston, and Pardey (JPA 2012)

Output Elasticity wrt Labor:

- Cobb-Douglas: +, not statistically significant
- Translog: - , statistically significant.

Identifying the Problem

- If econometric estimates not fully consistent with economic theory…
- How robust are economic analyses and policy recommendations based on such estimates?

Problem: Lack of Counterfactuals

Main Goal

Investigate the consequences of failing to impose <u>concavity</u> and <u>monotonicity</u> in estimation on a flexible functional form of U.S. ag production:

- Pdfs of parm. estimates
- Characterization of production technology

Additional Contributions

- Technical Change estimates by State
- Technical Change vs. USDA's TFP
- Advocate for Bayesian estimation of flexible forms

Main take-home message

- Imposing concavity and monotonicity in estimation changes the characterization of U.S. agricultural technology.

The Model

- <u>Production function</u>: Generalized Quadratic

$$f(X,t) = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \beta_t t + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} x_i x_j + \sum_{i=1}^{n} \beta_{ti} x_i t + \frac{1}{2}\beta_{tt} t^2$$

$$\beta_{ij}=\beta_{ji}$$

- <u>Concavity</u>: max eigenvalue of H ≤0

$$H \equiv \nabla^2 f(X) = \begin{bmatrix} \beta_{11} & \cdots & \beta_{1n} \\ \vdots & \ddots & \vdots \\ \beta_{1n} & \cdots & \beta_{nn} \end{bmatrix},$$

- <u>Monotonicity</u>:

$$MPP_{x_i} = \frac{\partial f(X,t)}{\partial x_i} = \beta_i + \sum_{j=1}^{n} \beta_{ij} x_j + \beta_{ti} t \geq 0,$$

The Model

- Weak Essentiality:

$$f(0_n, t) = \beta_0 + \beta_t t + \frac{1}{2}\beta_{tt} t^2 = 0$$

Does not hold with a time trend.

Alternative Models	Conditions Imposed in Estimation		
	Concavity	Monotonicity @ Mean Input Levels	Monotonicity @ All Data Points
M1: Unrestricted	no	no	no
M2: Concavity	YES	no	no
M3: Mon@Mean	no	YES	no
M4: Conc+Mon@Mean	YES	YES	no
M5: Mon@All	no	no	YES
M6: Conc+Mon@All	YES	no	YES

Data

- USDA panel dataset on U.S. agricultural production (Ball et. al. 2004)
- 1 aggregate agricultural output
- 3 variable inputs: capital, labor, and materials
- 48 states
- 45 years: 1960-2004

Data (cont'd)

- Output: livestock, dairy, poultry, eggs, grains, oilseeds, cotton, tobacco, fruit, vegetables, nuts, and other miscellaneous outputs
- Capital: service flows of real estate, durable equipment and stocks of inventories.
- Labor: quality-adjusted amount of hired and self-employed labor.
- Materials: fertilizers, pesticides, energy and other miscellaneous inputs.

Descriptive Statistics (million $ 1996)

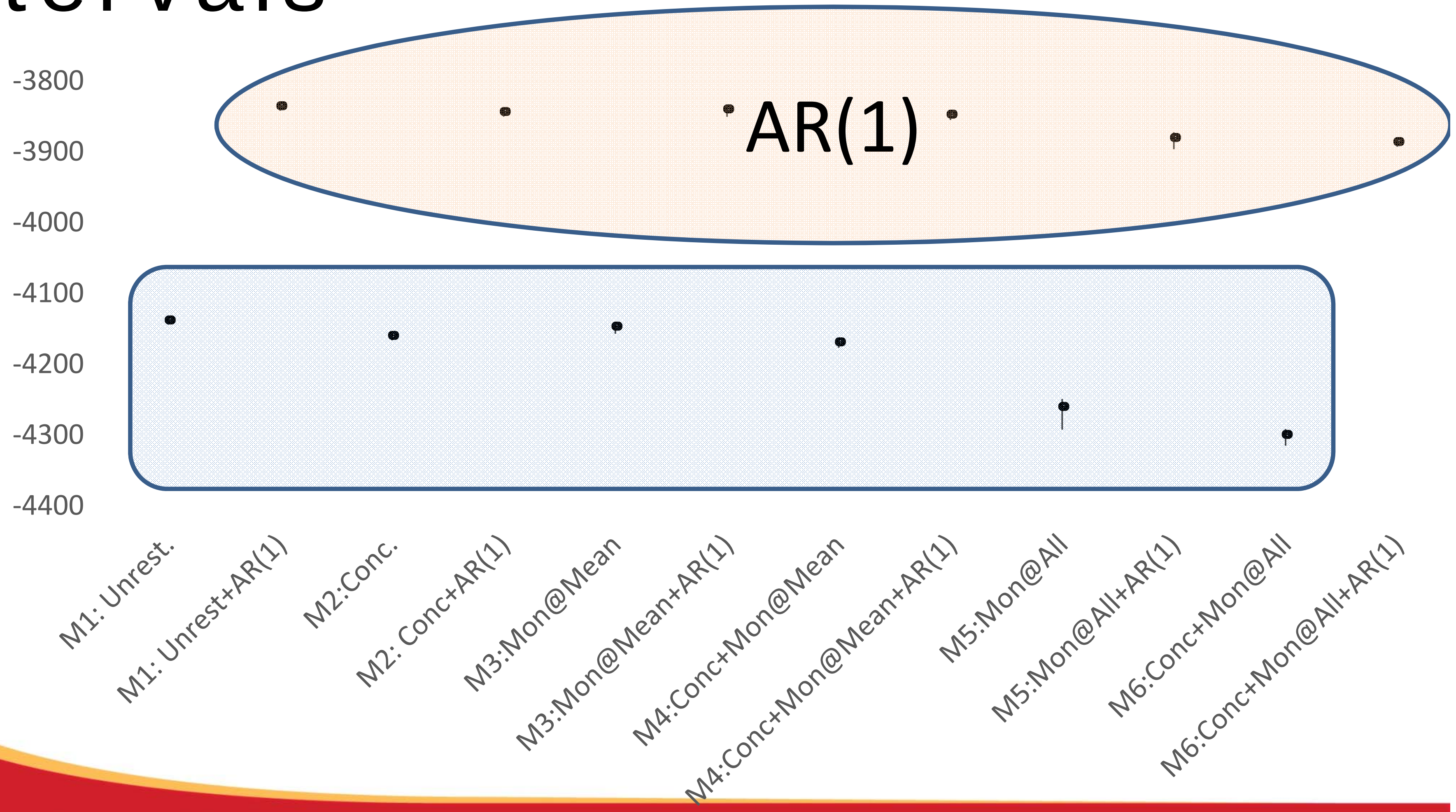
Implicit Quantity Index	Mean	Std. Dev.	Min	Max	N
Output	3,845.8	3,937.5	42.9	31,595.5	2,160
Materials	1,761.2	1,635.9	12.9	9,451.8	2,160
Capital	662.0	591.4	7.4	3,330.6	2,160
Labor	1,971.8	1,742.1	18.2	9,476.4	2,160

