Estimating Production Functions

Applications

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Section 1

Amiti and Konings (2007)

Overview

- Effect of reducing input and output tariffs on productivity
- Reducing output tariffs affects productivity by increasing competition
- Reducing input tariffs affects productivity through learning, variety, and quality effects
- Previous empirical work focused on output tariffs; might be estimating combined effect
- Input tariffs hard to measure; with Indonesian data on plant-level inputs can construct plant specific input tariff

Trade Liberalization in Indonesia

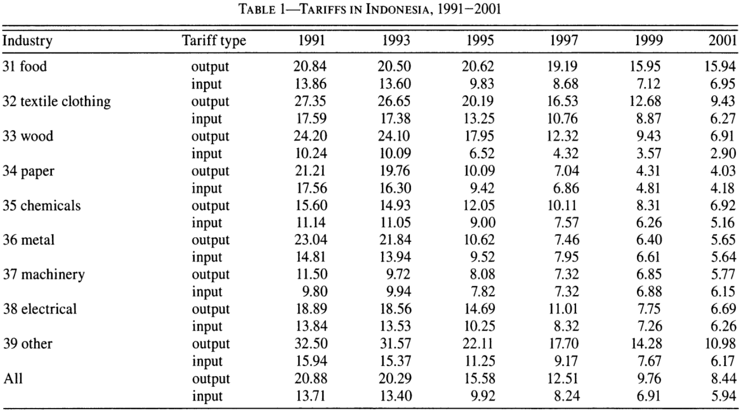

TABLE 1—TARIFFS IN INDONESIA, 1991–2001

Industry	Tariff type	1991	1993	1995	1997	1999	2001
31 food	output	20.84	20.50	20.62	19.19	15.95	15.94
	input	13.86	13.60	9.83	8.68	7.12	6.95
32 textile clothing	output	27.35	26.65	20.19	16.53	12.68	9.43
	input	17.59	17.38	13.25	10.76	8.87	6.27
33 wood	output	24.20	24.10	17.95	12.32	9.43	6.91
	input	10.24	10.09	6.52	4.32	3.57	2.90
34 paper	output	21.21	19.76	10.09	7.04	4.31	4.03
	input	17.56	16.30	9.42	6.86	4.81	4.18
35 chemicals	output	15.60	14.93	12.05	10.11	8.31	6.92
	input	11.14	11.05	9.00	7.57	6.26	5.16
36 metal	output	23.04	21.84	10.62	7.46	6.40	5.65
	input	14.81	13.94	9.52	7.95	6.61	5.64
37 machinery	output	11.50	9.72	8.08	7.32	6.85	5.77
	input	9.80	9.94	7.82	7.32	6.88	6.15
38 electrical	output	18.89	18.56	14.69	11.01	7.75	6.69
	input	13.84	13.53	10.25	8.32	7.26	6.26
39 other	output	32.50	31.57	22.11	17.70	14.28	10.98
	input	15.94	15.37	11.25	9.17	7.67	6.17
All	output	20.88	20.29	15.58	12.51	9.76	8.44
	input	13.71	13.40	9.92	8.24	6.91	5.94

Data and tariff measure

- Indonesian annual manufacturing census of 20+ employee plants 1991-2001, after cleaning $15,000$ firms per year
- Input tariffs:
    - Data on tariffs on goods, τ_{jt}, but also need to know inputs
    - 1998 only: have data on inputs, use to construct input weights at industry level, w_{jk}
    - Industry input tariff $= \sum_j w_{jk} \tau_{jt}$

