Remarks on
on Firm-Level Production Function Estimation

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Outline

- Levinsohn-Petrin (2003), Ackerberg et al. (2006) critique, Wooldridge (2009)
- Correct for measurement error in capital
- Stata code in Appendix (see also Amil Petrin‘s web page)

- This presentation draws on Galuščák and Lízal, „The Impact of Capital Measurement Error Correction on Firm-Level Production Function Estimation,“ mimeo; the previous version published as CNB WP 9/2011

Introduction I

- Estimation of TFP and returns to scale depends on the first-stage correct identification of production functions
  - Simultaneity bias caused by the relationship between unobserved productivity shocks and production inputs
  - Measurement issues: the true stock of capital is difficult to measure
    - Perpetual investment method (depreciation rate and initial stock of capital are unknown)
    - Stock of fixed assets deflated by industry deflators
  - Gorodnichenko (2010): the large variation of input prices across firms does not allow for non-stochastic inversion of firm‘s input choice into firm‘s unobserved productivity

Introduction II

- We correct for measurement error in capital in the estimation of production functions, using Czech manufacturing firm-level data merged with firm-level data on energy consumption in physical units
  - Wooldridge (2009), using instruments for capital
  - Modify the Levinsohn and Petrin (2003) approach implemented in Stata to correct for the measurement error in capital
    - We generate predicted values of capital and use these predictions as the capital data input
    - We modify the non-parametric bootstrap used to obtain standard errors to account for the IV regression in the first stage
- Correction for measurement error in capital yields sizeably higher coefficient estimates of capital; increasing returns to scale cannot be rejected

Estimation I

- Consider a Cobb-Douglas production function:

$$y_t = \beta_0 + \beta_l l_t + \beta_k k_t + \omega_t + \varepsilon_t$$

- y_t is log of output (value added or revenue), l_t is log of freely variable inputs (labour), k_t is log of quasi-fixed capital
- The error term has two components: the unobserved productivity component ω_t, and an error term ε_t uncorrelated with inputs
- ω_t affects the choice of inputs, leading to simultaneity problem in the estimation
- Levinsohn and Petrin (2003): two-step estimation using intermediate inputs as a proxy to invert out the unobserved productivity shock ω_t

Estimation II

- Demand for the intermediate input:

$$m_t = f_t(k_t, \omega_t)$$

- Under mild assumptions about the firm's production technology, the demand function is monotonically increasing in ω_t, allowing the inversion of the demand function:

$$\omega_t = g_t(k_t, m_t)$$

  - The unobservable productivity term is a function of two observed inputs

- Assume the productivity can be expressed as a first-order Markov process:

$$\omega_t = E[\omega_t \mid \omega_{t-1}] + \xi_t$$

  where ξ_t is uncorrelated with k_t, but not necessarily with l_t

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Estimation III

- LP method is implemented in Stata (Poi, Petrin, and Levinsohn, 2004)
- In the value added case:

$$y_t = \beta_0 + \beta_1 l_t + \beta_k k_t + \omega_t + \varepsilon_t$$

$$y_t = \beta_1 l_t + \phi_t\left(k_t, m_t\right) + \varepsilon_t$$

where $\phi_t\left(k_t, m_t\right) = \beta_0 + \beta_k k_t + g_t\left(k_t, m_t\right)$

and $E(\varepsilon_t \mid l_t, k_t, m_t) = 0$

- Substitute a third-order polynomial approximation in k_t and m_t in place of Φ_t and estimate β_l using OLS; this completes the first stage of the LP routine

