Income Differences and IO Structure

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Motivation

Determinants of income differences across countries

The current state of debate – "development accounting":

- A simple aggregate production function for value added:

$$Y_i = \Lambda_i K_i^{\alpha} L_i^{1-\alpha} \tag{1}$$

Y_i = real GDP in country i, Λ_i = TFP (unobserved), K_i = real physical capital, L_i = labor.

- Dividing equation (1) by L_i:

$$\frac{Y_i}{L_i} = \Lambda_i \left(\frac{K_i}{L_i}\right)^{\alpha}. \tag{2}$$

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- High multiplier sectors (Transport, Energy) supply to a large number of sectors or are used intensively as inputs by others.
- Low productivities in different sectors have very distinct effects on GDP, depending on the size of the sectoral IO multiplier.

This paper

Research questions

- Study how differences in economic structure across countries (IO linkages) affect cross-country differences in aggregate income per capita:
  - Use data on IO tables, sectoral TFPs and tax rates for a large cross section of countries in the year 2005,
  - Use network theory to get simple mapping between the distributions of IO multipliers, productivities, taxes and income per capita.
  - Estimate distributions and simulate model.
  - Investigate how the IO structure interacts with sectoral TFP differences and taxes to determine aggregate income.

This paper

Main findings (1)

IO structure differs between rich and poor countries:

- In all countries, there are relatively few sectors with very large IO multipliers, which have large impact on aggregate income.
- But the difference is:
  - **Poor** countries have a very small number of sectors with high multipliers;
  - **Rich** countries have a relatively large number of sectors with average multipliers (denser input-output network).

Go to IO Tables

This paper

Main findings (2)

Sectoral productivities and tax distortions interact with IO structure differently in poor and rich countries:

- **Poor** economies have relatively **high** (compared to their average TFP) productivities and taxes in **high** IO-multiplier sectors;
- **Rich** economies, have relatively **high** productivities and taxes in **low** IO-multiplier sectors.

Go to Productivities and Taxes

This paper

Main findings (3)

- Interaction of sector-level productivities and IO structure is quantitatively important in explaining income differences across countries:
  - The model with IO structure performs significantly better in predicting cross-country income differences than one without IO structure.
  - If poor countries had the US IO structure they would be up to 80% poorer: with denser US IO structure low-productivity sectors would have larger impact.
  - If poor countries did not have above-average productivities in high-multiplier sectors, they would be up to 50% poorer.

Literature

- Development accounting literature (Hall and Jones, 99; Caselli, 2005) ignores intermediate goods and cross-country differences in IO structure.
- Literature on the role of IO structure and IO multipliers for aggregate income (Hirschman, 1958; Ciccone, 2002; Jones, 2011a,b):
  (i) theoretical context, (ii) emphasis on the role of IO structure as an amplifier of small firm (or industry-level) productivity differences.
  $\rightarrow$ Little empirical evidence for (ii) in our paper.
- Literature on dual economies (Caselli, 2005; Restuccia et al., 2008; Gollin et al., 2014) abstracts from intermediate linkages between industries.
- Literature on sectoral productivity shocks and aggregate fluctuations (Acemoglu et al., 2012).
- Closest empirical paper: Bartelme and Gorodnichenko (2014).

Theoretical model

- n competitive sectors, technology is Cobb-Douglas with CRS:

$$q_i = \Lambda_i \left(k_i^{\alpha} l_i^{1-\alpha}\right)^{1-\gamma_i} d_{1i}^{\gamma_{1i}} d_{2i}^{\gamma_{2i}} \cdot \ldots \cdot d_{ni}^{\gamma_{ni}}.$$

  - Λ_i is productivity of sector i, k_i and l_i are capital and labor used by sector i and d_{ji} is intermediate good produced by sector j used by sector i;
  - $\gamma_i = \sum_{j=1}^{n} \gamma_{ji} \in (0,1)$ is total intermediate goods' share of sector i;
  - in the following we assume that $\gamma_i = \gamma_j = \gamma \ \forall i, j \in 1 : n$.

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$$y_i + \sum_{j=1}^{n} d_{ij} = q_i \qquad i = 1:n$$

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Competitive equilibrium with taxes

Definition

A competitive equilibrium with taxes is a collection of quantities q_i, k_i, l_i, y_i, d_{ij}, Y, C and prices p, p_i, w, and r for $i \in 1 : n$ such that

1. y_i solves the profit max. problem of a firm in a perfectly competitive final good's market:

$$\max_{\{y_i\}} p y_1^{\frac{1}{n}} \cdot \ldots \cdot y_n^{\frac{1}{n}} - \sum_{i=1}^{n} p_i y_i$$

2. $\{d_{ij}\}$, k_i, l_i solve the profit max. problem of a sector i's firm:

$$\max_{\{d_{ij}\},k_i,l_i} (1-\tau_i) p_i \Lambda_i \left(k_i^{\alpha} l_i^{1-\alpha}\right)^{1-\gamma_i} d_{1i}^{\gamma_{1i}} d_{2i}^{\gamma_{2i}} \cdot \ldots \cdot d_{ni}^{\gamma_{ni}} - \sum_{j=1}^{n} p_j d_{ji} - r k_i - w l_i .$$

3. Budget constraint determines C: $C = w + rK + \sum_{i=1}^{n} \tau_i p_i q_i$.
4. Markets clear: $\sum_{i=1}^{n} k_i = K$, $\sum_{i=1}^{n} l_i = 1$, $y_i + \sum_{j=1}^{n} d_{ij} = q_i$, $Y = C$.

