Empirical Productivity Distributions and International Trade

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Motivation

The new primacy of the trade elasticity:

- Following Arkolakis, Costinot and Rodriguez-Clare (2012) the trade elasticity is a sufficient statistic for welfare analysis in many canonical models of trade.
- These models include traditional approaches such as Armington and Krugman (1980), but also models featuring heterogeneous firms such as Eaton-Kortum (2002) and Melitz (2003).
- All these models lead to the *same old gains* from trade...

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- These models include traditional approaches such as Armington and Krugman (1980), but also models featuring heterogeneous firms such as Eaton-Kortum (2002) and Melitz (2003).
- All these models lead to the *same old gains* from trade...
- ...as long as the heterogeneity follows *strong functional form restrictions* (Pareto).

This paper

- Develops a multi-country trade model featuring heterogeneous firms, multiple sectors and input-output linkages.
- Uses micro-data for several countries and sectors to estimate firm-level productivity.
- Estimates non-parametric productivity distributions and feeds these empirical distributions into the model.

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- Uses micro-data for several countries and sectors to estimate firm-level productivity.
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How large are the deviations of aggregate economic outcomes under standard functional form assumptions from those under an empirical distribution?

Outline

1. Background & literature
2. Workhorse heterogeneous trade model
3. Data and estimation
4. Counterfactual experiments
5. Agenda & Conclusion

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Why functional form assumptions?

- **Analytically tractable**: this is especially true for Pareto (Baldwin, 2005; Chaney, 2008) but also – to a lesser extent – for Log-normal (Head, Mayer and Thoenig, 2014).
- **Firm-level evidence** shows that
  - Pareto is a fairly good match for the upper tail of the productivity distribution (Axtell, 2001 & Luttmer, 2007 for the US; di Giovanni, Levchenko and Rancière, 2011 for France) .
  - Log-normal is for the remaining support of the data (Head, Mayer and Thoenig, 2014 for France and Spain).
  - A mixed distribution of Log-normal and Pareto matches firm-level estimates even better (Nigai, 2017 for France).

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   - Welfare gains from trade.
   - Entry and exporting.
   - Available varieties and their prices.

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1. In general, a **quantification of the error** triggered by deviations from the empirical distribution is an important result since it determines to a large extent our ideas of
   - Welfare gains from trade.
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   - Available varieties and their prices.
2. There are important **differences across countries and sectors** that might not be captured by relying on a single functional form:
   - Distribution might depend on economic development of a country (Arkolakis, 2015).
   - Distribution might depend on the market structure of a sector (Mrazova, Neary and Parenti, 2015).

Related literature

- **Going beyond standard distributional assumptions**:
  - Melitz (2003)
  - Arkolakis (2015)
  - Mrazova, Neary and Parenti (2015)
  - Melitz and Redding (2015)
  - Nigai (2017)
- **General equilibrium models of trade with industry-linkages**:
  - Caliendo and Parro (2015)
  - Ossa (2015)

Outline

Workhorse trade model with heterogeneous firms

The model is a version of Melitz (2003) featuring multiple sectors, s, multiple countries, i, and input-output linkages.

- Each country i is endowed with measure L_i of *equipped* labor (Alvarez and Lucas, 2007).
- Heterogeneous firms: ϕ.
- Variable and fixed cost of exporting: τ_{ij}^s and f_{ij}^s (paid in units of domestic labor).
- Fixed cost of entry: e_i^s.
- Productivity is randomly drawn upon paying entry cost, e_i^s, from a country- and sector-specific distribution with p.d.f. $f_i^s(\phi)$ and c.d.f. $F_i^s(\phi)$.
- Free entry, markets clear.

Workhorse trade model with heterogeneous firms

Demand side

- Consumers in country i maximize

$$U_i(Q_i^{s,F}) = \prod_{s=1}^{\mathcal{S}} (Q_i^{s,F})^{\alpha_i^s} \text{ , where } \sum_{s=1}^{\mathcal{S}} \alpha_i^s = 1,$$

  where $Q_i^{s,F}$ is a CES aggregate of all goods of sector s available for **final consumption** in country i with the sector-specific substitutability being governed by σ^s.