Estimation IV

- In the second stage, the coefficient β_k is identified
- Estimated values computed: $\hat{\phi}_t = \widehat{y_t} - \widehat{\beta_l} l_t$
- For a candidate value β_k^* calculate (up to a constant) a prediction: $\widehat{\omega_t} = \hat{\phi}_t - \beta_k^* k_t$
- Consistent non-parametric approximation to $E[\omega_t \mid \omega_{t-1}]$ is given by predicted values from regression:

  $$\widehat{\omega}_t = \gamma_0 + \gamma_1 \widehat{\omega}_{t-1} + \gamma_2 \widehat{\omega}_{t-2}^2 + \gamma_3 \widehat{\omega}_{t-1}^3 + \varepsilon_t$$

  which LP call $E[\widehat{\omega_t \mid \omega_{t-1}}]$
- The estimate of β_k is defined as a solution to the minimization of

  $$\min_{\beta_k^*} \sum \left(y_t - \widehat{\beta_l} l_t - \beta_k^* k_t - E\left[\widehat{\omega_t \mid \omega_{t-1}}\right] \right)^2$$

- Bootstrap approach is used to construct standard errors for the estimates β_l and β_k

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Estimation V

- LP assume that given k_t, the firm decides on l_t and then, given l_t, determines m_t
- Ackerberg, Caves and Frazer (2006) show that l_t and m_t are chosen simultaneously so that β_l is not identified in the first step
- Recall that $m_t = f_t(k_t, \omega_t)$
- Since l_t is not in f, *it* may also be chosen as $l_t = h_t(k_t, \omega_t)$
- While h_t is a different function than f_t, substituting yields

$$l_t = h_t(k_t, g_t(k_t, m_t)) = i_t(k_t, m_t)$$

- This invalidates the identification of β_l in the first step

Estimation VI

- Wooldridge (2009) proposes to estimate β_l and β_k together
- In $y_t = \beta_0 + \beta_l l_t + \beta_k k_t + \omega_t + \varepsilon_t$
- Assume $E(\varepsilon_t \mid l_t, k_t, m_t, l_{t-1}, k_{t-1}, m_{t-1}, \ldots, l_1, k_1, m_1) = 0$
- Restrict the dynamics of productivity shocks

$$E(\omega_t \mid k_t, l_{t-1}, k_{t-1}, m_{t-1}, \ldots) = E(\omega_t \mid \omega_{t-1}) = j(\omega_{t-1}) = j\left(g\left(k_{t-1}, m_{t-1}\right)\right)$$

- Now we can write $\omega_t = j(\omega_{t-1}) + a_t$

$$E(a_t \mid k_t, l_{t-1}, k_{t-1}, m_{t-1}, \ldots) = 0$$

- This means that variable inputs l_t and m_t are correlated with productivity innovations a_t, but k_t, and all past values of l_t, k_t, m_t (and functions of these) are uncorrelated with a_t
- Plugging into the production function yields

$$y_t = \beta_0 + \beta_l l_t + \beta_k k_t + j\left(g\left(k_{t-1}, m_{t-1}\right)\right) + u_t$$

where $u_t = a_t + \varepsilon_t$ and $E(u_t \mid k_t, l_{t-1}, k_{t-1}, m_{t-1}, \ldots) = 0$

Estimation VII

- Now we have two equations which identify β_l and β_k:

$$y_t = \beta_0 + \beta_l l_t + \beta_k k_t + g\left(k_t, m_t\right) + \varepsilon_t$$

$$y_t = \beta_0 + \beta_l l_t + \beta_k k_t + j\left(g\left(k_{t-1}, m_{t-1}\right)\right) + u_t$$

where $u_t = a_t + \varepsilon_t$ and

$$E(\varepsilon_t \mid l_t, k_t, m_t, l_{t-1}, k_{t-1}, m_{t-1}, ..., l_1, k_1, m_1) = 0$$

$$E(u_t \mid k_t, l_{t-1}, k_{t-1}, m_{t-1}, ..., l_1, k_1, m_1) = 0$$

- *g* may be a low-degree polynomial; the productivity process (function *j*) may be a random walk with drift $\omega_t = \tau + \omega_{t-1} + a_t$
- The second equation becomes

$$y_t = \left(\beta_0 + \tau\right) + \beta_l l_t + \beta_k k_t + g\left(k_{t-1}, m_{t-1}\right) + u_t$$

