Computational Applications in International Trade, Lecture 2

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Interdependent Discrete Choice Problems

- Firms often have to make multiple discrete decisions
  - Which market to enter, where to build plants, etc
- Melitz (2003) and others: profit function is additively seperable

$$\Pi(I) = \sum_k \Pi_k(I_k)$$

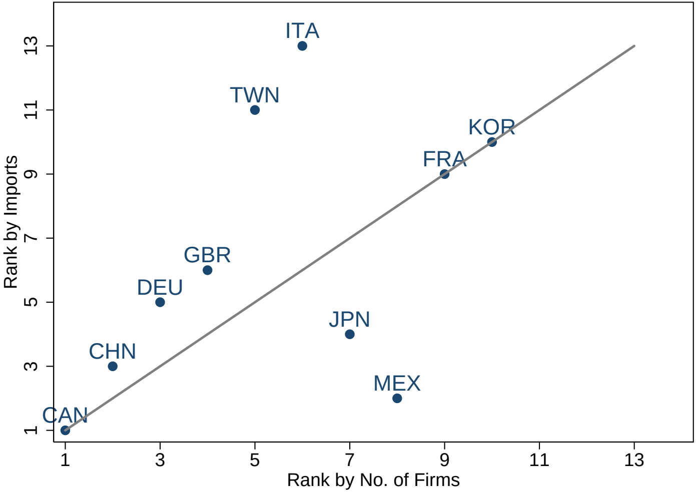
- Problem with solving more general profit function $\max_{I \in B^n} \Pi(I)$, $\Pi : B^n \to R \; , \quad B^n \in \{0,1\}^n \; :$
  - **Really** hard (e.g. 2^n alternative choices)
  - There is no free-lunch (without structure you cannot beat random search)

- Assume no interdependence (most papers in trade, IO, etc)
- Assume N not too large ($2^{12} = 4,096$ - still tractable)
  - e.g., Tintelnot (2017)
- Use moment inequalities for estimation
  - e.g., Morales, Sheu, and Zahler (forthcoming)
  - Counterfactuals?
- Put some structure on the problem - exploit strucure to develop solution algorithm
  - Jia (2008); Antras, Fort, and Tintelnot (2017); Arkolakis and Eckert (2018)

Antras , Fort, and Tintelnot (2014)

- Global sourcing decisions are important for firm performance, employment and welfare
- Firms source multiple inputs from multiple countries
- Extensive margins (firms, products) account for most of the cross-country variation in U.S. imports and exports
- Extensive margins of exporting are much better understood than extensive margins of importing
- Yet two-thirds of world trade is intermediate inputs
  - Potential for importers' decisions to be key determinant of trade

AFT (2014): Country Rank by Importers vs. Total Imports



Challenges for a Multi-Input, Multi-Country Model of Global Sourcing

- Export models generally assume constant marginal costs
- Importing inputs naturally affects the marginal cost of the firm
- Import entry decisions are thus interdependent across markets
- Interdependencies across markets complicate the firm's decision
  - Which countries should a firm invest in importing from?
  - From which particular country should each input be bought?
  - How much of each input should be purchased?

AFT (2014): Main Contributions

- Develop a quantifiable multi-country sourcing model
  - countries differ along two dimensions
  - closed-form solution for intensive margin of sourcing
  - characterization of firms' extensive margin sourcing decisions
  - includes models by Eaton and Kortum (2002) and Chaney (2008) as special cases

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- Reduced form evidence on interdependencies in US firm sourcing
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- Study effects of shocks to global sourcing
  - apply theoretical insights and IO algorithm to estimate model
  - changes to aggregate trade patterns
  - heterogeneous impact across firm size distribution
  - distinction between net and gross changes in sourcing / employment

AFT (2014): Model – Environment

- J countries
- Measure of L_j consumers / workers
- Dixit-Stiglitz preferences over manufacturing varieties, elasticity of substitution $\sigma > 1$ (later introduce non-manufacturing sector)
- Final good sector producing these varieties:
  - Measure N_j of heterogeneous firms (pinned down by free entry)
  - Non-tradable final output
  - Monopolistic competition
- Intermediate good sector
  - Each firm uses a unit measure of (firm-specific) intermediate inputs
  - Trade cost τ_{ij} to import from country j by country i
  - Perfect competition $\Longrightarrow$ Marginal-cost pricing of inputs