Source: USDA

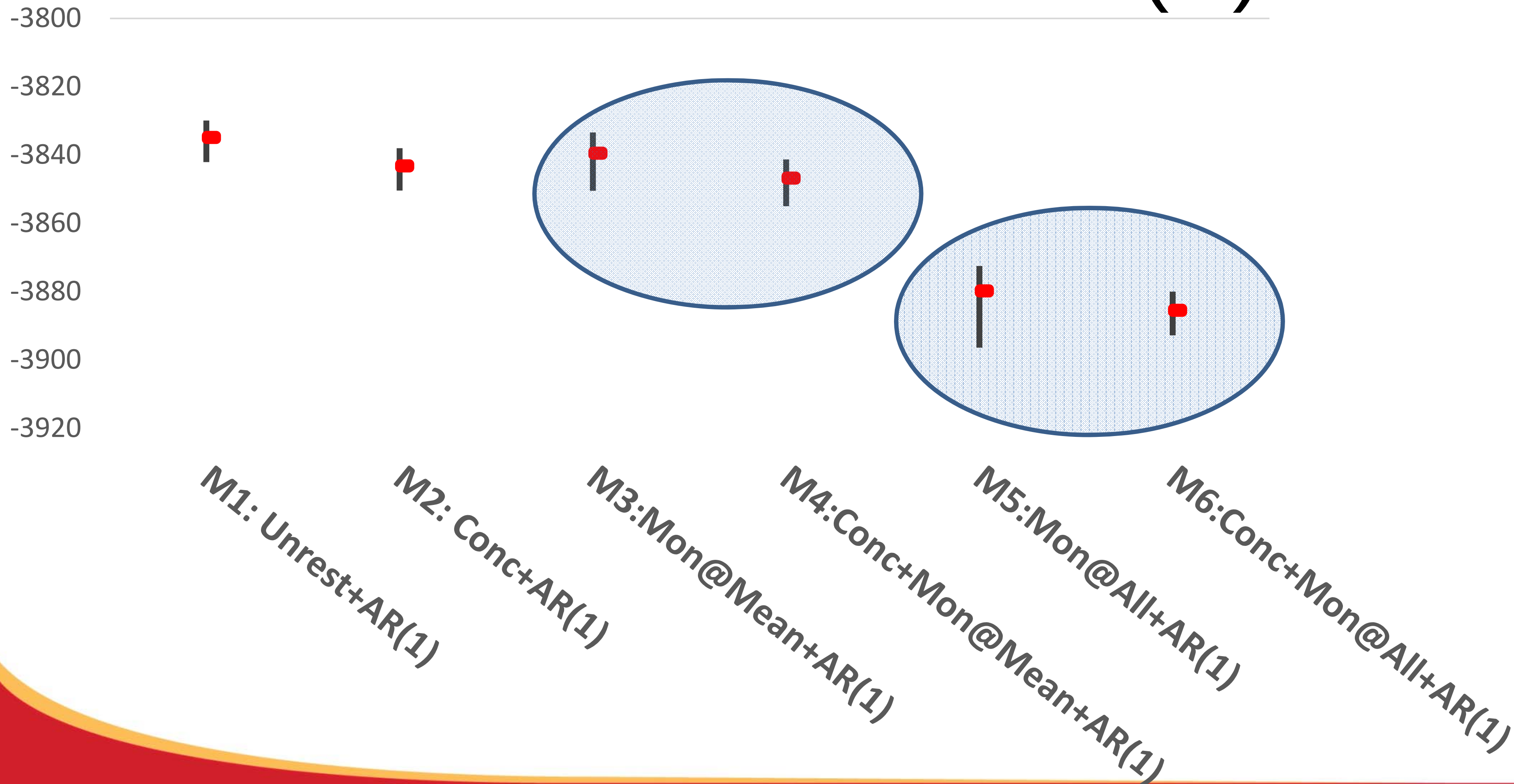
Estimation of Models 1-6

- 2 versions of M1-M6: AR(0), AR(1)
- Monte Carlo Markov Chain methods in R
- 4 chains of 5 million draws per chain
- First half of each chain discarded (burn-in)
- To avoid high correlation across sets of parameter estimates, only 1 every 5,000 ordered sets of par. est. is used
- 2,000 simulated values for each parameter