Expected income per capita

- Model can be explicitly solved for income per capita.
- Assuming that IO multipliers, productivities, and tax rates are random variables, (log) income per capita is:

$$E(y) \approx n\left(E(\mu)E(\Lambda^{rel}) + cov(\mu, \Lambda^{rel}) - E(\mu)E(\tau) - cov(\mu, \tau)\right) + \alpha \log(K) + const$$

- $\boldsymbol{\mu} = \{\mu_i\}_i = \frac{1}{n}[\boldsymbol{I} - \boldsymbol{\Gamma}]^{-1}\mathbf{1}$, where $[\boldsymbol{I} - \boldsymbol{\Gamma}]^{-1}$ is the *Leontief inverse*.

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- A typical element l_{ij} of the Leontief inverse shows how a 1% increase in productivity of sector i affects the output of sector j
- μ_i reveals how a 1% change in productivity of sector i affects *aggregate* income.

Expected aggregate output

- We use a statistical approach: employ moments of the distributions instead of actual values.
- The distribution of $(\mu_i, \Lambda_i^{rel}, \tau_i)$ is close to (truncated) log-Normal.
- Parameters $\{(m_\mu, m_\tau, m_{\Lambda^{rel}}), \Sigma\}$ can vary with GDP per capita.
- Then

$$E(y) \approx n\left(e^{m_\mu + m_\Lambda + 1/2(\sigma_\mu^2 + \sigma_\Lambda^2) + \sigma_{\mu,\Lambda}} - e^{m_\mu + m_\tau + 1/2(\sigma_\mu^2 + \sigma_\tau^2) + \sigma_{\mu,\tau}}\right) + \alpha \log(K) + const.$$

- [Assume: $\gamma_{ij} = \hat{\gamma}\ \forall \gamma_{ij} > 0$]

Empirical analysis – main steps

1. Estimate parameters of the distribution allowing them to vary with per capita GDP;
2. Using the derived expression for $E(y)$, simulate $E(y)$ for each country $\Rightarrow$ assess income differences as predicted by the model;
3. Evaluate how well the model fits the data;
4. Conduct counterfactual experiments and robustness checks.

Datasets

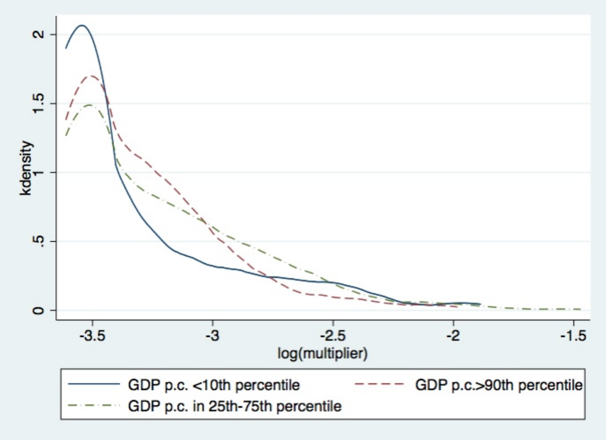
1. World Input-Output Database (WIOD): 39 countries, for year 2005
    - Data includes: IO-tables in basic prices (35 sectors), sector-level data on gross output, physical capital stocks, labor inputs, intermediate inputs, PPP-deflators for sector-level gross output, sector-level input shares, net taxes (non-deductable) on sector-level gross output
    - We use data to construct sectoral TFPs assuming country-sector-specific Cobb-Douglas technologies
2. Global Trade Analysis Project (GTAP): 70 countries, for year 2004
    - Data includes IO-tables (37 sectors)
    - We use GTAP data to get more information about IO tables of low-income countries
3. Penn World Tables (PWT 7.1): 155 countries, for year 2005
    - Data on income per capita in PPP, physical capital stocks, employment
    - We use PWT table data to make out-of-sample predictions