- Total final demand for $Q_i^{s,F}$ is hence,

$$Q_i^{s,F} = \frac{\alpha_i^s L_i w_i}{P_i^s}.$$

Workhorse trade model with heterogeneous firms

Supply side

- Production function is Cobb-Douglas and combines equipped labor and materials

$$q_i^s(\phi) = \phi \, \ell_i^s(\phi)^{\beta_i^s} m_i^s(\phi)^{1-\beta_i^s} \text{ , where } \beta_i^s \in (0,1).$$

- The aggregate measure of materials, M_i^s, is defined as:

$$M_i^s = \prod_{k=1}^{\mathcal{S}} (Q_i^{k,I})^{\gamma_i^{k,s}} \text{ , where } \sum_{k=1}^{\mathcal{S}} \gamma_i^{k,s} = 1,$$

with $\gamma_i^{k,s}$ being the intensity of sector k output used in the production of sector s.

Workhorse trade model with heterogeneous firms

Given factor prices

- w_i for equipped labor, $\ell_i^s(\phi)$,
- $r_i^s = \prod_{k=1}^{\mathcal{S}} \left(\frac{P_i^s}{\gamma_i^{k,s}} \right)^{\gamma_i^{k,s}}$ for materials, $m_i^s(\phi)$,

CES demand (for varieties within sectors) and Cobb-Douglas production, the profit maximization problem for firm ϕ from country i in each potential destination j yields constant mark-up pricing

$$p_{ij}^s(\phi) = \frac{\sigma^s}{\sigma^s - 1} \frac{a_i^s w_i^{\beta_i^s} (r_i^s)^{1-\beta_i^s} \tau_{ij}^s}{\phi},$$

and profits

$$\pi_{ij}^s(\phi) = \frac{1}{\sigma^s} \left(\frac{\sigma^s}{\sigma^s - 1} \frac{a_i^s w_i^{\beta_i^s} (r_i^s)^{1-\beta_i^s} \tau_{ij}^s}{\phi} \right)^{1-\sigma} (P_j^s)^{\sigma^s - 1} Y_j^s - w_i f_{ij}^s.$$

Workhorse trade model with heterogeneous firms

Equilibrium

- Zero profit condition: $\pi_{ij}^{s}(\phi_{ij}^{s*}) = 0$
- Free entry: $E\left(\sum_{j=1}^{\mathcal{I}} \pi_{ij}^{s}(\phi) - e_i^s w_i\right) = 0$
- Balanced trade: $\sum_{s=1}^{\mathcal{S}} \sum_{j=1}^{\mathcal{I}} \lambda_{ji}^{s} Y_i^s = \sum_{s=1}^{\mathcal{S}} \sum_{j=1}^{\mathcal{I}} \lambda_{ij}^{s} Y_j^s$,

  where λ_{ij}^{s} denotes the trade share in sector s shipped from country i to country j and Y_i^s is the demand for tradable goods of sector s in country i (final and intermediate consumption).

Solution

The solution of the system depends on two selection statistics:

- $1 - F_i^s(\phi_{ij}^*)$ which measures the probability of firms from i being active in j for all i, j
- $\int_{\phi_{ij}^*}^{\bar{\phi}} \phi^{\sigma-1} f_i^s(\phi) d\phi$, which is required to calculate total revenues of firms from i in market j for all i, j
- Third statistics $\int_{\phi_{ij}^*}^{\bar{\phi}} f_i^s(\phi) d\phi$ is redundant due to the following identity:

$$\int_{\phi_{ij}^*}^{\bar{\phi}} f_i^s(\phi) d\phi = \int_0^{\bar{\phi}} f_i^s(\phi) d\phi - \int_0^{\phi_{ij}^*} f_i^s(\phi) d\phi = 1 - F_i^s(\phi_{ij}^*)$$

International trade outcomes

Upon solving the model, one can explore different trade outcomes:

- Welfare Gains

$$100\% \times \left(\frac{w_i(\tau)}{P_i(\tau)} \frac{P_i(\tau')}{w_i(\tau')} - 1 \right)$$

- International trade shares:

$$\lambda_{ij}^s = N_i^s \left(\frac{\sigma^s w_i f_{ij}^s}{Y_j^s} \right) (\phi_{ij}^{s*})^{1-\sigma^s} \int_{\phi_{ij}^{s*}}^{\bar{\phi}_i^s} \phi^{\sigma^s - 1} f_i^s(\phi) d\phi$$

Outline

Productivity estimation

The estimation of firm-level productivity follows Gandhi, Navarro and Rivers (2016):

- We allow for a flexible production function that combines labor, capital and materials

$$q_t = \phi_t f(\ln(l_t), \ln(k_t), \ln(m_t)),$$

where $\phi_t = \exp(\omega_t)$ and $\omega_t = h(\omega_{t-1}) + \eta_t$ with $E(\eta_t | \bullet_{t-1}) = 0$.