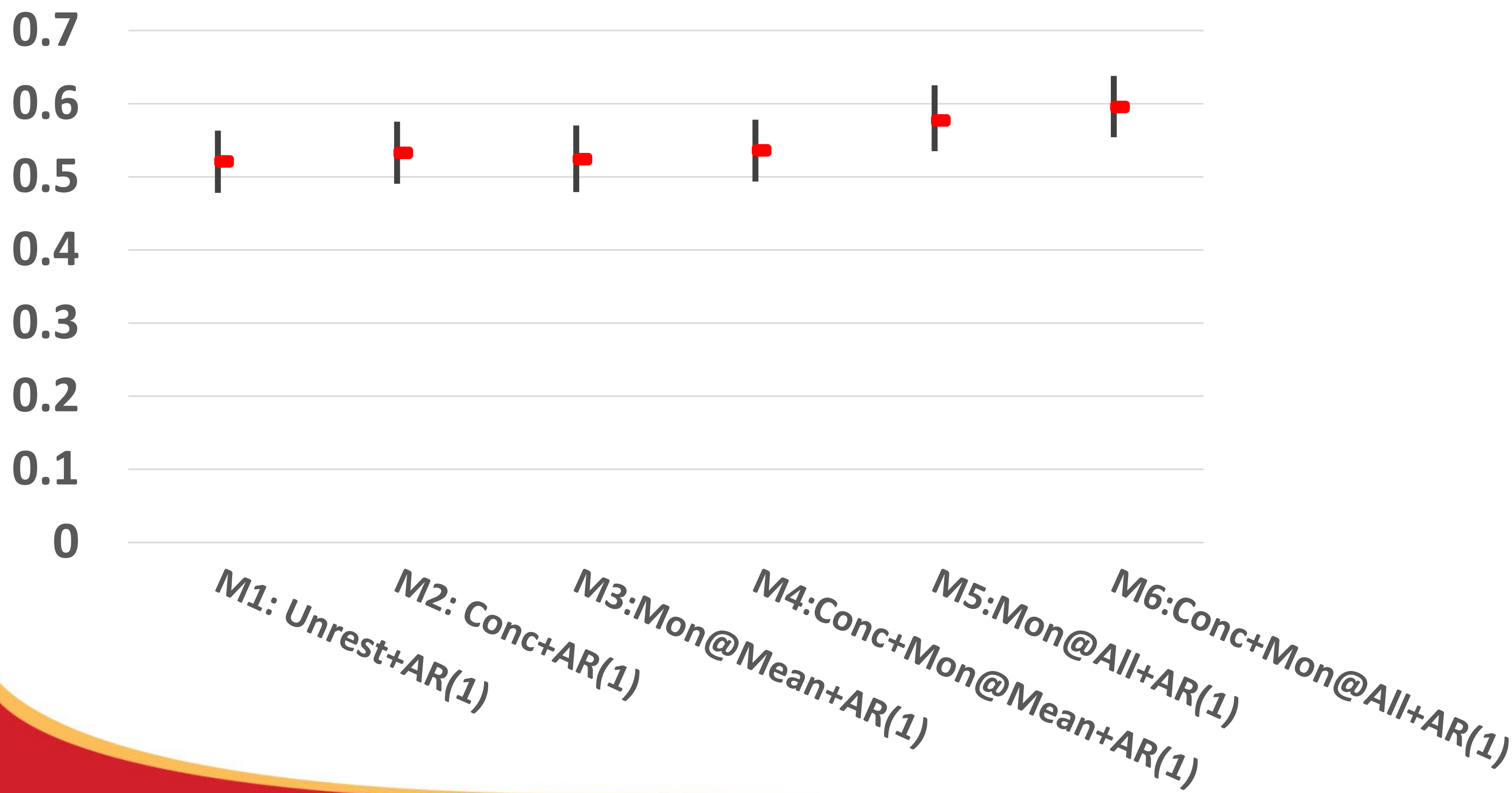
LikelihoodP: 95% Credible Intervals



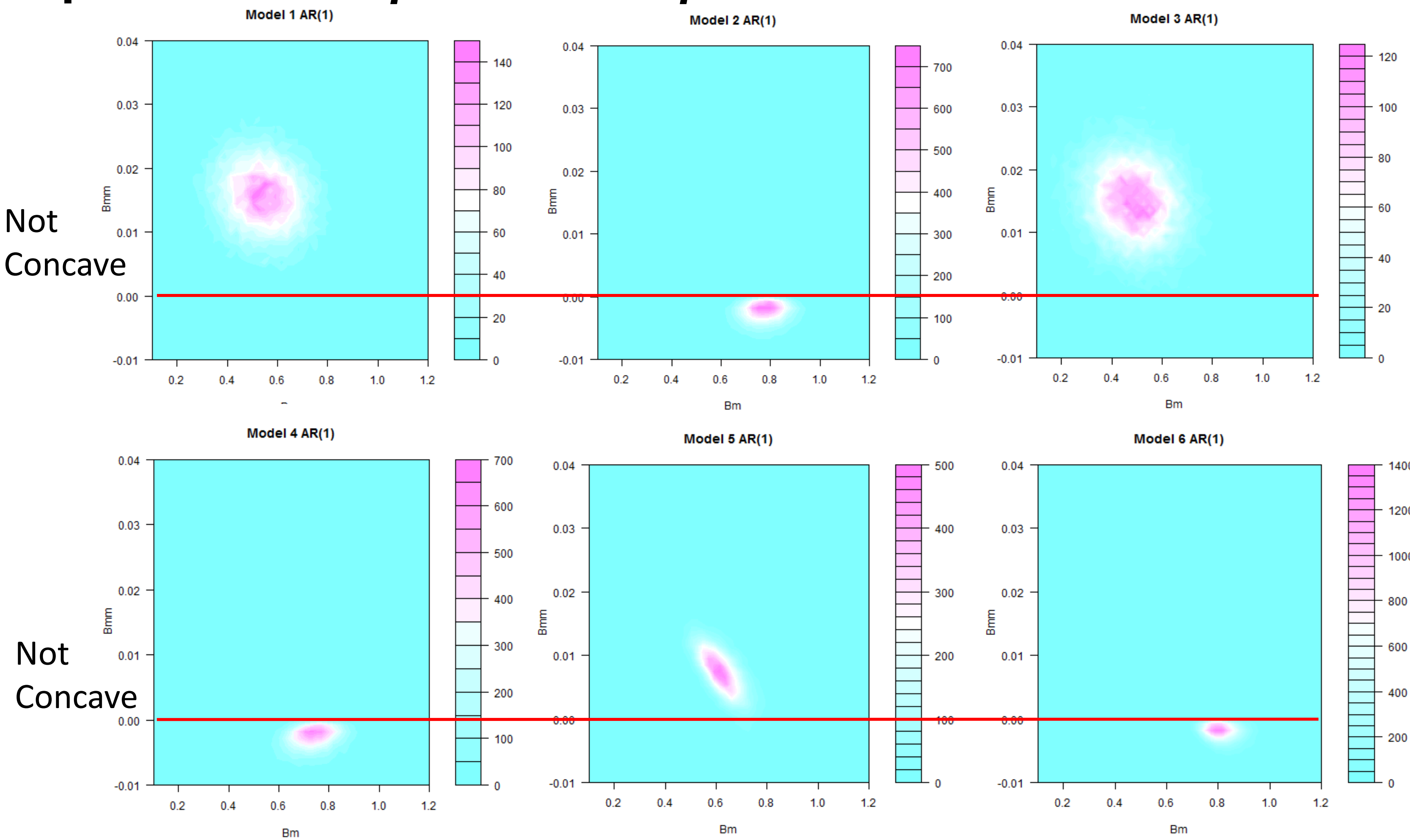
LikelihoodP: 95% Credible Intervals for M1-M6 AR(1)