Structural estimation: summary of results

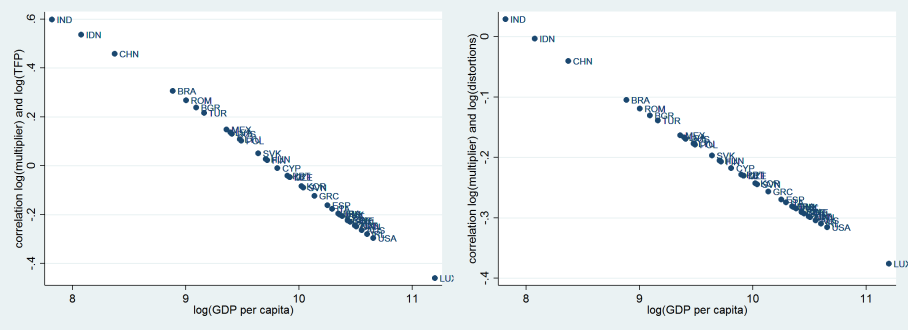
- The distribution of *IO multipliers* has a **larger variance** and more mass in the right tail in **poor** countries compared to rich ones.
- The distribution of *productivities* has **lower mean** and **larger variance** in **poor** countries compared to rich ones.
- The distribution of *taxes* has **lower mean** and **larger variance** in **poor** countries compared to rich ones.
- *Multipliers and productivities* are **positively correlated** in **poor** countries and **negatively** in **rich** ones.
- *Multipliers and taxes* are **positively correlated** in **poor** countries and **negatively** in **rich** ones.

Go to Maximum Likelihood Results

Distribution of sectoral (log) multipliers (GTAP sample)



Estimated correlation between multiplier and productivity/taxes



Evaluating model fit

- Using parameters estimates and calibrated values for the share of intermediates ($\gamma = 0.5$) in gross output and capital ($\alpha = 0.33$) in value added, we simulate the model.
- To evaluate fit:
  1. plot predicted GDP per capita relative to U.S. on actual GDP per capita rel. U.S.;
  2. compare with 2 simpler models:
     - ★ model without IO linkages, productivity differences, taxes: $E(y) = \alpha log(K)$ ('**naive model**')
     - ★ multi-sector model with estimated productivity differences but without IO linkages:

$E(y) = e^{m_\Lambda + 0.5 * \sigma^2_\Lambda} + \alpha \log(K) + const$ ('**no IO structure**')

Model Fit: WIOD sample

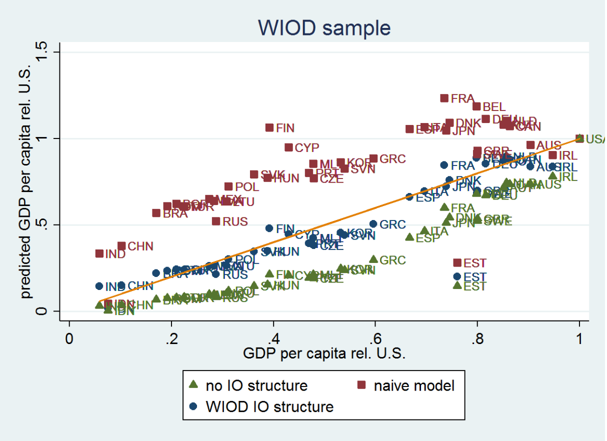


Figure: Predicted income per capita: baseline model with estimated IO structure vs. 'no IO structure' and 'naive model'

Model fit: Alternative Samples

Figure: Predicted income per capita: baseline model with estimated IO structure vs. 'no IO structure' and 'naive model'

Summary of model fit

Our baseline model with estimated IO structure performs substantially better in terms of predicting cross-country income differences than

- naive model (underestimates income differences),
- model with technology differences but without IO structure (overestimates income differences), and
- model with constant IO structure (underestimates income differences).

Counterfactuals

How are predictions affected by changing specific parameters?

1. Suppose we give all countries the U.S. IO structure (m_μ, σ_μ). How would their income change?
2. Suppose we set the correlation between multipliers and productivities to zero for all countries. How would their income change?
3. Suppose we give all countries the U.S. distribution of taxes (m_τ, σ_τ). How would their income change?
4. Suppose we set the correlation between multipliers and taxes to zero for all countries. How would their income change?