AFT (2014): Model – Production Technology

- Final good requires assembly of a bundle of intermediates
- Marginal cost of final good producer, φ:

$$c_i\left(\{j\left(v\right)\}_{v=0}^{1},\varphi\right)=\frac{1}{\varphi}\left(\int_{0}^{1}\left(p_i\left(v,j(v),\varphi\right)\right)^{1-\rho}dv\right)^{1/(1-\rho)}$$

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- Productivity $1/a_j(v,\varphi)$ for a given location j drawn from Fréchet distribution:

$$\Pr(a_j(v,\varphi) \geq a) = e^{-T_j a^{\theta}}, \quad \text{with } T_j > 0.$$

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- Country-specific fixed cost of offshoring $w_i f_{ij}$

AFT (2014): Model – Firm's problem

- Firm chooses:
  - Sourcing strategy $\mathcal{J}_i(\varphi) \subseteq \{1, ..., J\}$
  - Source country $j(v) \in \mathcal{J}_i(\varphi)$ for each intermediate v
  - Price of final good
- Sourcing strategy thus determines set of countries from which firm can buy inputs
- For all other countries $j \notin \mathcal{J}_i(\varphi)$, it is as if $a_j(v, \varphi) = +\infty$

AFT (2014): Model – Firm behavior conditional on sourcing strategy

- Share of intermediate input purchases sourced from any country j:

$$\chi_{ij}(\varphi) = \frac{T_j \left(\tau_{ij} w_j\right)^{-\theta}}{\Theta_i(\varphi)} \quad \text{if } j \in \mathcal{J}_i(\varphi)$$

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- Sourcing capability:

$$\Theta_i(\varphi) \equiv \sum_{k \in \mathcal{J}_i(\varphi)} T_k\left(\tau_{ik}w_k\right)^{-\theta}$$

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- Sourcing capability:

$$\Theta_i(\varphi) \equiv \sum_{k \in \mathcal{J}_i(\varphi)} T_k (\tau_{ik} w_k)^{-\theta}$$

- Marginal cost:

$$c_i(\varphi) = \frac{1}{\varphi} (\gamma \Theta_i(\varphi))^{-1/\theta}$$

AFT (2014): Model – Optimal Sourcing Strategy

- General profit function:

$$\max_{I_{ij}\in\{0,1\}_{j=1}^{J}} c_i(\varphi,\{I_{ij}\in\{0,1\}_{j=1}^{J}\})^{1-\sigma}B_i - w_i\sum_{j=1}^{J} I_{ij}f_{ij}$$

AFT (2014): Model – Optimal Sourcing Strategy

- With cost function plugged in:

$$\max_{I_{ij}\in\{0,1\}_{j=1}^{J}} \varphi^{\sigma-1}\left(\gamma\sum_{j=1}^{J} I_{ij}T_j\left(\tau_{ij}w_j\right)^{-\theta}\right)^{(\sigma-1)/\theta} B_i - w_i\sum_{j=1}^{J} I_{ij}f_{ij}$$

AFT (2014): Model – Optimal Sourcing Strategy

$$\max_{I_{ij}\in\{0,1\}_{j=1}^{J}} \varphi^{\sigma-1}\left(\gamma\sum_{j=1}^{J} I_{ij}T_j\left(\tau_{ij}w_j\right)^{-\theta}\right)^{(\sigma-1)/\theta} B_i - w_i\sum_{j=1}^{J} I_{ij}f_{ij}$$

- Profits are supermodular in φ and $\sum_{j=1}^{J} I_{ij}T_j\left(\tau_{ij}w_j\right)^{-\theta}$
- Proposition: The solution $I_{ij}(\varphi)\in\{0,1\}_{j=1}^{J}$ to the optimal sourcing problem is such that a firm's sourcing capability $\Theta_i(\varphi)\equiv\sum_{j=1}^{J} I_{ij}(\varphi)\,T_j\left(\tau_{ij}w_j\right)^{-\theta}$ is nondecreasing in φ
- Implications for size distribution of firms