95% Credible Intervals for ρ's

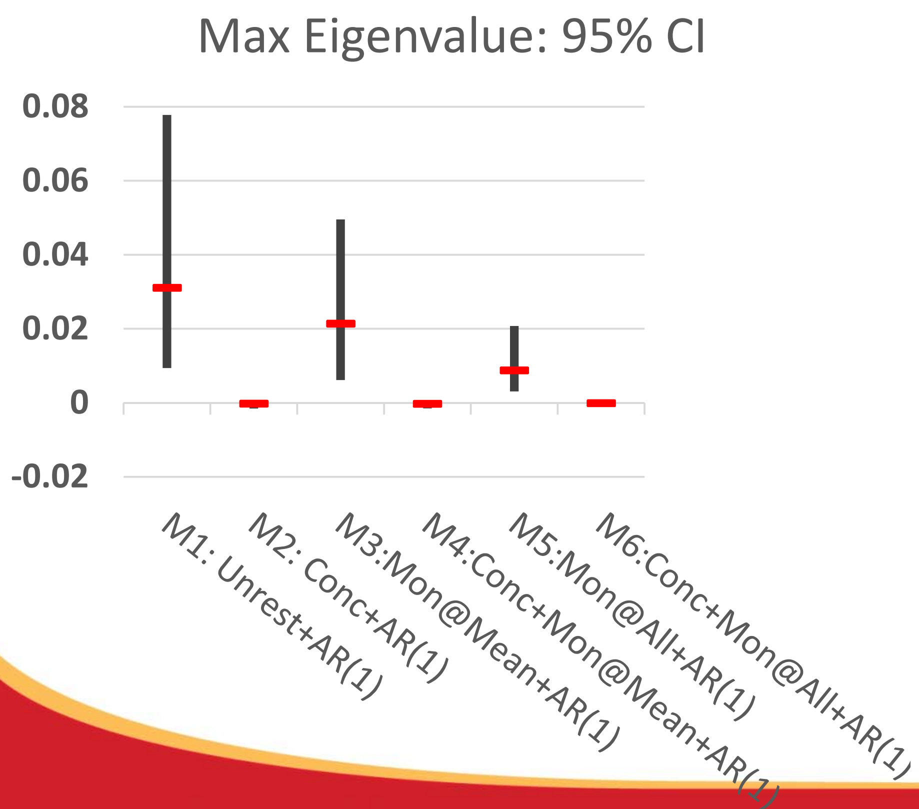


Example: bivariate posterior pdfs of β_M and β_{MM}

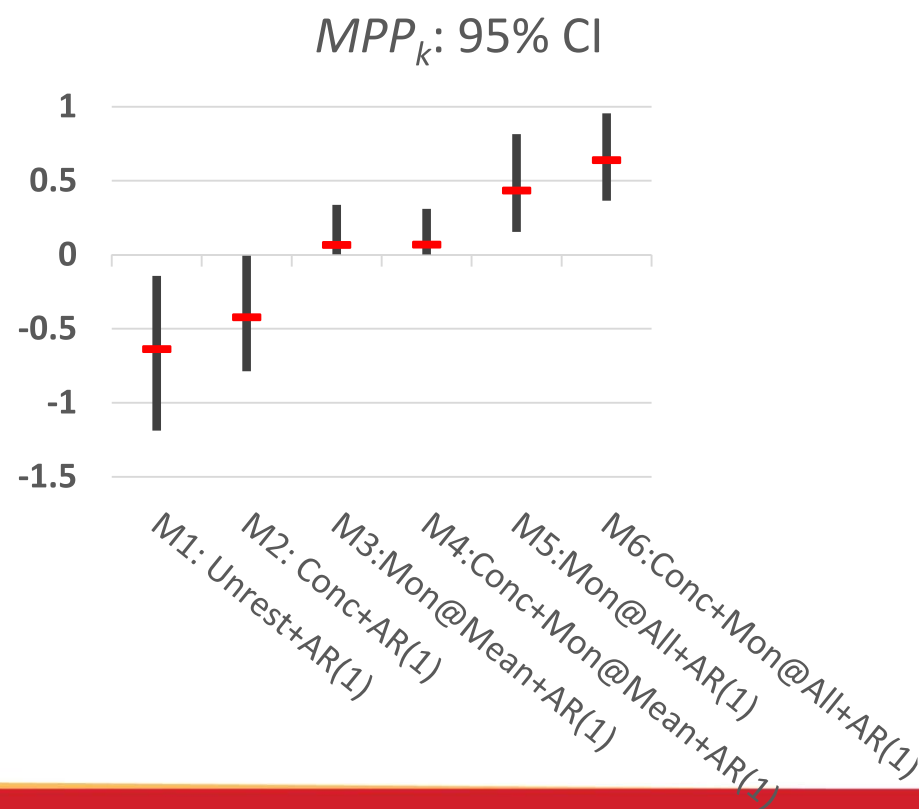


Concavity & Monotonicity

Concavity (Max Eig ≤0)



Monotonicity in Capital (MPP ≥0)



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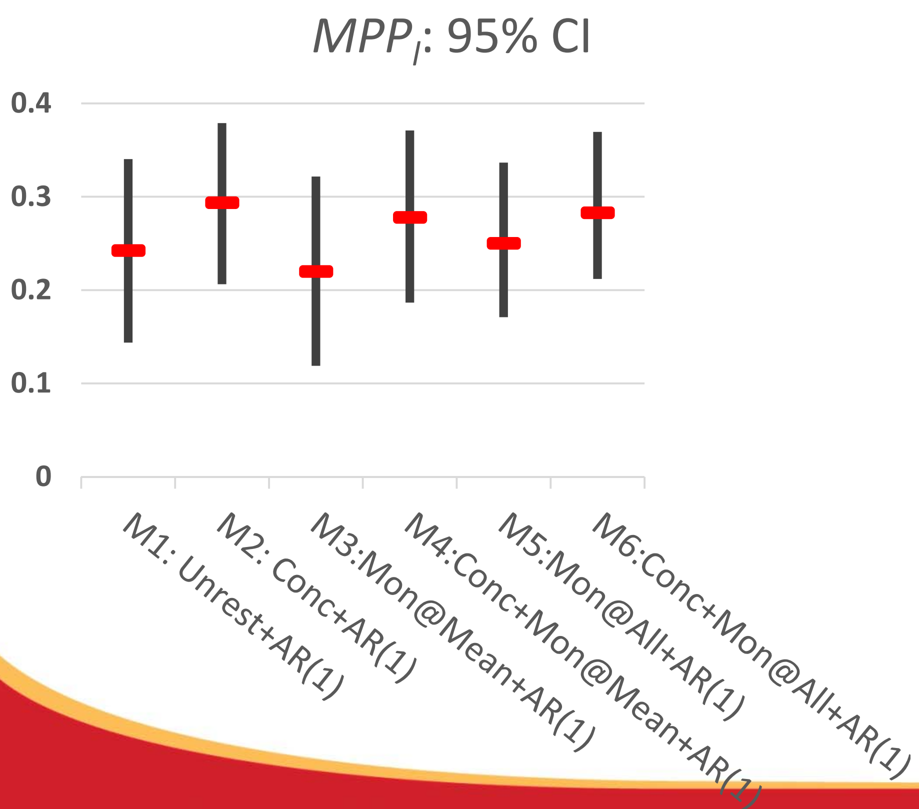
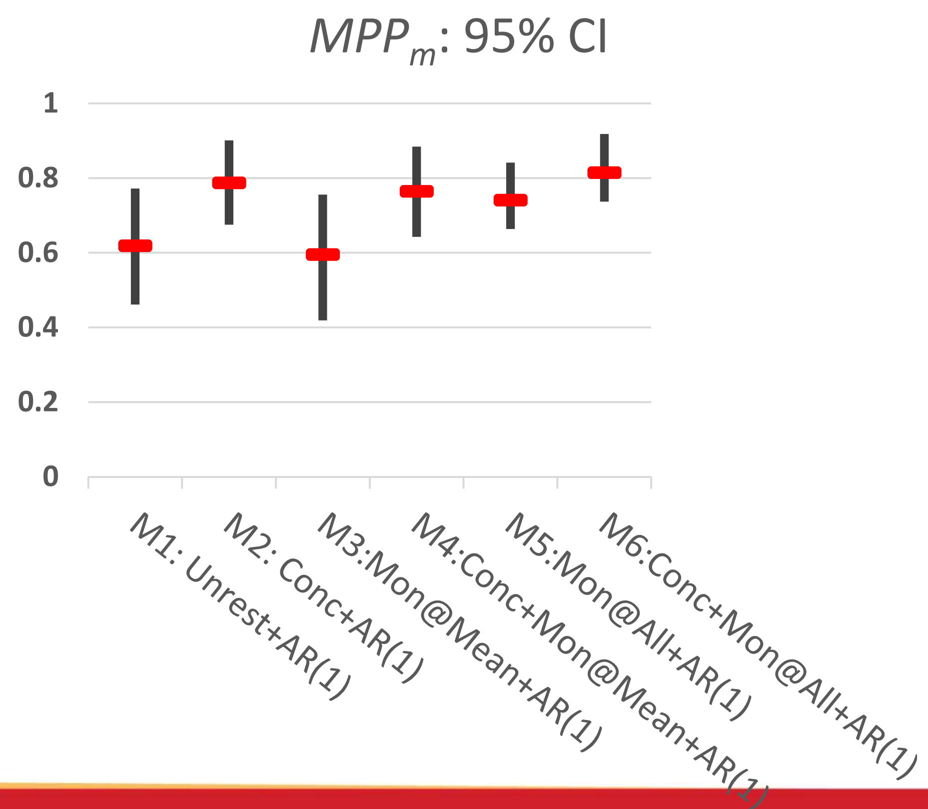
CONCAVITY & MONOTONICITY IN CAPITAL ONLY HOLD FOR M4 & M6