Counterfactuals: US IO structure

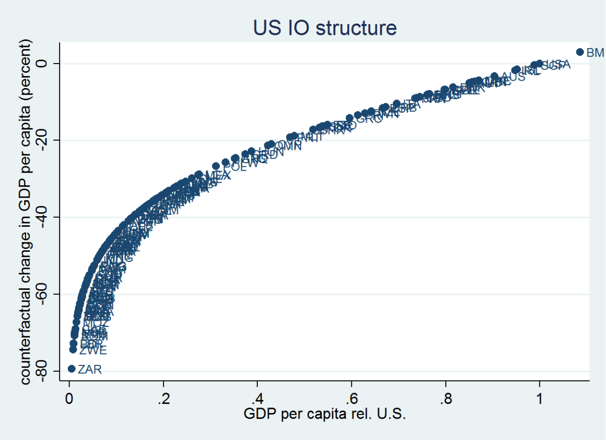


Figure: Counterfactuals 1

Counterfactuals: no correlation between productivity and IO structure

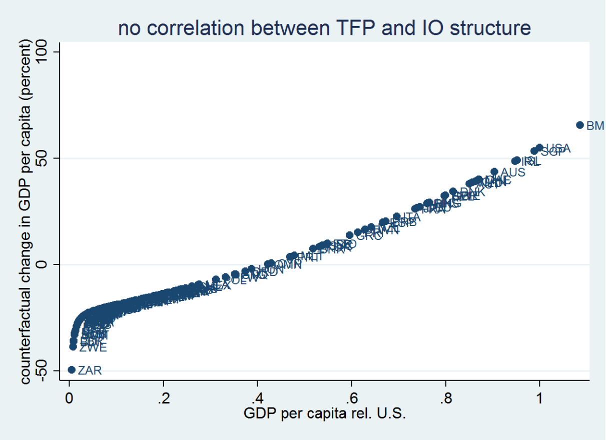


Figure: Counterfactuals 2

Counterfactuals: US distribution of taxes/no correlation between taxes and IO structure

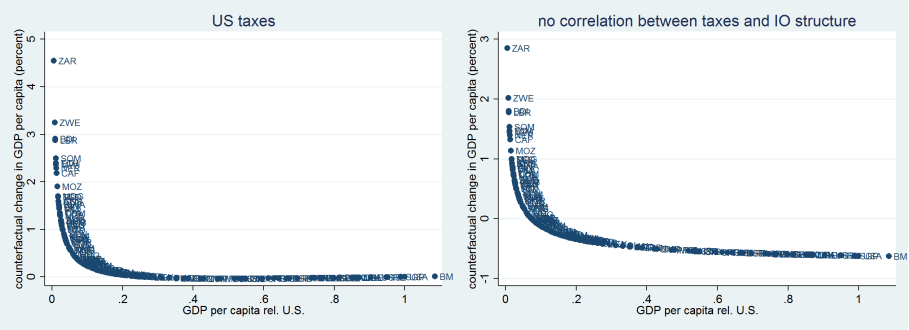


Figure: Counterfactuals 3 and 4

Summary of counterfactual experiments

- Imposing the dense IO structure of the U.S. on poor economies would reduce their income levels by up to 80 percent.
- If poor economies did not have above-average productivity levels in high-multiplier sectors, their income levels would be reduced by up to 40 percent.
- Imposing the distribution of tax rates of the U.S. on poor economies would lead to moderate income gains of up to 5 percent.
- If poor economies did not have above-average tax levels in high-multiplier sectors, their income levels would increase by up to 3 percent.

Conclusions

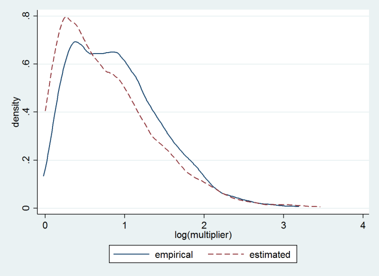
- IO structure and sectoral productivity differences across countries matter for the difference in aggregate income.
- In particular, sectoral productivity differences are even larger than aggregate ones:
  - Poor countries do relatively well since they have above-average TFP in high-multiplier sectors, the opposite is true for rich countries.
- Consequence: becoming rich is even harder than naive model predicts:
  - As countries become richer, network structure changes and average sector becomes more connected.
  - No longer sufficient to have high productivity in a few sectors, but need to increase productivity in many sectors.
  - Caveat: multipliers could be endogenous to productivity (if production functions not Cobb-Douglas).

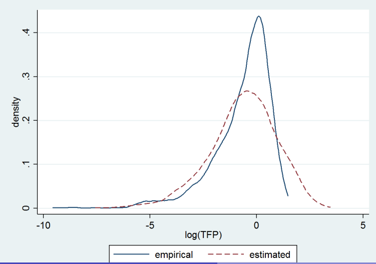
Table: Maximum likelihood

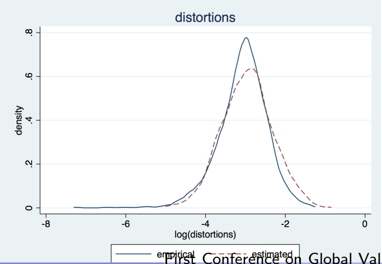
	WIOD sample	
	Coef.	Std. Err.
$\mathbf{m}_{\mu}$:		
constant	0.648	0.431
log(gdp per capita)	-0.081*	0.047
$\log(\sigma^2_{\mu})$:		
constant	-0.642***	0.145
$\mathbf{m}_{\mathbf{\Lambda}}$:		
constant	-13.327***	1.287
log(gdp per capita)	1.287***	0.142
$\log(\sigma^2_{\mathbf{\Lambda}})$:		
constant	4.102***	0.735
log(gdp per capita)	-0.375***	0.074
$\mathbf{m}_{\tau}$:		
constant	-3.847***	0.464
log(gdp per capita)	0.090***	0.046
$\log(\sigma^2_{\tau})$:		
constant	1.870***	0.617
log(gdp per capita)	-0.284***	0.062
z-transformed $\rho_{\mu\mathbf{\Lambda}}$:		
constant	3.440***	0.813
log(gdp per capita)	-0.352***	0.083
z-transformed $\rho_{\mu\tau}$:		
constant	1.010*	0.607
log(gdp per capita)	-0.126**	0.061
Log likelihood	-107.885	
Observations	1281	

