Production Networks, Input Trade, and Misallocation

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Value-added and the Cost of Misallocation

- Misallocation of resources leads to large TFP/income loss
- An extended literature quantifies the cost of misallocation using firm/plant data
- The literature typically uses the value-added concept instead of gross output
  - Value-added = Output - Intermediate Input
  - output more natural as firms take inputs symmetrically (true model)
  - value-added only appropriate under certain conditions (Bruno 1978)
  - value-added model ignores intersectoral linkages
- The use of value-added leads to biased estimates of the cost of misallocation
  - value-added model ignores the intersectoral linkages $\Rightarrow$ underestimation (Jones (2011, 2013))
  - with output data, firms are less heterogeneous (in TFP) $\Rightarrow$ overestimation (Gandhi, Navarro, and Rivers (2013, 2017))

Research Questions

- In theory, how would a value-added model bias the estimates of the cost of misallocation *conditional on observing the same data*?
  1. Is the value-added model misspecified?
  2. Can value-added data be used to infer firm productivity and distortions correctly?
- In data, how large is the bias, if there is any?

Findings

- Extend Hsieh and Klenow (2009) to incorporate sectoral linkages and compare the extended model to the original one
- Without distortions in intermediate input markets
    - correct specification + correct inference
    - value-added measures incorporate the effects of production networks, which naturally show more heterogeneity
    - Jones and Gandhi et al. focus on different sides of the same story
    - extend Hulten (1978) to allow for within sector heterogeneity
- With distortions in intermediate input markets
    - incorrect specification + incorrect inference
    - the bias however can be upward or downwardbias is small
- In Chinese data the bias is small (will look at Indian data)
    - intermediate markets less distorted than primary input markets
    - value-added model might overestimate the loss due to wrong parameterization

Related Literature

- Measurement of misallocation relaxing Hsieh and Klenow (2009)
  - Bartelsman, Haltiwanger, and Scarpetta (2013), Asker, Collard-Wexler, and Loecker (2014), Song and Wu (2015), David and Venkateswaran (2017), Gollin and Udry (2017), Bils, Klenow, and Ruane (2018), Haltiwanger and Syverson (2018), Jones (2011, 2013), and Gandhi, Navarro, and Rivers (2013, 2017)
  - focus on the use of value-added data and intersectoral linkages
- Misallocation under production networks
  - Bartelme and Gorodnichenko (2015), Bigio and La'O (2016), Baqaee and Farhi (2017), Caliendo, Parro, and Tsyvinski (2017), Liu (2017)
  - comparison with a value-added model *a la* Hulten (1978)
- Use of value-added and its implications
  - Sato (1976), Bruno (1978), and Basu and Fernald (1995, 1997)
  - look at the measurement of misallocation
- Two perspectives on sectors
  - Herrendorf, Rogerson, and Valentinyi (2013)
  - look at the measurement of misallocation

Theoretical Analysis

Basic Insights: The Equivalence (Hulten, 1978)

Final good production

$$Q = AL^{\alpha}X^{1-\alpha}$$

Final good use

$$Q = Y + X$$

$\Rightarrow$ Value-added (GDP in this simple economy)

$$Y = \alpha(1-\alpha)^{\frac{1-\alpha}{\alpha}} A^{\frac{1}{\alpha}} L$$

Two ways to look at the data generating process

1. Output: shock to the output TFP (A) is magnified through the use of intermediate input ($\frac{1}{\alpha}$)
2. Value-added: value-added TFP ($A^{\frac{1}{\alpha}}$) scales up the true productivity shock, incorporates the effect of production networks in the measures

Jones (2011, 2013) emphasizes the magnification, Gandhi, Navarro, and Rivers (2013, 2017) emphasize the scale up of value-added measures

Basic Insights: the Pitfall of Real Value-added (Bruno, 1978)