Monotonicity (Cont'd)

Monotonicity in Labor



Monotonicity in Materials



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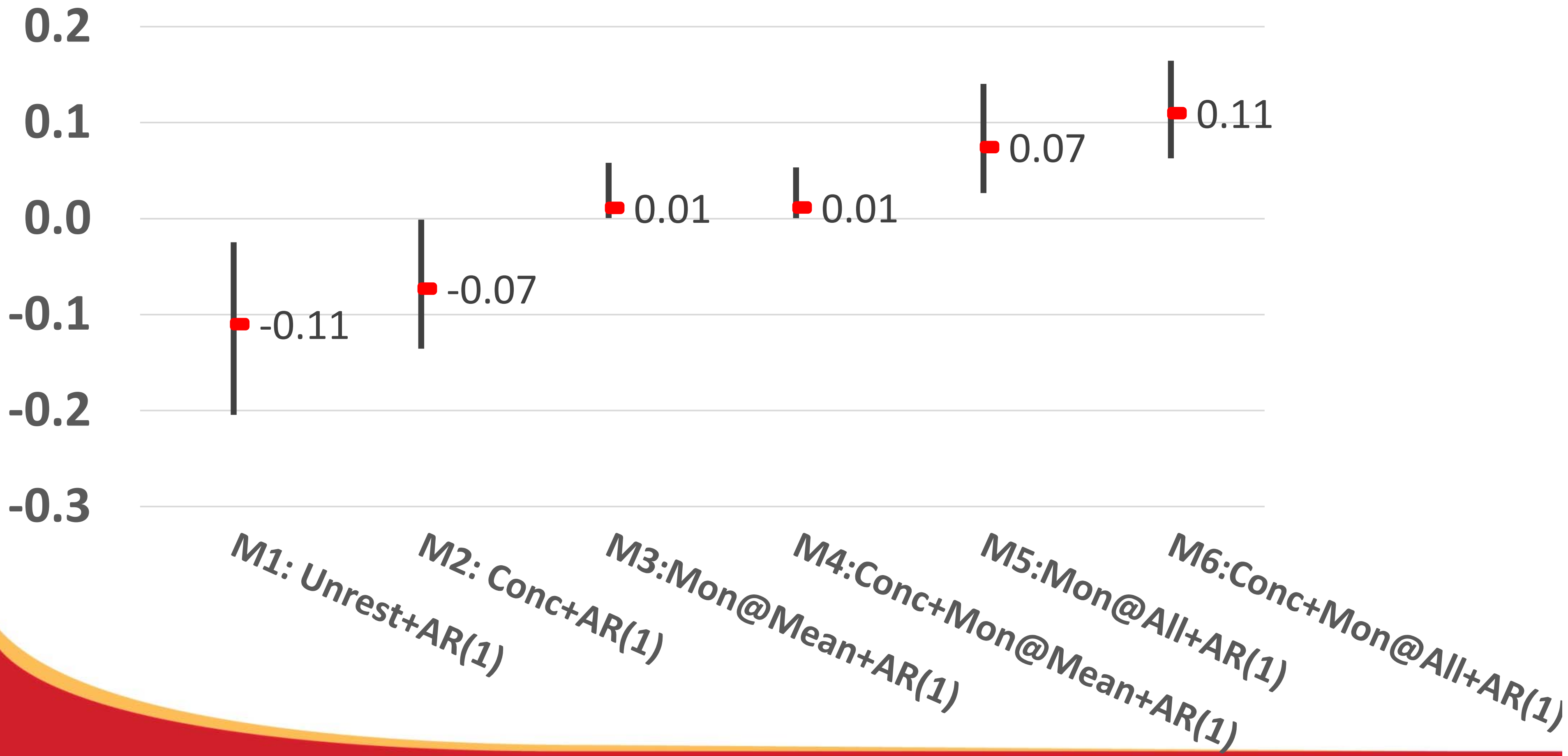
MONOTONICITY IN LABOR & MATERIALS HOLDS FOR M1-M6