Estimated vs. actual distribution of multipliers, productivity, and distortions

Go Back







Robustness

Extensions: estimation on approximated multipliers, unequal demand shares, open economy, skilled/unskilled labor, taxes as revenue (not waste).

- Approximation of multipliers:
  1st order approximation is $\boldsymbol{\mu} \approx \frac{1}{n} + \frac{1}{n}\mathbf{\Gamma 1}$,
  2nd order approximation is $\boldsymbol{\mu} \approx \frac{1}{n} + \frac{1}{n}\mathbf{\Gamma 1} + \frac{1}{n}\mathbf{\Gamma}^2\mathbf{1}$
- Unequal demand shares (by country-industry): $Y = y_1^{\beta_1} \cdot \ldots \cdot y_n^{\beta_n}$,
  Implications for multipliers: $\boldsymbol{\mu} = \{\mu_i\}_i = [\boldsymbol{I} - \mathbf{\Gamma}]^{-1}\boldsymbol{\beta}$
- Open economy: separate domestic and imported intermediate inputs

$$q_i = \Lambda_i \left(k_i^{\alpha} l_i^{1-\alpha}\right)^{1-\gamma_i-\sigma_i} d_{1i}^{\gamma_{1i}} d_{2i}^{\gamma_{2i}} \cdot \ldots \cdot d_{ni}^{\gamma_{ni}} \cdot m_{1i}^{\sigma_{1i}} m_{2i}^{\sigma_{2i}} \cdot \ldots \cdot m_{ni}^{\sigma_{ni}},$$

- Skilled/unskilled labor

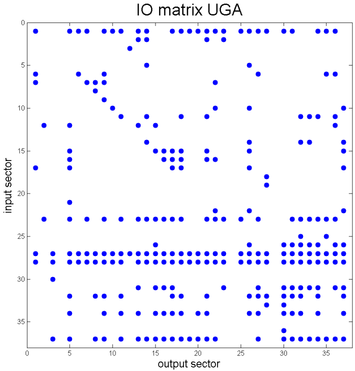
$$q_i = \Lambda_i \left(k_i^{\alpha} u_i^{\delta} s_i^{1-\alpha-\delta}\right)^{1-\gamma_i-\sigma_i} d_{1i}^{\gamma_{1i}} d_{2i}^{\gamma_{2i}} \cdot \ldots \cdot d_{ni}^{\gamma_{ni}}$$

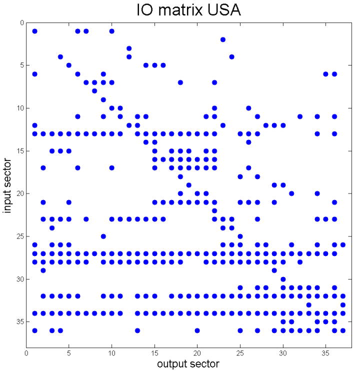
Robustness Checks

Table: Robustness: World IO sample

	1st order approximation	2nd order approximation	Expenditure shares	Human capital	Imported intermediates	No waste
constant	-0.106***	-0.133**	-0.128***	-0.055***	-0.153***	0.017
	(0.022)	(0.059)	(0.027)	(0.002)	(-0.026)	(0.021)
slope	0.989***	0.974***	0.901***	0.943***	1.004***	0.920***
	(0.056)	(0.059)	(0.064)	(0.055)	(0.063)	(0.057)
Observations	39	39	39	39	39	39
R-squared	0.883	0.884	0.865	0.845	0.884	0.852