Summary Statistics

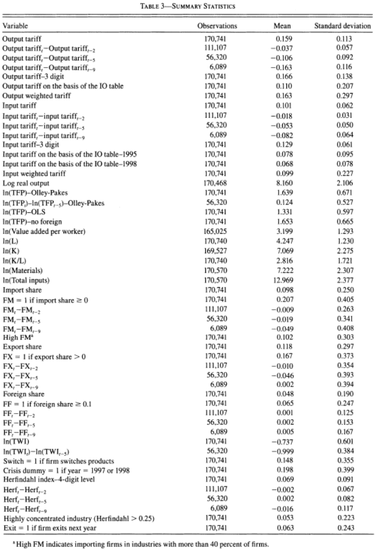

TABLE 3—SUMMARY STATISTICS

Variable	Observations	Mean	Standard deviation
Output tariff	170,741	0.159	0.113
Output tariff$_t-$Output tariff$_{t-2}$	111,107	−0.037	0.057
Output tariff$_t-$Output tariff$_{t-5}$	56,320	−0.106	0.092
Output tariff$_t-$Output tariff$_{t-9}$	6,089	−0.163	0.116
Output tariff–3 digit	170,741	0.166	0.138
Output tariff on the basis of the IO table	170,741	0.110	0.207
Output weighted tariff	170,741	0.163	0.297
Input tariff	170,741	0.101	0.062
Input tariff$_t-$input tariff$_{t-2}$	111,107	−0.018	0.031
Input tariff$_t-$input tariff$_{t-5}$	56,320	−0.053	0.050
Input tariff$_t-$input tariff$_{t-9}$	6,089	−0.082	0.064
Input tariff–3 digit	170,741	0.129	0.061
Input tariff on the basis of the IO table–1995	170,741	0.078	0.095
Input tariff on the basis of the IO table–1998	170,741	0.068	0.078
Input weighted tariff	170,741	0.099	0.227
Log real output	170,468	8.160	2.106
ln(TFP)–Olley-Pakes	170,741	1.639	0.671
ln(TFP$_t$)–ln(TFP$_{t-5}$)–Olley-Pakes	56,320	0.124	0.527
ln(TFP)–OLS	170,741	1.331	0.597
ln(TFP)–no foreign	170,741	1.653	0.665
ln(Value added per worker)	165,025	3.199	1.293
ln(L)	170,740	4.247	1.230
ln(K)	169,527	7.069	2.275
ln(K/L)	170,740	2.816	1.721
ln(Materials)	170,570	7.222	2.307
ln(Total inputs)	170,570	12.969	2.377
Import share	170,741	0.098	0.250
FM = 1 if import share ≥ 0	170,741	0.207	0.405
FM$_t-$FM$_{t-2}$	111,107	−0.009	0.263
FM$_t-$FM$_{t-5}$	56,320	−0.019	0.341
FM$_t-$FM$_{t-9}$	6,089	−0.049	0.408
High FM[a]	170,741	0.102	0.303
Export share	170,741	0.118	0.297
FX = 1 if export share > 0	170,741	0.167	0.373
FX$_t-$FX$_{t-2}$	111,107	−0.010	0.354
FX$_t-$FX$_{t-5}$	56,320	−0.046	0.393
FX$_t-$FX$_{t-9}$	6,089	0.002	0.394
Foreign share	170,741	0.048	0.190
FF = 1 if foreign share ≥ 0.1	170,741	0.065	0.247
FF$_t-$FF$_{t-2}$	111,107	0.001	0.125
FF$_t-$FF$_{t-5}$	56,320	0.002	0.153
FF$_t-$FF$_{t-9}$	6,089	0.005	0.167
ln(TWI)	170,741	−0.737	0.601
ln(TWI$_t$)−ln(TWI$_{t-5}$)	56,320	−0.999	0.384
Switch = 1 if firm switches products	170,741	0.148	0.355
Crisis dummy = 1 if year = 1997 or 1998	170,741	0.198	0.399
Herfindahl index–4-digit level	170,741	0.069	0.091
Herf$_t-$Herf$_{t-2}$	111,107	−0.002	0.067
Herf$_t-$Herf$_{t-5}$	56,320	0.002	0.082
Herf$_t-$Herf$_{t-9}$	6,089	−0.016	0.117
Highly concentrated industry (Herfindahl > 0.25)	170,741	0.053	0.223
Exit = 1 if firm exits next year	170,741	0.063	0.243

[a] High FM indicates importing firms in industries with more than 40 percent of firms.

Productivity Estimates

$$\overset{\text{log revenue}}{y_{it}} = \overset{\text{industry k}}{\beta_l^k} l_{it} + \beta_k^k k_{it} + \beta_m^k \overset{\text{cost of materials}}{m_{it}} + \underbrace{tfp_{it}^k}_{\omega_{it}+\epsilon_{it}}$$

- Output measure is revenue ⇒ may confound productivity and markups
- Materials measured as cost ⇒ may confound quality and productivity
- Estimate TFP using Olley-Pakes

