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:

\[ Y_i = \Lambda_i K_i^\alpha L_i^{1-\alpha} \]  

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

- Dividing equation (1) by \( L_i \):

\[ \frac{Y_i}{L_i} = \Lambda_i \left( \frac{K_i}{L_i} \right)^\alpha. \]  

(2)
Motivation

In reality the structure of the economy is more complex...

- GDP aggregates value of many economic activities connected through input-output (IO) linkages.
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  Transport sector $\rightarrow$ Mining $\rightarrow$ Steel sector $\rightarrow$ Transport Equipment sector $\rightarrow$ Transport sector $\rightarrow$ ...
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- Consider a productivity increase in the Transport sector: Transport sector → Mining → Steel sector → Transport Equipment sector → Transport sector → ... ⇒ Input-output multiplier effect
- IO multiplier of a sector summarizes all these intermediate effects. It measures by how much aggregate income will change if productivity of this sector changes by one percent.
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- High multiplier sectors (Transport, Energy) supply to a large number of sectors or are used intensively as inputs by others.
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- IO multiplier of a sector summarizes all these intermediate effects. It measures by how much aggregate income will change if productivity of this sector changes by one percent.
- 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
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.
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. → 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).

Theoretical model

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

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

- $\Lambda_i$ 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 $\gamma_i = \gamma_j = \gamma \forall i, j \in 1 : n$. 

$\Gamma = \{\gamma_{ji}\}_{i,j=1}^{n}$ is IO matrix.

A good produced by sector $i$ can be used for final consumption, $y_i$, or as an intermediate good:

$$y_i + \sum_{j=1}^{n} d_{ij} = q_i.$$ 

Final goods are aggregated into a single good (GDP):

$$Y = y_1 \cdot \cdots \cdot y_n \Gamma - \text{distortions (taxes) in sector } i.$$
Theoretical model

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

- Final goods are aggregated into a single good (GDP):

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Theoretical model

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  \[
  Y = y_1^{\frac{1}{n}} \cdots y_n^{\frac{1}{n}}
  \]
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:

\[
\max \left\{ p y_1^n \cdot \ldots \cdot y_n^n \right\} - \sum_{i=1}^{n} p_i y_i
\]

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

\[
\max \left\{ (1 - \tau_i) p_i \Lambda_i \left(k_i^{\alpha l_i^{1-\alpha}}\right)^{1-\gamma_i} d_1^{\gamma_1 i} d_2^{\gamma_2 i} \cdots d_n^{\gamma_n i} - \sum_{j=1}^{n} p_j d_{ji} - rk_i - w l_i \right\}
\]

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:

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

- \( \mu = \{\mu_i\}_i = \frac{1}{n}[I - \Gamma]^{-1}1 \), where \([I - \Gamma]^{-1}\) is the \textit{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 \(j\).
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\]

- \( \mu = \{\mu_i\}_i = \frac{1}{n}[I - \Gamma]^{-1}1 \), where \([I - \Gamma]^{-1}\) is the Leontief inverse.
- A typical element \( l_{ij} \) of the Leontief inverse shows how a 1% increase in productivity of sector \( i \) affects the output of sector \( j \).
- \( \mu_i \) 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

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

- [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 ⇒ 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.
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:
       \[ E(y) = \alpha \log(K) \text{ ('naive model')} \]
     - multi-sector model with estimated productivity differences but without IO linkages:
       \[ E(y) = e^{m^A+0.5*\sigma^2_A} + \alpha \log(K) + \text{const} \text{ ('no IO structure')} \]
Model Fit: WIOD sample

**Figure:** Predicted income per capita: baseline model with estimated IO structure vs. 'no IO structure' and 'naive model'
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 \((m_\mu, \sigma_\mu)\). 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 \((m_\tau, \sigma_\tau)\). 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

<table>
<thead>
<tr>
<th>WIOD sample</th>
<th>Coef.</th>
<th>Std. Err.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>m$_{\mu}$</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant</td>
<td>0.648</td>
<td>0.431</td>
</tr>
<tr>
<td>log(gdp per capita)</td>
<td>-0.081*</td>
<td>0.047</td>
</tr>
<tr>
<td>log($\sigma^2_{\mu}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant</td>
<td>-0.642***</td>
<td>0.145</td>
</tr>
<tr>
<td><strong>m$_{\Lambda}$</strong></td>
<td></td>
<td></td>
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<tr>
<td>constant</td>
<td>-13.327***</td>
<td>1.287</td>
</tr>
<tr>
<td>log(gdp per capita)</td>
<td>1.287***</td>
<td>0.142</td>
</tr>
<tr>
<td>log($\sigma^2_{\Lambda}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant</td>
<td>4.102***</td>
<td>0.735</td>
</tr>
<tr>
<td>log(gdp per capita)</td>
<td>-0.375***</td>
<td>0.074</td>
</tr>
<tr>
<td><strong>m$_{\tau}$</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant</td>
<td>-3.847***</td>
<td>0.464</td>
</tr>
<tr>
<td>log(gdp per capita)</td>
<td>0.090***</td>
<td>0.046</td>
</tr>
<tr>
<td>log($\sigma^2_{\tau}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant</td>
<td>1.870***</td>
<td>0.617</td>
</tr>
<tr>
<td>log(gdp per capita)</td>
<td>-0.284***</td>
<td>0.062</td>
</tr>
<tr>
<td><strong>z-transformed $\rho_{\mu\Lambda}$</strong></td>
<td></td>
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</tr>
<tr>
<td>constant</td>
<td>3.440***</td>
<td>0.813</td>
</tr>
<tr>
<td>log(gdp per capita)</td>
<td>-0.352***</td>
<td>0.083</td>
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<tr>
<td><strong>z-transformed $\rho_{\mu\tau}$</strong></td>
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<tr>
<td>constant</td>
<td>1.010*</td>
<td>0.607</td>
</tr>
<tr>
<td>log(gdp per capita)</td>
<td>-0.126**</td>
<td>0.061</td>
</tr>
</tbody>
</table>