IO-matrices: Uganda and USA





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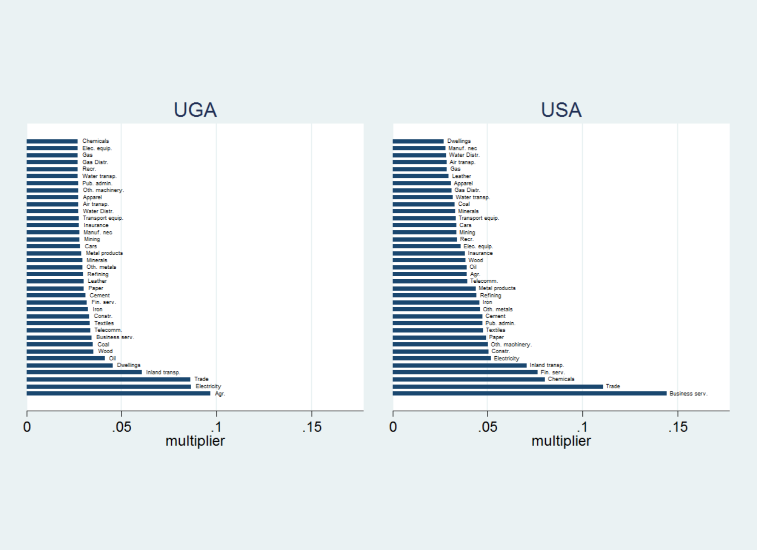
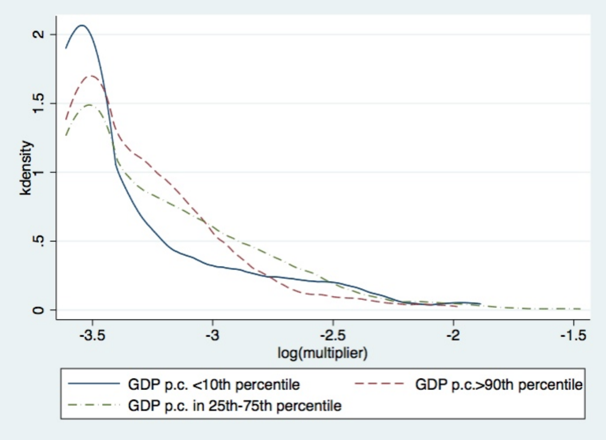


Figure: Sectoral IO-multipliers by country

Distribution of sectoral (log) multipliers (GTAP sample)

Go To Main Findings



▸ Go To Main Findings

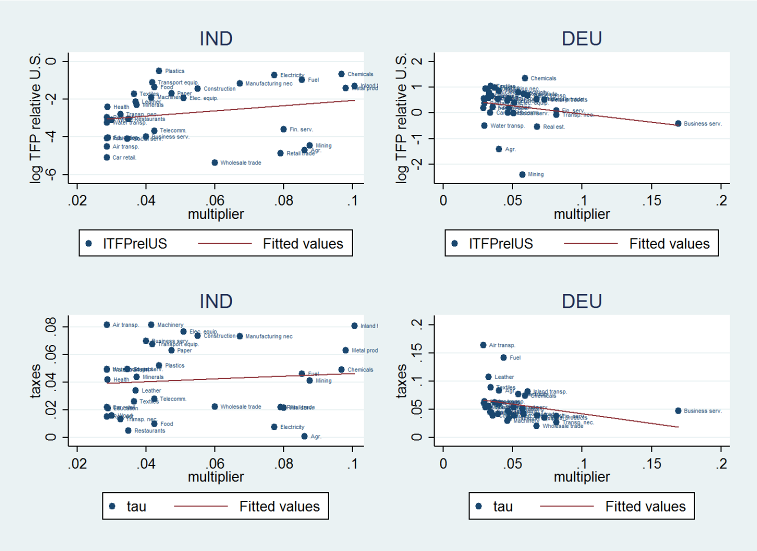
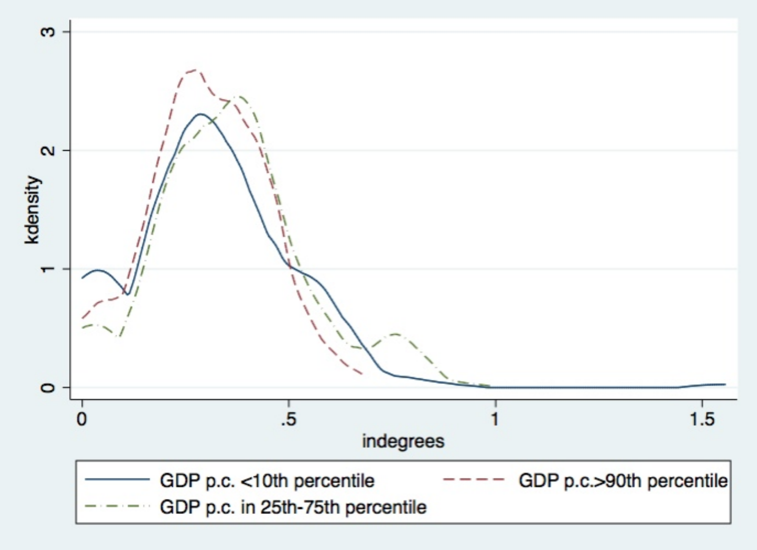


Figure: Correlation between IO-multipliers and productivity/taxes

Distribution of sectoral in-degrees (GTAP sample)



Distribution of sectoral out-degrees (GTAP sample)