AFT (2014): Model – Optimal Sourcing Strategy

$$\max_{I_{ij}\in\{0,1\}_{j=1}^{J}} \varphi^{\sigma-1}\left(\gamma\sum_{j=1}^{J} I_{ij}T_j\left(\tau_{ij}w_j\right)^{-\theta}\right)^{(\sigma-1)/\theta} B_i - w_i\sum_{j=1}^{J} I_{ij}f_{ij}$$

- Complements case: $\frac{\sigma-1}{\theta} > 1$
- Substitutes case: $\frac{\sigma-1}{\theta} < 1$

AFT (2014): Model – Optimal Sourcing Strategy

$$\max_{I_{ij}\in\{0,1\}_{j=1}^{J}} \varphi^{\sigma-1}\left(\gamma\sum_{j=1}^{J} I_{ij}T_j\left(\tau_{ij}w_j\right)^{-\theta}\right)^{(\sigma-1)/\theta} B_i - w_i\sum_{j=1}^{J} I_{ij}f_{ij}$$

- Complements case: $\frac{\sigma-1}{\theta} > 1$
- Proposition: Whenever $(\sigma-1)/\theta > 1$, the solution $I_{ij}(\varphi) \in \{0,1\}_{j=1}^{J}$ to the optimal sourcing problem satisfies $\mathcal{J}_i(\varphi_L) \subseteq \mathcal{J}_i(\varphi_H)$ for $\varphi_H \geq \varphi_L$, where $\mathcal{J}_i(\varphi) = \{j : I_{ij}(\varphi) = 1\}$.
- Hierarchies in the complements case

- Consumers spend constant share η on manufacturing sector.

AFT (2014): Model – Industry and General Equilibrium

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- Workers are perfectly mobile across sectors (other sector pins down wage level)

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- Industry Equilibrium is characterized by:
  - Fixed point for the market potential, B_i
  - Free entry condition

AFT (2014): Model – Industry and General Equilibrium

- Consumers spend constant share η on manufacturing sector.
- Workers are perfectly mobile across sectors (other sector pins down wage level)
- Industry Equilibrium is characterized by:
  - Fixed point for the market potential, B_i
  - Free entry condition
- Proposition: Given a positive wage vector, solution for B_i and N_i is unique

AFT (2014): Model – Gravity

- Special case 1: Universal importing
  - Aggregate trade flows as in Eaton and Kortum (2002)
  - Extensive margin effect at the product level
- Special case 2: Independent entry decisions ($(\sigma - 1)/\theta = 1$ and core efficiency Pareto)
  - Aggregate trade flows as in Chaney (2008)
  - Extensive margin effect at product and firm level
- General case
  - Extensive margin effect at product and firm level
  - Third market effects

▸ Universal Importing ▸ General Case ▸ Independent Entry Decisions

AFT (2014): Prel. evidence for interdependencies

- Exploit massive and exogenous rise of China and estimate

$$\Delta y_n = \beta_0 + \beta_{Ch} \Delta China_n + \varepsilon_n$$

- $\Delta China_n = \frac{Imports^{Ch}_{n2007} - Imports^{Ch}_{n1997}}{(Imports^{Ch}_{n2007} + Imports^{Ch}_{n1997})/2}$
- Δy_n is 1997 to 2007 change in firm n's:
  - log inputs
  - log domestic inputs
  - DHS growth rate of non-China imports
  - log number of non-China source countries

AFT (2014): Prel. evidence for interdependencies

- Instrument changes in firm-level sourcing from China using export from China to EU of inputs of industries in which the firm is active

$$China_{ht}^{input} = \sum_m s_{mh} \frac{EUimports_{mt}^{China}}{EUimports_{mt}^{World/US}}$$

  - s_{mh} is expenditure share of inputs from industry m in industry h
- Firm-level shock based on firm's industries

$$shock_n^{input} = \sum_{h \in n} s_{nh} China_{h2007}^{input} - \sum_{h \in n} s_{nh} China_{h1997}^{input}$$