Restricted profit function (nominal value-added)

$$\max_X P_Q A L^\alpha X^{1-\alpha} - (1+\tau_X) P_X X$$

Measured nominal value-added (real value-added)

$$P_Y Y = P_Q A L^\alpha X^{1-\alpha} - P_X X = \left[\frac{(1-\alpha)P_Q A}{(1+\tau_X)P_X}\right]^{\frac{1}{\alpha}} \left[\frac{(1+\tau_X)P_X}{1-\alpha} - 1\right] L$$

- τ_X is an implicit tax/subsidy, it affects input demand but does not show up in data
  - shadow price of constraints on intermediate input use
  - intermediate input measured net of taxes (or taxes rebated)
- Marginal product (TFP with only one primary input) incorrectly measured with value-added data

The Output Model: Production

Final good production

$$Y = \sum_{s=1}^{S} C_s^{\theta_s}, \text{ with } \sum_{s=1}^{S} \theta_s = 1$$

Sectoral good production and use

$$Q_s = \left(\sum_{i=1}^{N_s} Q_{si}^{\frac{\sigma_s - 1}{\sigma_s}} \right)^{\frac{\sigma_s}{\sigma_s - 1}} = C_s + M_s$$

Variety production

$$Q_{si} = A_{si} \left(K_{si}^{\alpha_s} L_{si}^{1-\alpha_s} \right)^{\eta_s} \left(\prod_{q=1}^{S} M_{qsi}^{\lambda_{qs}} \right)^{1-\eta_s}, \text{ with } \sum_{q=1}^{S} \lambda_{qs} = 1$$

Competitive markets, firms maximize profits given generic wedges

$$\pi_{si} = P_{si} Q_{si} - (1 + \tau_{Ksi}) R K_{si} - (1 + \tau_{Lsi}) W L_{si} - (1 + \tau_{Msi}) \sum_{q=1}^{S} P_q M_{qsi}$$

Marginal Revenue Products and Revenue TFP

Marginal revenue products provide measures of distortions

$$
\begin{aligned}
MRPK_{si} &\equiv \alpha_s \eta_s \frac{P_{si} Q_{si}}{K_{si}} = (1 + \tau_{Ksi}) R, \\
MRPL_{si} &\equiv (1 - \alpha_s) \eta_s \frac{P_{si} Q_{si}}{L_{si}} = (1 + \tau_{Lsi}) W, \\
MRPM_{qsi} &\equiv \lambda_{qs} (1 - \eta_s) \frac{P_{si} Q_{si}}{M_{qsi}} = (1 + \tau_{Msi}) P_q,
\end{aligned}
$$

Revenue TFP (profitability) and physical TFP (productivity)

$$
\begin{aligned}
TFPR_{si} &\equiv \frac{P_{si} Q_{si}}{\left(K_{si}^{\alpha_s} L_{si}^{1-\alpha_s}\right)^{\eta_s} \left(\prod_{q=1}^{S} M_{qsi}^{\lambda_{qs}}\right)^{1-\eta_s}}, \\
TFPQ_{si} &\equiv \frac{Q_{si}}{\left(K_{si}^{\alpha_s} L_{si}^{1-\alpha_s}\right)^{\eta_s} \left(\prod_{q=1}^{S} M_{qsi}^{\lambda_{qs}}\right)^{1-\eta_s}} = A_{si}.
\end{aligned}
$$

Revenue TFP summarizes the effects of all distortions

$$
TFPR_{si} \propto \left(MRPK_{si}^{\alpha_s} MRPL_{si}^{1-\alpha_s}\right)^{\eta_s} \left(\prod_{q=1}^{S} MRPM_{qsi}^{\lambda_{qs}}\right)^{1-\eta_s}
$$

The Output Model: Aggregate Production Function

Sectoral production function

$$Q_s = TFP_s \cdot \left(K_s^{\alpha_s} L_s^{1-\alpha_s}\right)^{\eta_s} \left(\prod_{q=1}^{S} M_{qs}^{\lambda_{qs}}\right)^{1-\eta_s}$$