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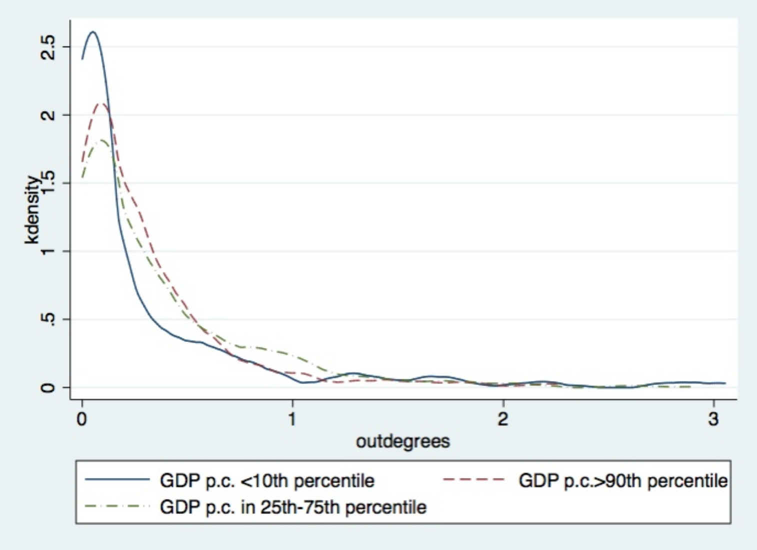

2-term approximation of sectoral multipliers (GTAP sample)

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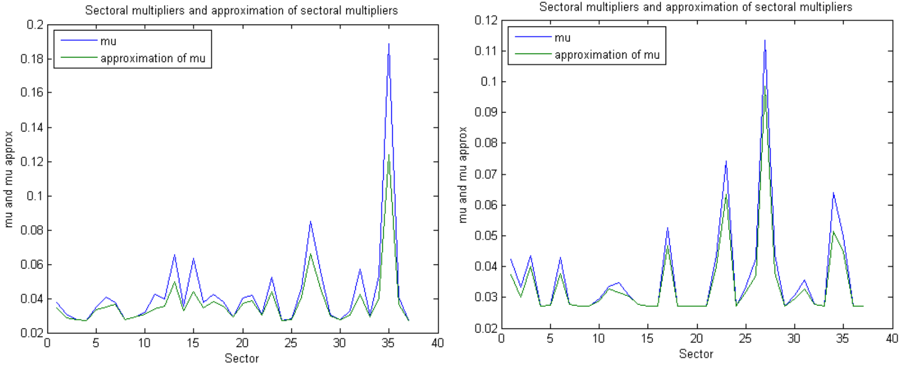

Figure: Sectoral multipliers in Germany (left) and Botswana (right).

		Sectors	USA	GER	CHN	IND	MOZ	UGA
1	AGR	Agriculture	4	5	11	17	8	25
2	OIL	Oil	1	1	4	3	0	4
3	GAS	Gas	1	1	3	1	0	1
4	MIN	Minerals	3	0	1	3	0	0
5	OFD	Food products	4	1	7	5	3	2
6	BT	Beverages, tobacco	5	5	8	3	2	6
7	TEX	Textiles	6	4	8	6	3	5
8	WAP	Apparel	1	1	2	0	0	1
9	LEA	Leather products	1	1	2	1	0	1
10	LUM	Wood products	4	2	4	3	2	3
11	PPP	**Paper, publishing**	**11**	**11**	**12**	**10**	5	8
12	P_C	Petroleum, coal	7	5	14	9	0	5
13	CRP	**Chemicals**	**26**	**21**	**28**	**30**	**14**	0
14	NMM	Minerals	3	2	13	4	2	4
15	IS	Ferrous metals	9	5	10	10	3	7
16	NFM	Metals nec	8	4	4	10	0	6
17	FMP	**Metal products**	**11**	**14**	**14**	**15**	0	5
18	MVH	Motor vehicles	3	8	7	6	0	1
19	OTN	Transport equip.	3	2	4	2	0	1
20	ELE	Electronic equip.	5	14	6	2	0	0
21	OME	**Machinery**	**15**	**14**	**29**	**11**	0	1
22	OMF	Manufactures nec	1	6	15	11	1	2
23	ELY	**Electricity**	**19**	**18**	**19**	**28**	**21**	**22**
24	GDT	Gas manuf., distrib.	3	0	2	0	0	0
25	WTR	Water	2	2	1	1	5	2
26	CNS	**Construction**	**12**	**17**	7	**14**	**18**	8
27	TRD	**Trade**	**36**	**33**	**35**	**35**	**32**	**32**
28	OTP	**Transport nec**	**28**	**28**	**24**	**35**	**26**	**31**
29	WTP	Water transport	2	1	0	3	14	0
30	ATP	Air transport	1	2	1	0	13	1
31	CMN	Communication	9	8	8	10	14	12
32	OFI	**Financial services**	**31**	4	**11**	**31**	**29**	**14**
33	ISR	Insurance	1	6	1	4	8	2
34	OBS	**Business services**	**35**	**20**	7	**10**	**13**	**16**
35	ROS	Other services	5	35	9	14	0	0
36	OSG	Public Admin., Health, Edu.	14	8	[illegible]	[illegible]	[illegible]	[illegible]