Production Function Estimates

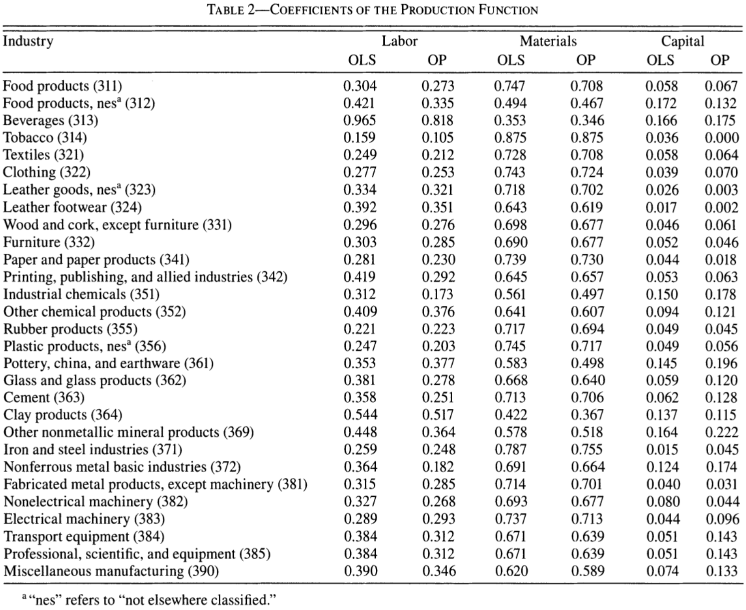

TABLE 2—COEFFICIENTS OF THE PRODUCTION FUNCTION

Industry	Labor		Materials		Capital	
	OLS	OP	OLS	OP	OLS	OP
Food products (311)	0.304	0.273	0.747	0.708	0.058	0.067
Food products, nes[a] (312)	0.421	0.335	0.494	0.467	0.172	0.132
Beverages (313)	0.965	0.818	0.353	0.346	0.166	0.175
Tobacco (314)	0.159	0.105	0.875	0.875	0.036	0.000
Textiles (321)	0.249	0.212	0.728	0.708	0.058	0.064
Clothing (322)	0.277	0.253	0.743	0.724	0.039	0.070
Leather goods, nes[a] (323)	0.334	0.321	0.718	0.702	0.026	0.003
Leather footwear (324)	0.392	0.351	0.643	0.619	0.017	0.002
Wood and cork, except furniture (331)	0.296	0.276	0.698	0.677	0.046	0.061
Furniture (332)	0.303	0.285	0.690	0.677	0.052	0.046
Paper and paper products (341)	0.281	0.230	0.739	0.730	0.044	0.018
Printing, publishing, and allied industries (342)	0.419	0.292	0.645	0.657	0.053	0.063
Industrial chemicals (351)	0.312	0.173	0.561	0.497	0.150	0.178
Other chemical products (352)	0.409	0.376	0.641	0.607	0.094	0.121
Rubber products (355)	0.221	0.223	0.717	0.694	0.049	0.045
Plastic products, nes[a] (356)	0.247	0.203	0.745	0.717	0.049	0.056
Pottery, china, and earthware (361)	0.353	0.377	0.583	0.498	0.145	0.196
Glass and glass products (362)	0.381	0.278	0.668	0.640	0.059	0.120
Cement (363)	0.358	0.251	0.713	0.706	0.062	0.128
Clay products (364)	0.544	0.517	0.422	0.367	0.137	0.115
Other nonmetallic mineral products (369)	0.448	0.364	0.578	0.518	0.164	0.222
Iron and steel industries (371)	0.259	0.248	0.787	0.755	0.015	0.045
Nonferrous metal basic industries (372)	0.364	0.182	0.691	0.664	0.124	0.174
Fabricated metal products, except machinery (381)	0.315	0.285	0.714	0.701	0.040	0.031
Nonelectrical machinery (382)	0.327	0.268	0.693	0.677	0.080	0.044
Electrical machinery (383)	0.289	0.293	0.737	0.713	0.044	0.096
Transport equipment (384)	0.384	0.312	0.671	0.639	0.051	0.143
Professional, scientific, and equipment (385)	0.384	0.312	0.671	0.639	0.051	0.143
Miscellaneous manufacturing (390)	0.390	0.346	0.620	0.589	0.074	0.133

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[a] "nes" refers to "not elsewhere classified."