Log likelihood: -107.885
Observations: 1281
Estimated vs. actual distribution of multipliers, productivity, and distortions
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 $\mu \approx \frac{1}{n} + \frac{1}{n} \Gamma 1$,
  2nd order approximation is $\mu \approx \frac{1}{n} + \frac{1}{n} \Gamma 1 + \frac{1}{n} \Gamma^2 1$

- Unequal demand shares (by country-industry): $Y = y_1^{\beta_1} \cdot \ldots \cdot y_n^{\beta_n}$, Implications for multipliers: $\mu = \{\mu_i\}_i = [I - \Gamma]^{-1} \beta$

- Open economy: separate domestic and imported intermediate inputs

$$q_i = \Lambda_i \left( k_i^{\alpha} l_i^{1-\alpha} \right)^{1-\gamma_i-\sigma_i} d_1^{\gamma_1 i} d_2^{\gamma_2 i} \cdot \ldots \cdot d_n^{\gamma_n i} \cdot m_1^{\sigma_1 i} m_2^{\sigma_2 i} \cdot \ldots \cdot m_n^{\sigma_n i},$$

- Skilled/unskilled labor

$$q_i = \Lambda_i \left( k_i^{\alpha} u_i^{\delta} s_i^{1-\alpha-\delta} \right)^{1-\gamma_i-\sigma_i} d_1^{\gamma_1 i} d_2^{\gamma_2 i} \cdot \ldots \cdot d_n^{\gamma_n i}$$
# Robustness Checks

## Table: Robustness: World IO sample

<table>
<thead>
<tr>
<th></th>
<th>1st order approximation</th>
<th>2nd order approximation</th>
<th>Expenditure shares</th>
<th>Human capital</th>
<th>Imported intermediates</th>
<th>No waste</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>constant</strong></td>
<td>-0.106***</td>
<td>-0.133**</td>
<td>-0.128***</td>
<td>-0.055***</td>
<td>-0.153***</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td>(0.022)</td>
<td>(0.059)</td>
<td>(0.027)</td>
<td>(0.002)</td>
<td>(-0.026)</td>
<td>(0.021)</td>
</tr>
<tr>
<td><strong>slope</strong></td>
<td>0.989***</td>
<td>0.974***</td>
<td>0.901***</td>
<td>0.943***</td>
<td>1.004***</td>
<td>0.920***</td>
</tr>
<tr>
<td></td>
<td>(0.056)</td>
<td>(0.059)</td>
<td>(0.064)</td>
<td>(0.055)</td>
<td>(0.063)</td>
<td>(0.057)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td><strong>R-squared</strong></td>
<td>0.883</td>
<td>0.884</td>
<td>0.865</td>
<td>0.845</td>
<td>0.884</td>
<td>0.852</td>
</tr>
</tbody>
</table>
IO-matrices: Uganda and USA

IO matrix UGA

IO matrix USA
Figure: Sectoral IO-multipliers by country
Distribution of sectoral (log) multipliers (GTAP sample)
Figure: Correlation between IO-multipliers and productivity/taxes
Distribution of sectoral in-degrees (GTAP sample)
Distribution of sectoral out-degrees (GTAP sample)
2-term approximation of sectoral multipliers (GTAP sample)

Figure: Sectoral multipliers in Germany (left) and Botswana (right).
<table>
<thead>
<tr>
<th>Sectors</th>
<th>USA</th>
<th>GER</th>
<th>CHN</th>
<th>IND</th>
<th>MOZ</th>
<th>UGA</th>
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<tbody>
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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

![Graph showing distribution of number of outward linkages for different GDP percentiles.](image)

- **GDP p.c. <10th percentile**
- **GDP p.c. >90th percentile**
- **GDP p.c. in 25th-75th percentile**

H. Fadinger, C. Ghiglino, M. Teteryatnikova