Sectoral TFP

$$TFP_s = \left[\sum_{i=1}^{N_s} \left(A_{si} \frac{TFPR_s}{TFPR_{si}}\right)^{\sigma_s - 1}\right]^{\frac{1}{\sigma_s - 1}}$$

Aggregate production function

$$Y = AK^{\alpha} L^{1-\alpha}, \text{ with } \alpha = \theta'(I - B')^{-1}\delta_K$$

Distortions only show up in aggregate TFP while the Cobb-Douglas form of aggregate production function is preserved

Aggregate TFP and Domar Weights

Aggregate TFP

$$A = \gamma \prod_{s=1}^{S} (TFP_s)^{\tilde{v}_s} \prod_{s=1}^{S} \left[(\beta_{Ks})^{\alpha_s \eta_s \tilde{v}_s} (\beta_{Ls})^{(1-\alpha_s)\eta_s \tilde{v}_s} \right]$$

- $\gamma = \prod_{s=1}^{S} \left(\frac{\theta_s}{v_s} \right)^{\theta_s} \prod_{s=1}^{S} \left[\prod_{q=1}^{S} \left(\frac{1}{\mathcal{T}_{Ms}} b_{qs} \frac{v_s}{v_q} \right)^{(1-\eta_s)\lambda_{qs}} \right]^{\tilde{v}_s}$: distortions in production network
- $\tilde{v}_s$ is element of $(I - B)^{-1}\theta$: elasticity of sectoral TFP
- β_{Ks} and β_{Ls}: sectoral share of primary inputs

$\tilde{v}_s$ different from Domar weights, defined as

$$V = \left(I - B \circ \text{diag}(\mathcal{T}_M^{\circ -1}) \right)^{-1} \theta$$

- $\mathcal{T}_M$ sectoral wedge in intermediate input
- Domar weights depend on distortions, deviating from Hulten (1978)

The Value-added Model: Production

Final good production

$$Y = \Phi \sum_{s=1}^{S} Y_s^{\widehat{\theta}_s}, \text{ with } \sum_{s=1}^{S} \widehat{\theta}_s = 1$$

Sectoral good production

$$Y_s = \left(\sum_{i=1}^{N_s} Y_{si}^{\frac{\widehat{\sigma}_s - 1}{\widehat{\sigma}_s}} \right)^{\frac{\widehat{\sigma}_s}{\widehat{\sigma}_s - 1}}$$

Variety production $\quad Y_{si} = \widehat{A}_{si} K_{si}^{\alpha_s} L_{si}^{1-\alpha_s}$

Again competitive markets, firm maximizes profit

$$\widehat{\pi}_{si} = P_{Ysi} Y_{si} - (1 + \tau_{Ksi}) R K_{si} - (1 + \tau_{Lsi}) W L$$

Essentially the Hsieh and Klenow (2009) framework except

- sector specific $\widehat{\sigma}_s$
- competitive markets

The Value-added Model: Aggregate Production Function

Sectoral production function

$$Y_s = \widehat{TFP}_s \cdot K_s^{\alpha_s} L_s^{1-\alpha_s}, \text{ with } \widehat{TFP}_s = \left[\sum_{i=1}^{N_s} \left(\widehat{A}_{si} \frac{\widehat{TFPR}_s}{\widehat{TFPR}_{si}} \right)^{\widehat{\sigma}_s - 1} \right]^{\frac{1}{\widehat{\sigma}_s - 1}}$$

Aggregate production function

$$Y = \widehat{A} K^{\widehat{\alpha}} L^{1-\widehat{\alpha}}, \text{ with } \widehat{\alpha} = \sum_{s=1}^{S} \widehat{\theta}_s \alpha_s$$