- Estimate both equations using the joint GMM, or the second equation by pooled IV with instruments for l_t (Petrin, Levinsohn, 2011)

Estimation VIII

- Measurement error in capital, yielding biased estimates (capital coefficient is attenuated towards zero, see LP 2003)
- Given the iid measurement error e_t, true values $\widehat{k_t} = k_t - e_t$ are obtained as predicted values from the OLS estimation of

$$k_t = \gamma_0 + \gamma_1 z_{1t} + \ldots + \gamma_N z_{Nt} + e_t$$

where $z_{1t},\ldots,z_{Nt}$ are determinants (instruments) of capital and γ_0 is a firm-specific fixed effect

- Then the first step of LP becomes

$$y_t = \beta_0 + \beta_l l_t + \beta_k \widehat{k_t} + g\left(\widehat{k_t}, m_t\right) + \varepsilon_t, \text{ where } E\left(e_t \mid \varepsilon_t\right) = 0$$

- The estimates are inconsistent for a higher-order polynomial:
  - If $g = d_1(k_t - e_t) + d_2(k_t - e_t)^2 + \ldots$, then $E\{(k_t - e_t)^2\} \neq \{E(k_t - e_t)\}^2$
  - Linear approximation could be used instead as

$$E\left(k_t - e_t\right) = E\left(k_t\right) \text{ since } E\left(k_t, e_t\right) = 0$$

Estimation IX

- Modify the LP routine:
- The IV regression is used in the first stage instead of OLS, using appropriate instruments for capital
- Predicted values of capital are used in the second stage:

$$\min_{\beta_k^*} \sum \left(y_t - \widehat{\beta_l} l_t - \beta_k^* \widehat{k_t} - E\left[\widehat{\omega_t \mid \omega_{t-1}} \right] \right)^2$$

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Estimation X

- The current LP non-parametric bootstrap (based on random sampling from observations) used to get standard errors for the estimates is modified to account for IV regression in the first stage: we sample the observations from a distribution that reflects the uncertainty in the capital value
  - Capital values for each firm are drawn with 100 replications from a distribution $\hat{k}_t + \eta_t$, where $\hat{k}_t$ is the predicted capital (including fixed effect) from the IV regression and $\eta_t \sim N(0,\sigma_k^2)$. The parameter σ_k^2 is the firm-specific variance of predicted capital $\hat{k}_t$ obtained by bootstrap with 1,000 replications. (Sampling is done twice: first, the firm-specific variance of the predicted capital is obtained; second, standard LP sampling is done where capital is randomly drawn from the distribution reflecting the firm-specific variance of the predicted capital.)

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Estimation XI

- In Wooldridge (2009) approach, capital is instrumented using depreciation, employment and gas consumption as instruments

Data I

- Selected items from yearly datasets obtained from the Czech Statistical Office:
  - Balance sheet and income statement information
  - Energy consumption in physical units: electricity, gas, oil
- Value added deflators in manufacturing industries (at 2-digit NACE level)
- All manufacturing firms with 20 or more employees in 2002-2007
- Our sample covers economically active firms in each year without organizational changes
- All intermediate inputs are reported in physical units so that there is no (even potential) problem with prices and deflating

Data II

- Value added
  - Accounting approach: sales + stocks + new investments - intermediate inputs – sales and services costs (some values are missing)
  - Economic approach: wage bill + profit +depreciation
  - Results do not differ qualitatively => we use the „accounting measure“
- Labour
  - Average number of employees (full-time equivalent) used as instrument
  - Number of hours worked used as production input

Data III

- Capital
  - Tangible and intangible assets at the beginning of the period, net of depreciation
    - Measured with an error due to deflation or due to using book values
  - Instruments: depreciation, full-time equivalent of the average number of employees, gas consumption in physical units
- Two alternative deflators for capital
  - Average inflation rate
  - Interest rate of new borrowing (cost of capital)
- Proxy variables: electricity consumption, (gas consumption)
- We imputed missing values as averages of adjacent observations
  - 6 % of all observations; the results are robust when these observations are dropped