- Labor and capital are classified as *predetermined inputs* while materials are assumed to be a *flexible input*

$$m_t = m_t(\omega_t, k_t, l_t).$$

Productivity estimation

This assumption allows for a two-step identification strategy:

1. Identify the material input elasticity nonparametrically from the first order condition:

$$m_t(\omega_t, k_t, l_t) = \arg\max_{m_t} p_t q_t - m_t r_t.$$

and define a partial differential equation that can be integrated to identify the material input part in the production function:

$$\int \frac{\partial \ln f\left(\ln(l_t), \ln(k_t), \ln(m_t)\right)}{\partial \ln(m_t)} d\ln(m_t) = \ln f\left(\ln(l_t), \ln(k_t), \ln(m_t)\right) + C(\ln(k_t), \ln(l_t)).$$

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2. Estimate the remainder of the production function
$$\tilde{s}_t = -\left(1 - \frac{1}{\sigma}\right) C(\ln(k_t), \ln(l_t)) + \frac{1}{\sigma}\ln(Y_t) + \left(1 - \frac{1}{\sigma}\right)\omega_t,$$
using the Markov structure of productivity, $\omega_t = h(\omega_{t-1}) + \eta_t$ and the moments $E(\eta_t \mathbf{x}) = 0, \mathbf{x} = (\ln(k_t), \ln(l_t), \ln(Y_t), \tilde{s}_{t-1})'$.

Data sources for productivity estimation

- Balance sheet data:
  - Bureau van Dijk's ORBIS (19 countries)
  - National Bureau of Statistics (NBS) of China (China)
  - Compustat (USA and Canada)
- WIOD (deflators)
- We use an unbalanced panel for the years 2006-2012 and take the average productivity per firm.

Summary statistics: firm-year obeservations and median across countries

Country	Firm-year obs.	log(Employees)	log(Capital)	Log(Material)	Log(Sales)
AUT	3,686	5.19	11.23	12.02	12.83
BEL	23,899	3.87	9.77	10.94	11.60
BGR	82,111	2.64	2.76	2.25	3.49
CHN	502,533	4.70	8.13	9.56	10.02
CZE	106,847	2.71	6.89	8.18	8.85
DEU	82,053	3.99	9.25	10.33	11.35
ESP	669,214	1.79	6.68	7.27	8.14
EST	29,626	1.61	4.83	6.07	6.85
FIN	67,571	1.79	6.82	7.32	8.62
FRA	373,758	1.79	6.48	7.46	8.71
HUN	20,204	3.89	8.28	8.58	9.45
ITA	644,287	2.08	7.36	7.99	9.08
KOR	229,341	2.64	8.57	9.41	9.66
LVA	1,179	1.79	4.69	5.43	6.30
POL	49,985	3.78	7.79	8.99	9.79
PRT	309,403	1.79	5.79	6.26	7.39
ROM	325,477	1.61	1.85	2.43	3.39
SVK	36,065	2.71	6.53	7.76	8.65
SVN	45,239	1.39	6.54	6.38	7.40
SWE	161,110	1.39	6.05	7.28	8.33
Total	3,761,588	1.95	6.51	7.31	8.35

USA, Canada - COMPUSTAT (in progress)

Estimated parameters across countries (median)

Country	Labor	Capital	Material
AUT	0.38	0.13	0.45
BEL	0.38	0.08	0.49
BGR	0.59	0.13	0.33
CHN	0.21	0.11	0.59
CZE	0.34	0.12	0.51
DEU	0.47	0.13	0.37
ESP	0.53	0.09	0.42
EST	0.50	0.09	0.47
FIN	0.68	0.10	0.30
FRA	0.53	0.12	0.28
HUN	0.40	0.18	0.42
ITA	0.49	0.12	0.33
KOR	0.12	0.06	0.78
LVA	0.42	0.14	0.45
POL	0.29	0.18	0.45
PRT	0.56	0.12	0.31
ROM	0.50	0.17	0.36
SVK	0.27	0.20	0.42
SVN	0.50	0.10	0.38
SWE	0.66	0.06	0.37
Total	0.50	0.11	0.37