Productivity and Tariffs

- Estimate relation between TFP and tariffs

$$\log(TFP_{it}) = \gamma_0 + \alpha_i + \alpha_{tl(i)} + \gamma_1(\text{output tariff})_{tk(i)} + \\ + \gamma_2(\text{input tariff})_{tk(i)} + \epsilon_{it} \tag{1}$$

  - $k(i)$ = 5-digit (ISIC) industry of plant i
  - $l(i)$ = island of plant i
- Explore robustness to:
  - Different productivity measure
  - Specification of 1
  - Endogeneity of tariffs

Productivity and Tariffs

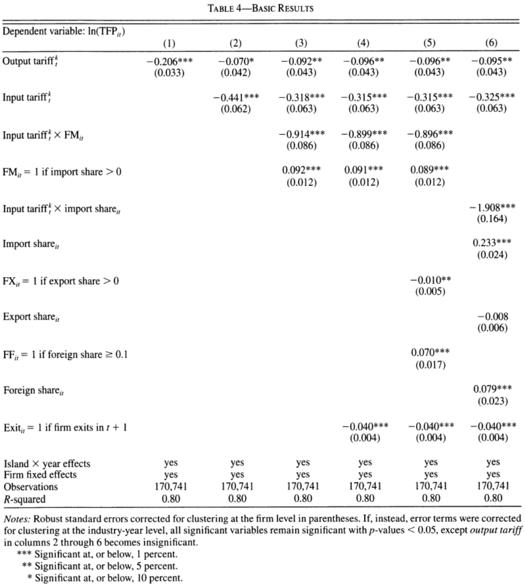

TABLE 4—BASIC RESULTS

Dependent variable: $\ln(\mathrm{TFP}_{it})$	(1)	(2)	(3)	(4)	(5)	(6)
Output tariff_t^k	−0.206***	−0.070*	−0.092**	−0.096**	−0.096**	−0.095**
	(0.033)	(0.042)	(0.043)	(0.043)	(0.043)	(0.043)
Input tariff_t^k		−0.441***	−0.318***	−0.315***	−0.315***	−0.325***
		(0.062)	(0.063)	(0.063)	(0.063)	(0.063)
Input $\mathrm{tariff}_t^k \times \mathrm{FM}_{it}$			−0.914***	−0.899***	−0.896***	
			(0.086)	(0.086)	(0.086)	
$\mathrm{FM}_{it} = 1$ if import share > 0			0.092***	0.091***	0.089***	
			(0.012)	(0.012)	(0.012)	
Input $\mathrm{tariff}_t^k \times$ import share_{it}						−1.908***
						(0.164)
Import share_{it}						0.233***
						(0.024)
$\mathrm{FX}_{it} = 1$ if export share > 0					−0.010**	
					(0.005)	
Export share_{it}						−0.008
						(0.006)
$\mathrm{FF}_{it} = 1$ if foreign share ≥ 0.1					0.070***	
					(0.017)	
Foreign share_{it}						0.079***
						(0.023)
$\mathrm{Exit}_{it} = 1$ if firm exits in $t + 1$				−0.040***	−0.040***	−0.040***
				(0.004)	(0.004)	(0.004)
Island × year effects	yes	yes	yes	yes	yes	yes
Firm fixed effects	yes	yes	yes	yes	yes	yes
Observations	170,741	170,741	170,741	170,741	170,741	170,741
R-squared	0.80	0.80	0.80	0.80	0.80	0.80

Notes: Robust standard errors corrected for clustering at the firm level in parentheses. If, instead, error terms were corrected for clustering at the industry-year level, all significant variables remain significant with p-values < 0.05, except *output tariff* in columns 2 through 6 becomes insignificant.

*** Significant at, or below, 1 percent.

** Significant at, or below, 5 percent.

* Significant at, or below, 10 percent.

Results

- Input tariffs have larger effect than output, $\hat{\gamma}_1 \approx -0.07$, $\hat{\gamma}_2 \approx -0.44$
- Robust to:
  - Productivity measure
  - Tariff measure
  - Including/excluding Asian financial crisis
- Less robust to instrumenting for tariffs
  - Qualitatively similar, but larger coefficient estimates
- Explore channels for productivity change
  - Markups (maybe), product switching/addition (no), foreign ownership (no), exporters (no)

Section 2

Grieco and McDevitt (2017)

Grieco and McDevitt (2017)

`https://www.ftc.gov/sites/default/files/documents/public_events/fifth-annual-microeconomics-conference/grieco-p_0.pdf`

Model details

- Timing:
  1. Quality chosen $q_{it} = q(k_{it}, \ell_{it}, x_{it}, \omega_{i,t-b})$
  2. Production occurs, ω_{it} revealed to firm
  3. Hiring chosen $\ell_{i,t+1} - \ell_{it} = h_{it} = h(k_{it}, \ell_{it}, x_{it}, \omega_{it})$
- ω follows Markov process:

$$\mathrm{E}[\omega_{i,t-b}|\mathcal{I}_{i,t-b}] = \mathrm{E}[\omega_{i,t-b}|\omega_{i,t-1}] \text{ \& } \mathrm{E}[\omega_{it}|\mathcal{I}_{i,t}] = \mathrm{E}[\omega_{it}|\omega_{i,t-b}$$

and $\omega_{it} = \mathrm{E}[\omega_{it}|\omega_{i,t-1}] + \eta_{it} = g(\omega_{i,t-1}) + \eta_{it}$