Results I

- We estimate firm-level production functions for 2-digit NACE level manufacturing industries (excluding petroleum and refining) in 2003-2007
  - (1): Wooldridge (2009), capital endogenous
  - (2): Wooldridge (2009), capital exogenous
  - (3): Standard LP method
  - (4): LP method with correction for capital measurement error
  - Repeat (3) and (4) with linear approximation of *g*
- Robustness checks: alternative definition of value added (economic approach), alternative capital deflator, gas consumption as a proxy in the LP method; electricity consumption as an instrument for real capital

Results II

Food products and beverages, Textiles

	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
	Man. of food (NACE 15-16)						*Man. of textiles (NACE 17-19)*					
Log hours	0.636***	0.686***	0.700***	0.690***	0.700***	0.687***	0.675***	0.553***	0.587***	0.586***	0.609***	0.607***
	[0.0403]	[0.0372]	[0.0348]	[0.0347]	[0.0323]	[0.0383]	[0.0576]	[0.0866]	[0.0885]	[0.0851]	[0.0958]	[0.0881]
Log real capital	0.578***	0.282***	0.301***	0.581***	0.348***	0.541***	0.609***	0.165***	0.156*	0.305***	0.264***	0.298***
	[0.122]	[0.0362]	[0.0721]	[0.103]	[0.0519]	[0.0994]	[0.185]	[0.0487]	[0.0796]	[0.101]	[0.0946]	[0.0967]
Observations	1510	1510	1510	1510	1510	1510	829	829	829	829	829	829
Firms	467	467	467	467	467	467	279	279	279	279	279	279
Returns to scale	1.214*	0.968	1.001	1.271**	1.048	1.228**	1.284	0.718***	0.744**	0.891	0.872	0.904

Notes: Standard errors in brackets, *** p<0.01, ** p<0.05, * p<0.1. Real value of capital (deflated by the average inflation rate).

Returns to scale (log labour + log real capital) and significance level of Wald test of constant returns reported (H0: log labour + log real capital = 1).

(1) Wooldridge (2009), real capital is instrumented using depreciation, employment and gas consumption.

(2) Wooldridge (2009).

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(5) Levinsohn-Petrin (2003), linear approximation used for *g*.

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- The correction significantly increases the coeff. estimate of capital
- LP (2003) gives similar results as Wooldridge (2009): (3) versus (2)
- „Linear“ LP method: results in (5) and (6) are similar as in (3) and (4)

Results III

Wood, Chemicals

	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
	Man. of wood (NACE 20-22)						*Man. of chemicals (NACE 24)*					
Log hours	0.580***	0.606***	0.657***	0.640***	0.654***	0.639***	0.624***	0.574***	0.610***	0.608***	0.629***	0.619***
	[0.0737]	[0.0908]	[0.0971]	[0.0830]	[0.0900]	[0.0758]	[0.100]	[0.140]	[0.129]	[0.147]	[0.115]	[0.115]
Log real capital	0.697***	0.254***	0.260**	0.326***	0.315***	0.458***	1.997***	0.374***	0.465***	1.204***	0.424**	1.206***
	[0.144]	[0.0588]	[0.111]	[0.118]	[0.110]	[0.153]	[0.561]	[0.0993]	[0.146]	[0.197]	[0.185]	[0.213]
Observations	620	620	620	620	620	620	444	444	444	444	444	444
Firms	201	201	201	201	201	201	120	120	120	120	120	120
Returns to scale	1.277*	0.859	0.917	0.965	0.969	1.097	2.621***	0.948	1.075	1.812***	1.052	1.825***

Notes: Standard errors in brackets, *** p<0.01, ** p<0.05, * p<0.1. Real value of capital (deflated by the average inflation rate).