Aggregate TFP

$$A = \Phi \prod_{s=1}^{S} \left(\widehat{TFP}_s \right)^{\widehat{\theta}_s} \prod_{s=1}^{S} \left[\left(\widehat{\beta}_{Ks} \right)^{\alpha_s \widehat{\theta}_s} \left(\widehat{\beta}_{Ls} \right)^{(1-\alpha_s)\widehat{\theta}_s} \right]$$

- Φ: constant
- $\widehat{\theta}_s$: elasticity of sectoral value-added TFP
- $\widehat{\beta}_{Ks}$ and $\widehat{\beta}_{Ls}$: sectoral share of primary inputs

The Specification of the Value-added Model

Let the output model be the true DGP, construct the value-added model by choosing parameters carefully

Proposition: *Let* $\tau_{Msi} = 0, \forall s$ *and* i*, the output model can be transformed into the value-added model if we set* $\widehat{A}_{si} = A_{si}^{\frac{1}{\eta_s}}$, $\widehat{\sigma}_s = 1 + \eta_s(\sigma_s - 1)$, $\widehat{\theta}_s = \eta_s \tilde{v}_s$*, and let* α_s *and distortions stay the same in the two models*

- The value-added model is correctly specified
- The magnification effect of production networks is implicitly reflected in firm TFP but explicitly modeled in the output model
- The transformation of elasticity resembles Herrendorf, Rogerson, and Valentinyi (2013) $\Rightarrow$ the literature might have calibrated the parameter wrong
- The equivalence holds with primary factor market distortions, extending Hulten (1978)

Mis-specification with Intermediate Input Distortions

Proposition: *If $\tau_{Ms} = 0 \ \forall s$, there exists a value-added representation even with intermediate input market distortions. The transformation still requires $\widehat{A}_{si} = A_{si}^{\frac{1}{\eta_s}}$, $\widehat{\sigma}_s = 1 + \eta_s(\sigma_s - 1)$, and $\widehat{\theta}_s = \eta_s \tilde{v}_s$, and the sectoral value-added production function now reads*

$$Y_s = \Phi_s \left(\sum_{i=1}^{N_s} (1 + \tau_{Msi})^{-\frac{(1-\eta_s)(\sigma_s-1)}{1+\eta_s(\sigma_s-1)}} Y_{si}^{\frac{\eta_s(\sigma_s-1)}{1+\eta_s(\sigma_s-1)}} \right)^{\frac{1+\eta_s(\sigma_s-1)}{\eta_s(\sigma_s-1)}}$$

with

$$\Phi_s = \left(\frac{\sum_{i=1}^{N_s} (1 + \tau_{Msi})^{-\frac{(1-\eta_s)(\sigma_s-1)}{1+\eta_s(\sigma_s-1)}} Y_{si}^{\frac{\eta_s(\sigma_s-1)}{1+\eta_s(\sigma_s-1)}}}{\sum_{i=1}^{N_s} (1 + \tau_{Msi})^{-\frac{\sigma_s}{1+\eta_s(\sigma_s-1)}} Y_{sj}^{\frac{\eta_s(\sigma_s-1)}{1+\eta_s(\sigma_s-1)}}} \right)^{\frac{1-\eta_s}{\eta_s}}$$

If $\tau_{Ms} \neq 0, \exists s$, the value-added representation does not exist.

- The value-added model is mis-specified with intermediate input distortions

Inference of Firm Wedges

Assume data on output and inputs, nominal value-added defined as

$$P_{Ysi}Y_{si} = P_{si}Q_{si} - \sum_{q=1}^{S} P_q M_{qsi} = \left(1 - \frac{1-\eta_s}{1+\tau_{Msi}}\right) P_{si}Q_{si}$$