Moment conditions

- Control function assumption: hiring is a monotonic function of ω

$$h_{it} = h(k_{it}, \ell_{it}, x_{it}, \omega_{it})$$

so

$$\omega_{it} = h^{-1}(k_{it}, \ell_{it}, x_{it}, h_{it})$$

- Substitute into production function:

$$\begin{aligned} y_{it} =& \alpha_q q_{it} + \beta_k k_{it} + \beta_\ell \ell_{it} + h^{-1}(k_{it}, \ell_{it}, x_{it}, h_{it}) + \epsilon_{it} \\ y_{it} =& \alpha_q q_{it} + \Phi(k_{it}, \ell_{it}, x_{it}, h_{it}) + \epsilon_{it} \end{aligned}$$

- Evolution of ω

$$\begin{aligned} \omega_{it} =& y_{it} - \alpha_q q_{it} - \beta_k k_{it} - \beta_\ell \ell_{it} - \epsilon_{it} = g(\omega_{i,t-1}) + \xi_{it} \\ =& g(\Phi(k_{it-1}, \ell_{it-1}, x_{it-1}, h_{it-1}) - \beta_\ell \ell_{it-1} - \beta_k k_{it-1}) + \xi_{it} \end{aligned}$$

- Moment conditions:

$$\begin{aligned} \mathrm{E}[\epsilon_{it} | q_{it}, k_{it}, \ell_{it}, x_{it}, h_{it}] = 0 \\ \mathrm{E}[\xi_{it} | k_{it}, \ell_{it}, x_{it}, k_{it-1}, \ell_{it-1}, x_{it-1}] = 0 \end{aligned}$$

Estimation

1. Estimate, α_q, Φ from

$$y_{it} = \alpha_q q_{it} + \Phi(k_{it}, \ell_{it}, x_{it}, h_{it}) + \epsilon_{it}$$

   by semiparametric regression

2. Estimate β_k, β_ℓ
   - Let $\omega(\beta)_{it} = \hat{\Phi}(k_{it}, \ell_{it}, x_{it}, h_{it}) - \beta_k k_{it} - \beta_\ell \ell_{it}$
   - For each β estimate $g()$

$$y_{it} - \hat{\alpha} q_{it} - \beta_k k_{it} - \beta_\ell \ell_{it} = g(\omega(\beta)_{it-1}) + \underbrace{\xi_{it} + \epsilon_{it}}_{\equiv \eta_{it}(\beta)}$$

     by nonparametric regression
   - Minimize empirical moment condition for η

$$\hat{\beta} = \arg\min\left(\frac{1}{NT}\sum_{it} k_{it}\eta_{it}(\beta)\right)^2 + \left(\frac{1}{NT}\sum_{it} \ell_{it}\eta_{it}(\beta)\right)^2$$

- Should hemoglobin level be controlled for when measuring quality?
  - Anemia (low hemoglobin) is risk-factor for infection
  - Anemia can be treated through diet, iron supplements (pills or IV), EPO, etc
    - Are dialysis facilities responsible for this treatment?
    - In 2006-2014 data average full-time dieticiens = 0.5, average part-time = 0.6

Measurement error

- Simplified setup:

$$y = \alpha \tilde{q} + \epsilon$$

  $\tilde{q}$ unobserved, observe $q = \tilde{q} + \epsilon^q$ with $\mathrm{E}[\epsilon^q | \tilde{q} = 0]$
- Then $\operatorname{plim} \hat{\alpha}^{OLS} = \alpha \frac{\mathrm{Var}(\tilde{q})}{\mathrm{Var}(\tilde{q}) + \mathrm{Var}(\epsilon^q)}$
- If $d = d(\tilde{q}) + \epsilon^d$ with $\mathrm{E}[\epsilon^d | \tilde{q}] = 0$ and $\mathrm{E}[\epsilon^d \epsilon^q] = 0$, then

$$\operatorname{plim} \hat{\alpha}^{IV} = \alpha$$

- Is $\mathrm{E}[\epsilon^d \epsilon^q] = 0$ a good assumption?
  - Paper argues $\mathrm{E}[\epsilon^d \epsilon^q] = O(1/(\text{patients per facility}))$