Returns to scale (log labour + log real capital) and significance level of Wald test of constant returns reported (H0: log labour + log real capital = 1).

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Results IV

Rubber, Other mineral products

	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
	Man. of rubber (NACE 25)						*Man. of other mineral products (NACE 26)*					
Log hours	0.548***	0.618***	0.642***	0.629***	0.644***	0.623***	0.345***	0.392***	0.430***	0.421***	0.436***	0.425***
	[0.0705]	[0.0671]	[0.0727]	[0.0701]	[0.0723]	[0.0584]	[0.0514]	[0.0644]	[0.0606]	[0.0637]	[0.0601]	[0.0692]
Log real capital	0.733***	0.290***	0.464***	0.601***	0.451***	0.610***	0.803***	0.328***	0.265**	0.392***	0.297***	0.482***
	[0.136]	[0.0798]	[0.0792]	[0.165]	[0.0805]	[0.152]	[0.191]	[0.0796]	[0.115]	[0.132]	[0.0948]	[0.143]
Observations	613	613	613	613	613	613	728	728	728	728	728	728
Firms	216	216	216	216	216	216	200	200	200	200	200	200
Returns to scale	1.281**	0.908	1.106	1.229	1.096	1.233	1.148	0.72***	0.695**	0.814	0.733**	0.907

Notes: Standard errors in brackets, *** p<0.01, ** p<0.05, * p<0.1. Real value of capital (deflated by the average inflation rate).

Returns to scale (log labour + log real capital) and significance level of Wald test of constant returns reported (H0: log labour + log real capital = 1).

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Results V

Metals, Machinery

	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
	Man. of metals (NACE 27-28)						*Man. of machinery (NACE 29)*					
Log hours	0.638***	0.664***	0.684***	0.680***	0.705***	0.700***	0.711***	0.812***	0.857***	0.849***	0.883***	0.874***
	[0.0398]	[0.0445]	[0.0430]	[0.0379]	[0.0404]	[0.0438]	[0.0452]	[0.0426]	[0.0517]	[0.0452]	[0.0438]	[0.0416]
Log real capital	0.575***	0.243***	0.247***	0.371***	0.228***	0.339***	0.633***	0.171***	0.185***	0.406***	0.193***	0.405***
	[0.104]	[0.0365]	[0.0551]	[0.0912]	[0.0596]	[0.0721]	[0.108]	[0.0350]	[0.0363]	[0.0753]	[0.0422]	[0.0852]
Observations	1673	1673	1673	1673	1673	1673	1510	1510	1510	1510	1510	1510
Firms	592	592	592	592	592	592	502	502	502	502	502	502
Returns to scale	1.213**	0.906*	0.931	1.052	0.934	1.039	1.344***	0.983	1.041	1.255***	1.076	1.279***

Notes: Standard errors in brackets, *** p<0.01, ** p<0.05, * p<0.1. Real value of capital (deflated by the average inflation rate).

Returns to scale (log labour + log real capital) and significance level of Wald test of constant returns reported (H0: log labour + log real capital = 1).

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Results VI

Optical and Electronics, Motor vehicles

	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
	Man. of electrical and optical machinery (NACE 30-33)						*Man. of motor vehicles (NACE 34-35)*					
Log hours	0.728***	0.820***	0.845***	0.843***	0.868***	0.862***	0.642***	0.647***	0.719***	0.685***	0.717***	0.690***
	[0.0392]	[0.0485]	[0.0493]	[0.0453]	[0.0402]	[0.0396]	[0.0861]	[0.0812]	[0.0911]	[0.0794]	[0.0868]	[0.0788]
Log real capital	0.747***	0.172***	0.204**	0.336***	0.162*	0.344***	0.597***	0.13	0.174	0.576***	0.171	0.623***
	[0.122]	[0.0437]	[0.0837]	[0.115]	[0.0886]	[0.0975]	[0.176]	[0.0923]	[0.115]	[0.145]	[0.107]	[0.136]
Observations	1250	1250	1250	1250	1250	1250	669	669	669	669	669	669
Firms	367	367	367	367	367	367	192	192	192	192	192	192
Returns to scale	1.475***	0.993	1.049	1.179	1.03	1.206**	1.239	0.777**	0.894	1.261	0.888	1.314**

Notes: Standard errors in brackets, *** p<0.01, ** p<0.05, * p<0.1. Real value of capital (deflated by the average inflation rate).