Output Elasticity wrt Capital

$$\varepsilon_k = MPP_k \times \text{mean}(K) / \text{mean}(Y)$$



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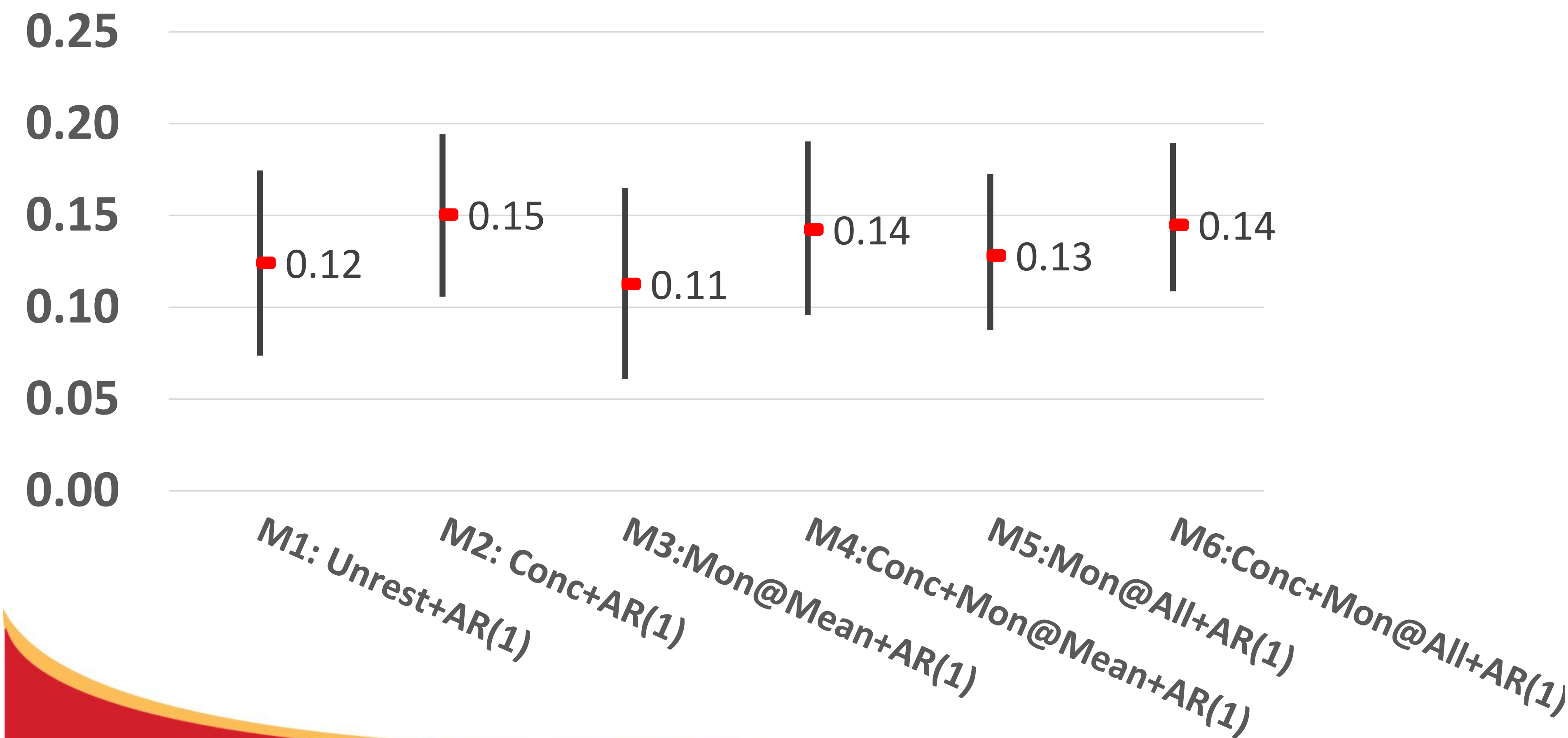
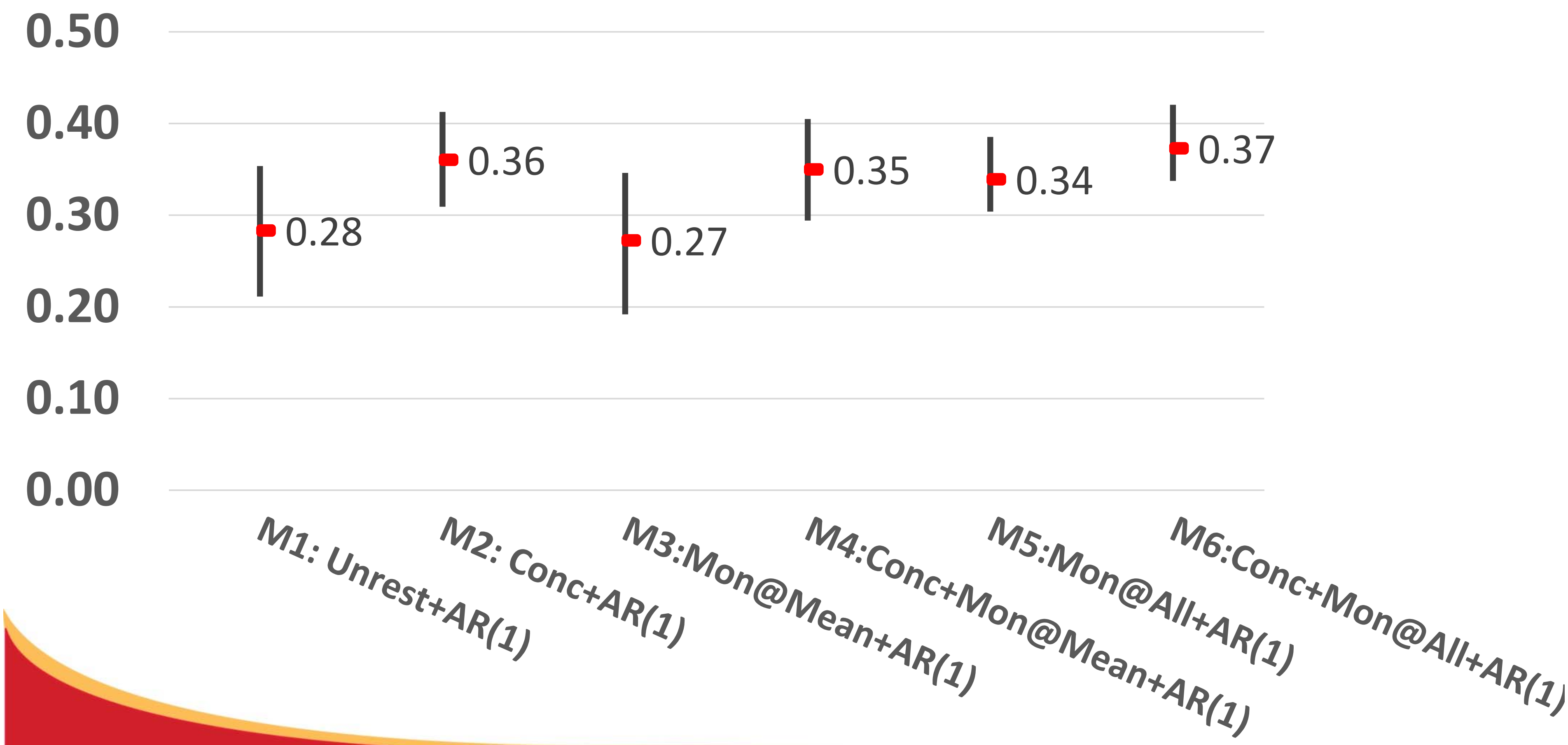
Output Elasticity wrt Labor