Wedges in the output model

$$\begin{aligned} 1+\tau_{Ksi} &= \frac{\alpha_s \eta_s P_{si}Q_{si}}{RK_{si}}, \\ 1+\tau_{Lsi} &= \frac{(1-\alpha_s)\eta_s P_{si}Q_{si}}{WL_{si}}, \\ 1+\tau_{Msi} &= \frac{(1-\eta_s)P_{si}Q_{si}}{\sum_{q=1}^{S} P_q M_{qsi}} \end{aligned}$$

Wedges in the value-added model

$$\begin{aligned} 1+\tau_{Ksi} &= \frac{\alpha_s P_{Ysi}Y_{si}}{RK_{si}}, \\ 1+\tau_{Lsi} &= \frac{(1-\alpha_s)P_{Ysi}Y_{si}}{WL_{si}} \end{aligned}$$

- If $\tau_{Msi} = 0$, τ_{Ksi} and τ_{Lsi} are correctly inferred with value-added data

Inference of Firm Productivity

Firm productivity in the output model

$$A_{si} = \chi_s \frac{(P_{si} Q_{si})^{\frac{\sigma_s}{\sigma_s - 1}}}{\left(K_{si}^{\alpha_s} L_{si}^{1-\alpha_s}\right)^{\eta_s} \left(\sum_{q=1}^{S} P_q M_{qsi}\right)^{1-\eta_s}}$$

Firm productivity in the value-added model

$$\widehat{A}_{si} = \tilde{\chi}_s \frac{(P_{Ysi} Y_{si})^{\frac{\widehat{\sigma}_s}{\widehat{\sigma}_s - 1}}}{K_{si}^{\alpha_s} L_{si}^{1-\alpha_s}}$$

- χ_s and $\tilde{\chi}_s$ can be normalized to 1 without affecting the results
- If $\tau_{Msi} = 0$, firm productivity are correctly inferred with value-added data

Summary of the Results

- Whether the value-added model leads to biased estimates of efficiency loss depends on intermediate input distortions
  - intermediate input distortions however are prevalent in data (Baqaee and Farhi, 2017; Bigio and La'O, 2016; Liu, 2017)
  - will the va model systematically under- or over-estimate the loss?
  - what determines the size of the bias?
- Consider only within sector allocation, efficiency loss given by

$$\left(\frac{Y^E}{Y}\right)^o = \prod_{s=1}^{S}\left(\frac{TFP_s^E}{TFP_s}\right)^{v_s}, \left(\frac{Y^E}{Y}\right)^v = \prod_{s=1}^{S}\left(\frac{\widehat{TFP}_s^E}{\widehat{TFP}_s}\right)^{\widehat{\theta}_s}$$

  - Hsieh and Klenow (2009) also focus on this case, as it is hard to separate technology and between-sector distortions
  - the va model actually leads to a correct expression, even though measured efficiency loss will still be biased given incorrect inference with value-added data

The Bias of the Value-added Model

- Sectoral TFP expressed in terms of primitives

$$TFP_s = \left(\sum_{i=1}^{N_s} \left(\frac{A_{si}}{[(1+\tau_{Ksi})^{\alpha_s}(1+\tau_{Lsi})^{1-\alpha_s}]^{\eta_s}\,(1+\tau_{Msi})^{1-\eta_s}} \right)^{\sigma_s - 1} \right)^{\frac{1}{\sigma_s - 1}},$$

$$\widehat{TFP}_s = \left(\sum_{i=1}^{N_s} \left(\frac{A_{si}\left(1 - \frac{1-\eta_s}{1+\tau_{Msi}}\right)^{\frac{1}{\sigma_s - 1}}}{[(1+\tau_{Ksi})^{\alpha_s}(1+\tau_{Lsi})^{1-\alpha_s}]^{\eta_s}\,(1+\tau_{Msi})^{1-\eta_s}} \right)^{\sigma_s - 1} \right)^{\frac{1}{\eta_s(\sigma_s - 1)}},$$

$$\widehat{TFP}_s^E = \left(\sum_{i=1}^{N_s} \left(A_{si}\left(1 - \frac{1-\eta_s}{1+\tau_{Msi}}\right)^{\frac{1+\eta_s(\sigma_s-1)}{\sigma_s - 1}} (1+\tau_{Msi})^{\eta_s - 1} \right)^{\sigma_s - 1} \right)^{\frac{1}{\eta_s(\sigma_s - 1)}}$$