Density estimation

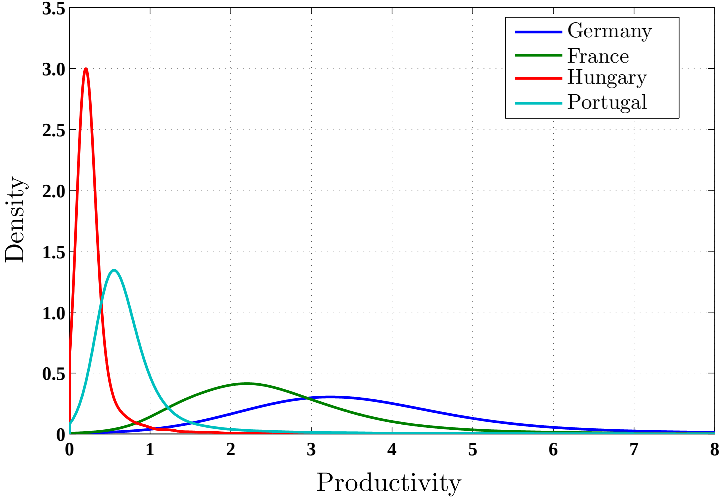
- Nonparametric kernel estimates (Li and Racine, 2003).
- For countries where micro-data are not available, assume a Two-piece distribution and relate its parameters to observable economic variables:

Variable	Coef.	Std. error
Capital-labor ratio	1.29	0.19
Employment	0.49	0.10
Rule of law	0.61	0.20
Macro T.F.P	1.38	0.49
Observations	120	
Adj. R^2	0.69	

Standard errors are robust to an unknown form of heteroskedasticity and autocorrelation. Year fixed effects are included.

LOCATION PARAMETER AND OBSERVABLE ECONOMIC CHARACTERISTICS.

Estimated productivity distributions



Example of estimated p.d.f.

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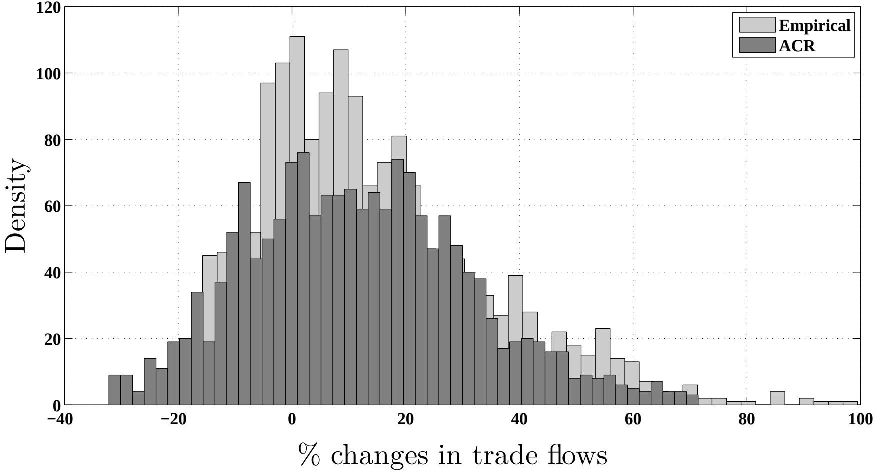
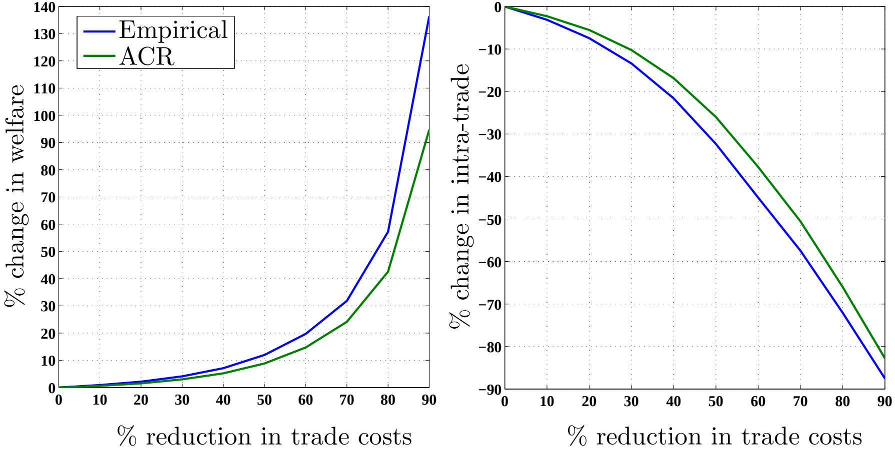
Changes in trade flows



CHANGES IN TRADE FLOWS UNDER A 10% REDUCTION IN TRADE COSTS

Changes in welfare and intra-trade



Population-weighted world average

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Agenda & Conclusion

- Preliminary results suggest important differences in aggregate outcomes
- Future work:
  - Extend calibration to multiple industries.
  - Ensure representativeness of firm-level data.
  - Implement a new methodology of estimating fixed costs of exporting.