$$\varepsilon_l = MPP_l \times \text{mean}(L) / \text{mean}(Y)$$



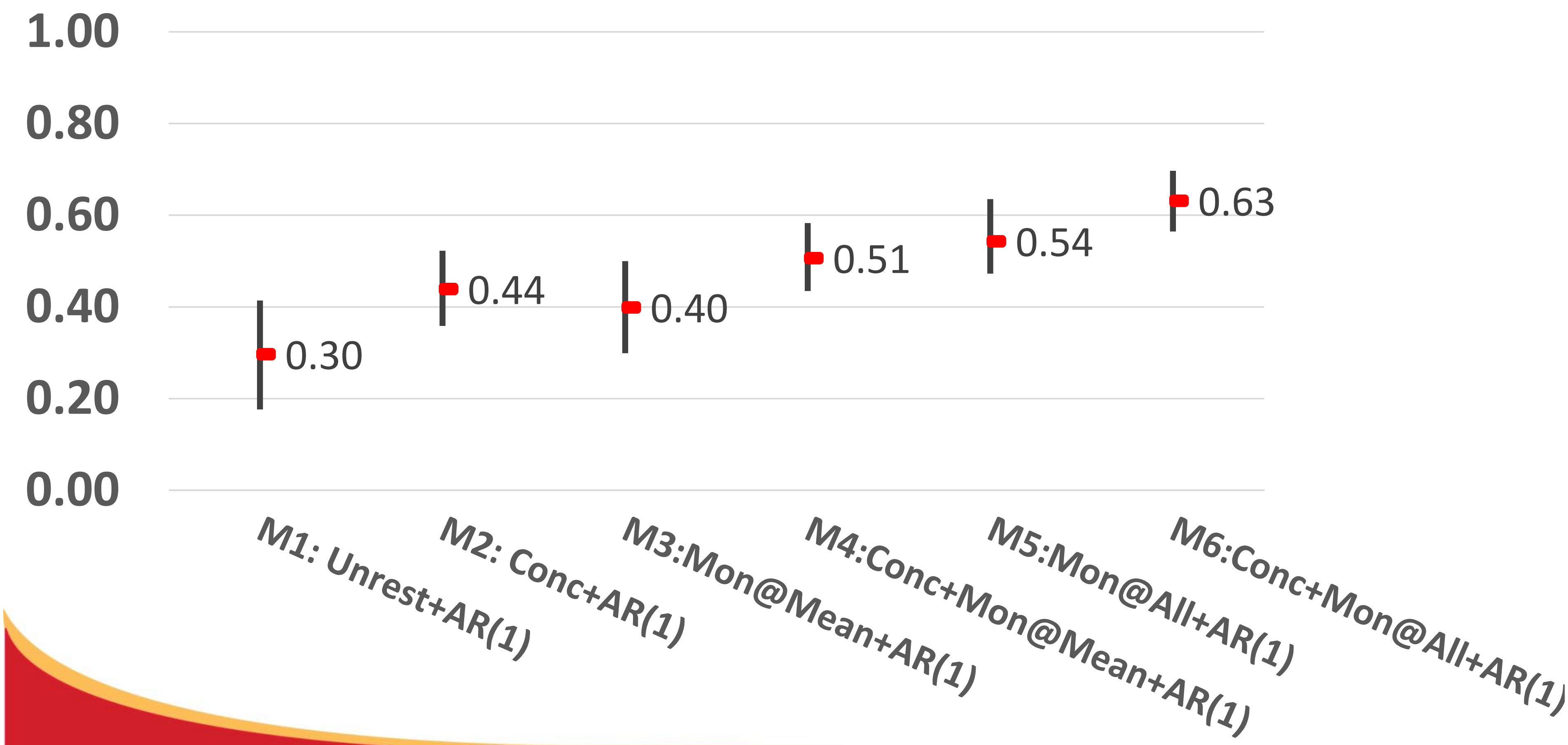
Output Elasticity wrt Materials

$$\varepsilon_m = MPP_m \times \text{mean}(M) / \text{mean}(Y)$$



Elasticity of Scale

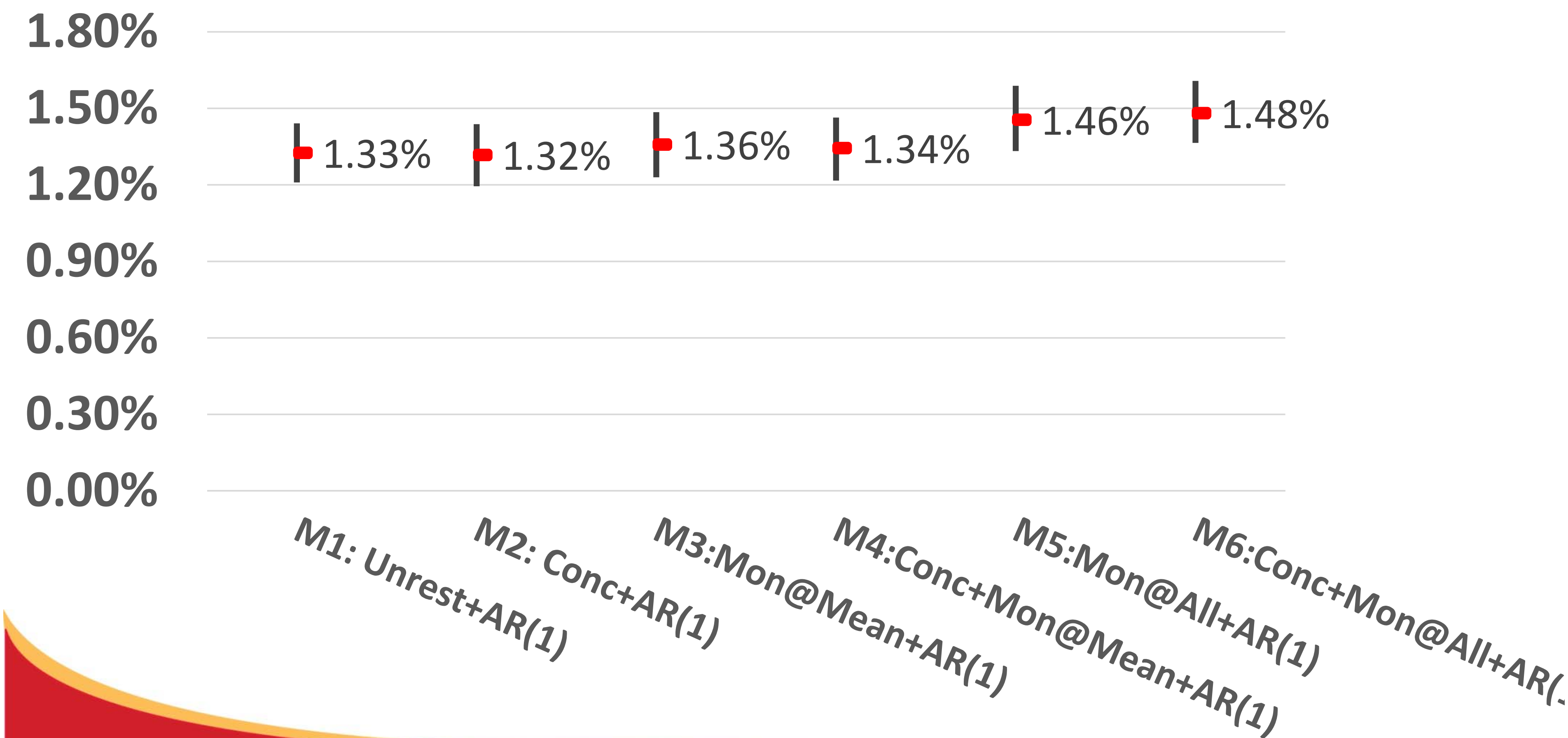
$$\in = \varepsilon_k + \varepsilon_l + \varepsilon_m$$