Returns to scale (log labour + log real capital) and significance level of Wald test of constant returns reported (H0: log labour + log real capital = 1).

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Results VII

Other manufacturing

	(1)	(2)	(3)	(4)	(5)	(6)
	Man. other (NACE 36-37)					
Log hours	1.112***	1.055***	1.093***	1.089***	1.101***	1.101***
	[0.0971]	[0.135]	[0.137]	[0.125]	[0.119]	[0.138]
Log real capital	0.758	0.140*	0.270**	0.752**	0.247**	0.837**
	[0.485]	[0.0783]	[0.135]	[0.321]	[0.118]	[0.363]
Observations	622	622	622	622	622	622
Firms	206	206	206	206	206	206
Returns to scale	1.87*	1.196	1.363**	1.841**	1.348**	1.937**

Notes: Standard errors in brackets, *** p<0.01, ** p<0.05, * p<0.1. Real value of capital (deflated by the average inflation rate).

Returns to scale (log labour + log real capital) and significance level of Wald test of constant returns reported (H0: log labour + log real capital = 1).

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Results VIII

Returns to scale in Czech manufacturing industries, 2002-2007

	(1)	(2)	(3)	(4)
Food products, beverages and tobacco products (NACE 15-16)	1.214*	0.968	1.001	1.271**
Textiles, wearing apparel and leather (NACE 17-19)	1.284	0.718***	0.744**	0.891
Wood, pulp and paper, publishing and printing (NACE 20-22)	1.277*	0.859	0.917	0.965
Chemicals (NACE 24)	2.621***	0.948	1.075	1.812***
Rubber and plastic products (NACE 25)	1.281**	0.908	1.106	1.229
Other non-metallic mineral products (NACE 26)	1.148	0.72***	0.695**	0.814
Metals (NACE 27-28)	1.213**	0.906*	0.931	1.052
Machinery and other equipment (NACE 29)	1.344***	0.983	1.041	1.255***
Electrical and optical machinery and equipment (NACE 30-33)	1.475***	0.993	1.049	1.179
Motor vehicles and other transport equipment (NACE 34-35)	1.239	0.777**	0.894	1.261
Furniture, other manufacturing, recycling (NACE 36-37)	1.87*	1.196	1.363**	1.841**

Notes: Returns to scale (log labour + log real capital) and significance level of Wald test of constant returns reported (H0: log labour+log real capital=1);

*** p<0.01, ** p<0.05, * p<0.1.

(1) Wooldridge (2009), real capital is instrumented using depreciation, employment and gas consumption.

(2) Wooldridge (2009).

(3) Levinsohn-Petrin (2003).

(4) Levinsohn-Petrin (2003), real capital is instrumented using depreciation, employment and gas consumption.

- Returns to scale are increasing in about half of manufacturing industries when the measurement error in capital is accounted for
  - Accounting for capacity utilization marginally decreases the coefficient estimates of capital; no impact on RTS test results

Conclusions

- Wooldridge (2009) is a superior method of production function estimation, but the results do not differ much from LP (hence, little impact on TFP); runs faster in Stata
- The measurement error of capital is a substantial problem: the correction significantly increases the coefficient estimate of capital
  - Ignoring the measurement error may lead to underestimation of the effect of capital on value added formation
- The measurement error matters more than specific assumptions approximating the unknown function *g*
- While most industries using the standard methods exhibit constant or decreasing returns to scale, we cannot reject the presence of increasing returns in some industries when the estimation is corrected for the measurement error in capital