- The size of the bias depends on the size of τ_{Msi}
- The bias can go either direction
  - approximation assuming log-normal distribution and $\eta_s = 0.5$

$$\left(\frac{TFP_s^E}{TFP_s}\right)^{v_s} > \left(\frac{\widehat{TFP}_s^E}{\widehat{TFP}_s}\right)^{\widehat{\theta}_s} \iff \sigma_m^2 + \sigma_{ym} < 0$$

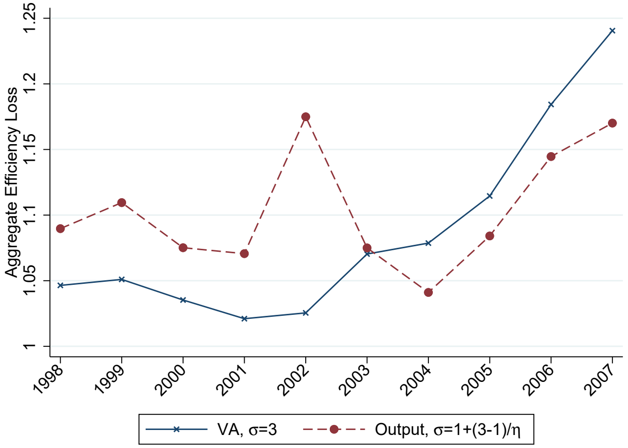
  - If σ_{ym} is not too small, the va model overestimates the loss
- The size and the direction of the bias is an empirical matter

An Application to Chinese (and Indian) Data

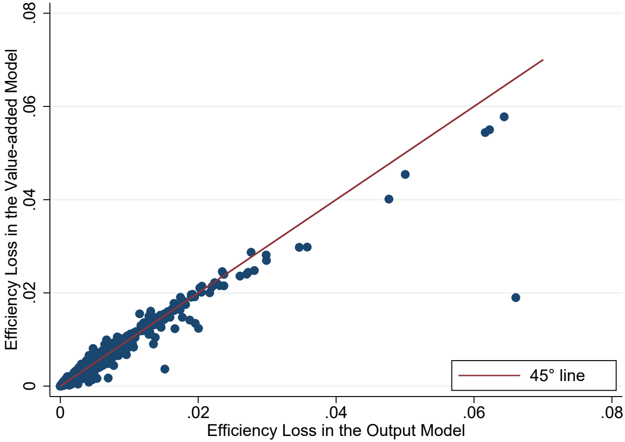
Chinese Data and Parameterization

- Chinese data (1998-2007)
  - Manufacturing firm survey data from China's National Bureau of Statistics (NBS)
  - Covers all state-owned firms and all private firms with sales > 5 million RMB (about 600,000 USD during the sample period)
  - Sample: 200-300k plants per year
  - Balanced-sheet variables: firm ownership, output, value added, employment, original value of fixed asset, and intermediate inputs
  - Look at misallocation within 4-digit industries
- Parameterization
  - Factor shares from U.S. data
  - $\hat{\sigma}_s = 3$ following Hsieh and Klenow (2009) $\Rightarrow \sigma_s = 1 + (\hat{\sigma}_s - 1)/\eta_s$
  - Sectoral value-added to GDP ratios calculated from data, $\tilde{v}_s$ calculated with va ratios and U.S. intermediate input shares
  - Inference of firm primitives as shown before