DECREASING RETURNS TO SCALE

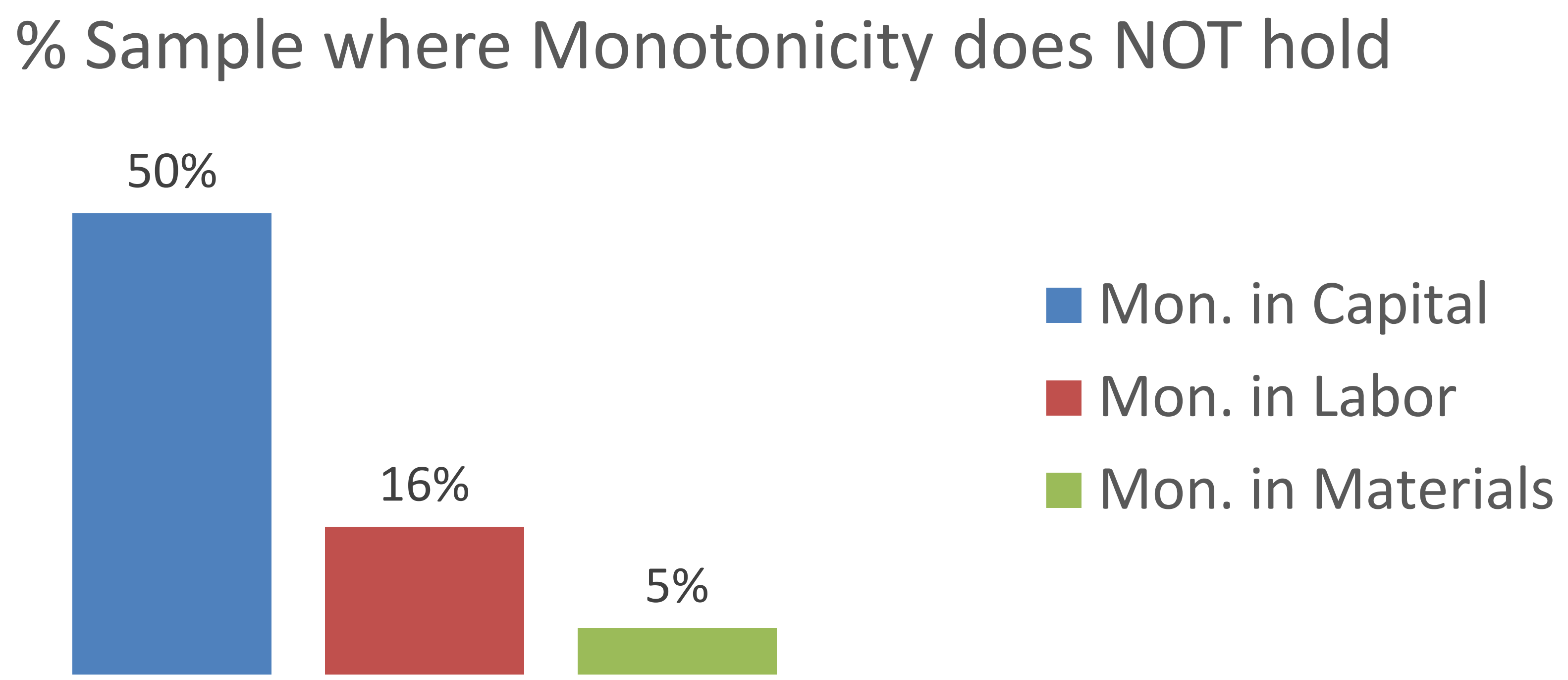
Technical Change

$$TC = \partial f(X,t)/\partial t = \beta_t + \sum_i \beta_{ti}\overline{x_i} + \beta_{tt}\bar{t}$$



TC at Mean Input Values

So…M4 or M6? Calculated MMPs with mean parameter estimates from M4 and all input values



Preferred Model M6: Conc.+Mon@All+AR(1)

M6: Technical Change

- TC Not Hicks-neutral: $\beta_{tL}, \beta_{tM} > 0$; $\beta_{tK} < 0$ (all statistically significant at 5%)
- Disembodied TC explains 1.48% of annual growth in ag output over 1960-2004
- Top 3 states: Colorado (1.82%), Oklahoma (1.80%), Missouri (1.77%)
- TC very variable across states and decades

M6: Catch-up in Tech. Change

- Median TC per state in the 2000s vs. Median TC per state in the 1960s:
- Slope coefficient -0.27
- P-value <0.1%
- Rsquare = 0.824

Technical Change vs TFP Growth 1960-2004

- TFP Growth Ranking: CO 45th,OK 48th, MO 27th
- Correlation between state rankings in TC and TFP growth: -0.50
- Correlation between average annual rates of TC and TFP growth: -0.41
- Differences: technical and allocative efficiency?

Translog vs. Quadratic?

Concluding Remarks: Methodology

- Recovered technology from unrestricted model neither concave nor monotonic.
- Both conditions must be imposed in estimation to perform meaningful economic analyses
- How monotonicity is imposed matters
- Bayesian methods allow to impose constraints at all data points

Concluding Remarks: Policy

- Decreasing Returns to Scale:

a) support recommendation to account for crop insurance subsidies to avoid upwardly biased TFP estimates (Shumway et.al. 2016)

b) Call into question assumption of CRS in calculation of TFP at the national level.

c) Extent of concentration in ag production limited by DRS

Next steps

- Similar analysis using Translog (underlying functional form in USDA's TFP measurement)
- Effect of capital utilization bias (Andersen, Alston, Pardey. JPA 2012)

Thank you for your attention!
Comments/Questions?

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