- Estimation details:

Step 1: Estimate α_q

$$y_{jt}\hat{E}[y|h_{jt}, i_{jt}, k_{jt}, \ell_{jt}, x_{jt}] = \alpha_q(qjt - \hat{E}[q|h_{jt}, i_{jt}, k_{jt}, \ell_{jt}, x_{jt}]) + \epsilon_{jt}$$

  - Drop observations with $h_{jt} = 0$ (not invertible)
  - Okay here, because selecting on ω, and residual, ϵ_{jt} is uncorrelated with ω
  - Problematic in last step? No, see footnote 49

Step 2: Estimate β_k, β_ℓ from

$$y_{jt} + \hat{\alpha}_q + \beta_k k_{jt} + \beta_\ell \ell_{jt} = g(\hat{\omega}_{jt-1}(\beta)) + \eta_{jt} + \epsilon_{jt}$$

  - Only have $\hat{\omega}_{jt-1}(\beta)$ when $h_{jt-1} \neq 0$, okay because ϵ_{jt} and η_{jt} are uncorrelated with ω_{jt-1}, would be problem if using $\hat{\omega}_{jt}$

- Nothing about selection – number of centers, 4270, vs center-years, 18295, implies there must be entry and exit

Results

- Estimate implications:
    - Holding inputs constant, reducing infections by one per year requires reducing output by 1.5 patients
        - Cost of treatment $\approx \$50,000$, so one infection $\approx \$75,000$
    - Holding output constant, reducing infections by one per year requires hiring 1.8 more staff
        - Cost of staff $\approx \$42,000$, so one infection $\approx \$75,000$

- Would like to see some results related to productivity dispersion e.g.
    - Decompose variation in infection rate into: productivity variation, incentive variation, quality-quantity choices, and random shocks
    - Compare strengthening incentives vs closing least productive facilities as policies to increase quality

Section 3

Doraszelski and Jaumandreu (2013)

Overview

- Estimable model of endogenous productivity, which combines:
    - Knowledge capital model of R&D
    - OP & LP productivity estimation
- Application to Spanish manufacturers focusing on R&D
    - Large uncertainty (20%-60% or productivity unpredictable)
    - Complementarities and increasing returns
    - Return to R&D larger than return to physical capital investment

Model (simplified) 1

- Cobb-Douglas production:

$$y_{it} = \beta_l l_{it} + \beta_k k_{it} + \omega_{it} + \epsilon_{it}$$

- Controlled Markov process for productivity, $p(\omega_{it+1} | \omega_{it}, r_{it})$,

$$\omega_{it} = g(\omega_{it-1}, r_{it-1}) + \xi_{it}$$

- Labor flexible and non-dynamic
- Value function

$$\begin{aligned} V(k_t, \omega_t, u_t) = \max_{i,r} \Pi(k_t, \omega_t) - C_i(i, u_t) - C_r(r, u_t) + \\ + \frac{1}{1+\rho} \mathrm{E}\left[V(k_{t+1}, \omega_{t+1}, u_{t+1}) | k_t, \omega_t, i, r, u_t \right] \end{aligned}$$

Model (simplified) 2

  - u scalar or vector valued shock
  - u not explicitly part of model, but identification discussion (especially p10 and footnote 6) implicitly adds it
  - u independent of? k, l? across time?
- Control function incorporating Cobb-Douglas assumption (and perfect competition):

$$\omega_{it} = h(l_{it}, k_{it}, w_{it} - p_{it}; \beta) = \lambda_0 + (1 - \beta_l) l_{it} - \beta_k k_{it} + (w_{it} - p_{it})$$

- Form moments based on

$$y_{it} = \beta_l l_{it} + \beta_k k_{it} + g\left(h(l_{it-1}, k_{it-1}, w_{it-1} - p_{it-1}; \beta), r_{it-1}\right) + \xi_{it} + \epsilon$$

- No collinearity because:
  - Parametric h
  - Variation in k, r due to u
- Estimated model adds

Model (simplified) 3

  - Material input instead of labor for control function
  - *h* based on imperfect competition
- Comparison to OP, LP, ACF

Results

- Look at tables and figures
- Large uncertainty (20%-60% or productivity unpredictable)
- Complementarities and increasing returns
- Return to R&D larger than return to physical capital

Amiti, Mary and Jozef Konings. 2007. “Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia.” *The American Economic Review* 97 (5):pp. 1611–1638. URL `http://www.jstor.org/stable/30034578`.

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