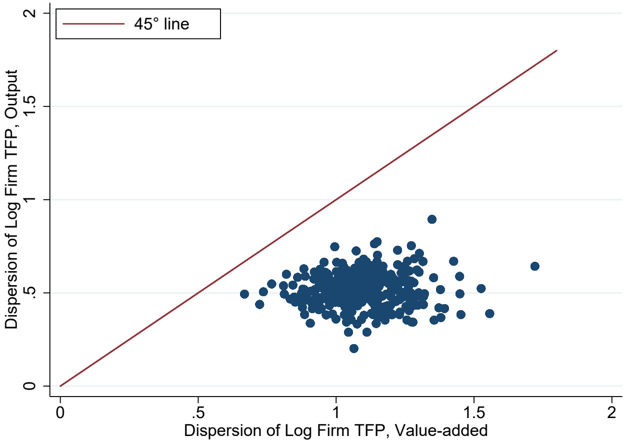
Both Models Produce Similar Aggregate Efficiency Loss



The Same Holds if We Look at Individual Industries

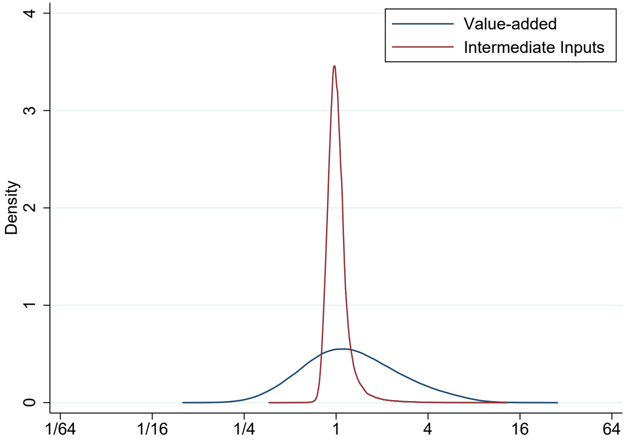


A_{si} is Less Dispersed than $\widehat{A}_{si}$



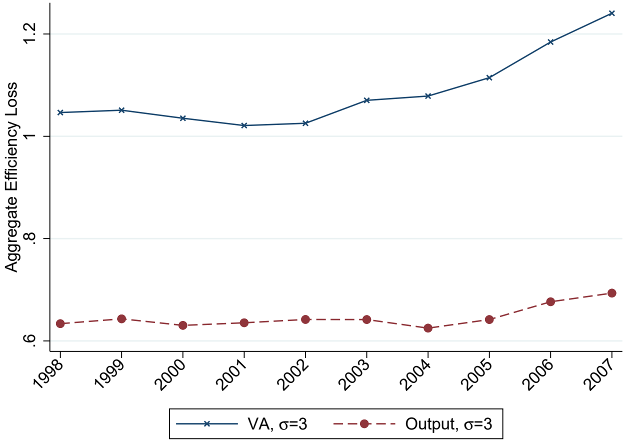
Dispersion is measured by standard deviation

Intermediate Input Markets are Less Distorted



Dispersion of the log of $MRPK_{si}^{\alpha_s} MRPL_{si}^{1-\alpha_s}$ and $\prod_{q=1}^{S} MRPM_{qsi}^{\lambda_{qs}}$, both relative to the industry average

Overestimation of the Value-added Model in Literature



Elasticity: $\sigma_s = \widehat{\sigma}_s = 3$

$\eta_s = 0.5 \Rightarrow \widehat{\sigma}_s = 2$

Conclusion

- Value-added model is only valid when there are no distortions in intermediate input use
- Otherwise, it leads to biased measures of efficiency loss
- The bias can go in either direction
- In data, bias is small because intermediate input markets are less distorted
- Studies using the value-added model however tend to overestimate the efficiency loss due to incorrect parameterization
- A burgeoning literature emphasize the importance of production networks in magnifying shocks, but do they actually help account for important phenomena like cross-country income differences and the origin of business cycles quantitatively?
  - maybe not as va data already incorporates the magnification effect

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