Appendix

```
* Wooldridge (2009) method of production function
estimation

* lagged variables
xtset ico rok, yearly
gen ln_L_l1=L.lnodprac_hod
gen ln_K_l1=L.lnkap_infl
gen ln_E_l1=L.lnelektrina

* defining exponential function of lnK and lnM
gen km_l1=ln_K_l1*ln_E_l1
gen k2_l1=ln_K_l1^2
gen m2_l1=ln_E_l1^2

gen k2m_l1=ln_K_l1^2*ln_E_l1
gen km2_l1=ln_K_l1*ln_E_l1^2
gen k3_l1=ln_K_l1^3
gen m3_l1=ln_E_l1^3

* defining instruments for capital and its interations
* ln_K_l1
gen ln_odp_l1=L.lnodpisy
gen ln_emp_l1=L.empl_avg_prepocteny
gen ln_plyn_l1=L.lnplyn_m3

* km_l1
gen odpm_l1=ln_odp_l1*ln_E_l1
gen empm_l1=ln_emp_l1*ln_E_l1
gen plynm_l1=ln_plyn_l1*ln_E_l1

* k2_l1
gen odp2_l1=ln_odp_l1^2
gen emp2_l1=ln_emp_l1^2
gen plyn2_l1=ln_plyn_l1^2

* k2m_l1
gen odp2m_l1=ln_odp_l1^2*ln_E_l1
gen emp2m_l1=ln_emp_l1^2*ln_E_l1
gen plyn2m_l1=ln_plyn_l1^2*ln_E_l1

* km2_l1
gen odpm2_l1=ln_odp_l1*ln_E_l1^2
gen empm2_l1=ln_emp_l1*ln_E_l1^2
gen plynm2_l1=ln_plyn_l1*ln_E_l1^2

* k3_l1
gen odp3_l1=ln_odp_l1^3
gen emp3_l1=ln_emp_l1^3
gen plyn3_l1=ln_plyn_l1^3

* denote the instruments for capital
global instr_K lnodpisy lnempl_avg_prepocteny
lnplyn_m3 ln_odp_l1 ln_emp_l1 ln_plyn_l1 odpm_l1
empm_l1 plynm_l1 odp2_l1 emp2_l1 plyn2_l1 odp2m_l1
emp2m_l1 plyn2m_l1 odpm2_l1 empm2_l1 plynm2_l1
odp3_l1 emp3_l1 plyn3_l1

* column 1: Wooldridge (2009), account for
measurement error in capital

ivreg2 lnph1_defl ln_E_l1 m2_l1 m3_l1 (lnodprac_hod
lnkap_infl ln_K_l1 km_l1 k2_l1 k2m_l1 km2_l1
k3_l1=ln_L_l1 $instr_K), gmm2s cluster(ico)

local rs=_b[lnodprac_hod]+_b[lnkap_infl]
local firms=e(N_clust)
test _b[lnodprac_hod]+_b[lnkap_infl]=1
local pvalue=r(p)
outreg2 using "ind106_1.xls", append br auto(3) nor2
addstat(Firms, `firms', Returns to scale, `rs', p-value,
`pvalue')

* column 2: Wooldridge (2009)
ivreg2 lnph1_defl lnkap_infl ln_K_l1 ln_E_l1 km_l1
k2_l1 m2_l1 k2m_l1 km2_l1 k3_l1 m3_l1
(lnodprac_hod=ln_L_l1), gmm2s cluster(ico)

local rs=_b[lnodprac_hod]+_b[lnkap_infl]
local firms=e(N_clust)
test _b[lnodprac_hod]+_b[lnkap_infl]=1
local pvalue=r(p)
outreg2 using "ind106_1.xls", append br auto(3) nor2
addstat(Firms, `firms', Returns to scale, `rs', p-value,
`pvalue')
```

- Thank you for your attention

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