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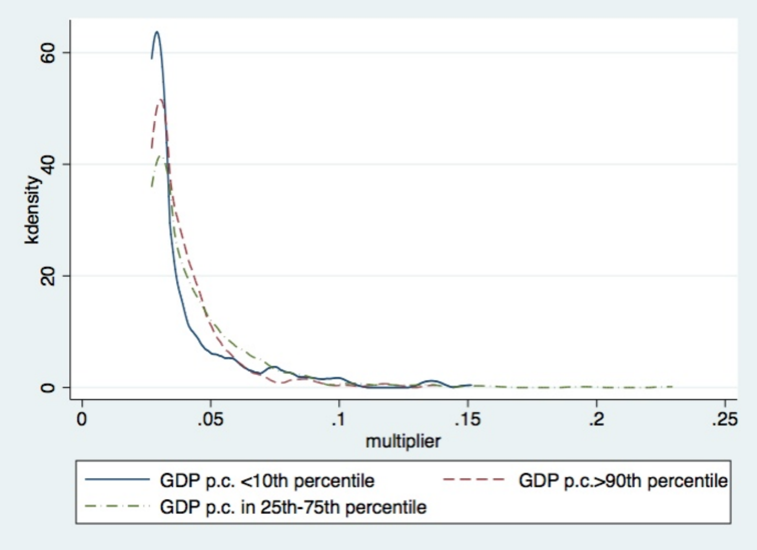
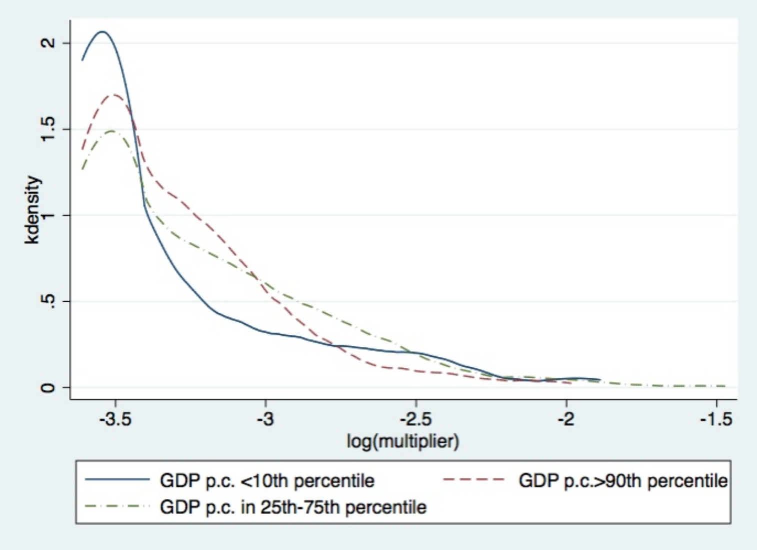
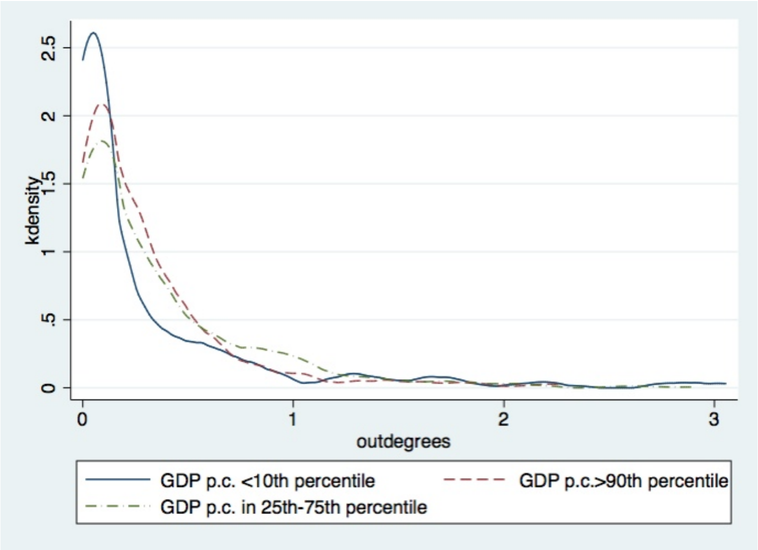
Distribution of sector centralities/multipliers (GTAP sample)



Distribution of log multipliers – GTAP sample



Distribution of out-degrees – GTAP sample



Distribution of number of outward linkages – GTAP sample