  - Change from 1997 to 2007
  - s_{nh} is industry h's share of firm n's manufacturing sales in 1997

AFT (2014): Prel. evidence for interdependencies – data

- 1997 and 2007 firm sourcing from U.S. Census Bureau
  - Economic Censuses
  - Import transactions data
  - Balanced panel of manufacturing firms
- EU share of Chinese imports from UN Comtrade data
- 1997 BEA Input-Output tables

AFT (2014): Prel. evidence for interdependencies

Table 10: Estimates of the impact of the China shock on firm-level sourcing

Dependent variable is firm-level change from 1997 to 2007 in:

	Domestic inputs	No. of countries	Foreign inputs	Firm empl.	Domestic inputs	No. of countries	Foreign inputs	Firm empl.
	OLS				IV			
China, DHS	0.064	0.255	0.362	0.097	0.758	0.551	0.670	-0.092
	(0.010)	(0.007)	(0.013)	(0.007)	(0.214)	(0.080)	(0.198)	(0.162)
Constant	0.054	0.144	0.315	-0.075	-0.054	0.098	0.267	-0.046
	(0.019)	(0.013)	(0.026)	(0.014)	(0.039)	(0.017)	(0.044)	(0.032)
N	127,400	127,400	127,400	127,400	127,400	127,400	127,400	127,400
First Stage Statistics	Coeff (se) 2.685 (0.505)				KP F stat 28.25			

Notes: All variables are changes or growth rates from 1997 to 2007. China, DHS is a Davis-Haltiwanger-Schuh growth rate in firm imports from China. Domestic inputs, foreign inputs, and firm employment are a DHS growth rate. No. of countries is the log difference in the number of countries (excluding China, but including the U.S.) from which the firm sources inputs. Foreign inputs exclude China. Standard errors are in parentheses and clustered by 439 NAICS industries. In the IV specifications, firm-level sourcing from China is instrumented by the change in Chinese market share in EU15 countries of a weighted average of the firm's inputs. KP F-stat is the Kleibergen Paap F-statistic. N is rounded for disclosure avoidance.

AFT (2014): Hierarchies in Firm Sourcing Patterns

Table 3: U.S. firms importing from strings of top 10 countries

	Data		Random Entry	
String	Firms	% of Importers	Firms	% of Importers
CA	17,980	29.82	6,760	11.21
CA-CH	2,210	3.67	3,730	6.19
CA-CH-DE	340	0.56	1,030	1.71
CA-CH-DE-GB	150	0.25	240	0.40
CA-CH-DE-GB-TW	80	0.13	50	0.08
CA-CH-DE-GB-TW-IT	30	0.05	10	0.02
CA-CH-DE-GB-TW-IT-JP	30	0.05	0	0.00
CA-CH-DE-GB-TW-IT-JP-MX	50	0.08	0	0.00
CA-CH-DE-GB-TW-IT-JP-MX-FR	160	0.27	0	0.00
CA-CH-DE-GB-TW-IT-JP-MX-FR-KR	650	1.08	0	0.00
TOTAL Following Pecking Order	21,680	36.0	11,820	19.6

Notes: The string CA means importing from Canada but no other among the top 10; CA-CH means importing from Canada and China but no other; and so forth. % of Importers shows percent of each category relative to all firms that import from top 10 countries.

AFT (2014): Estimation – Data

- 2007 data from the U.S. Census Bureau
  - Economic Censuses
  - Import transactions data
- Sample is all manufacturing firms (around 250,000 firms)
  - Include firms with non-manufacturing activity
  - 23% of employment and 38% of sales
  - 65% of (non-mining) imports
  - A quarter of these firms imports
- Structural Estimation
  - Limit analysis to countries with 200+ U.S. importers
  - 66 countries and the U.S.

AFT (2014): Estimation – Road Map

- Step 1: Back out sourcing potential from firm-level input shares
  - Recovered from country fixed effects in normalized share regressions
- Step 2: Estimate demand elasticity and productivity dispersion
  - Project fixed effect on human-capital adjusted labor cost
- Step 3: Estimate fixed costs of sourcing and residual demand
  - Simulated method of moments + Jia's (2008) algorithm

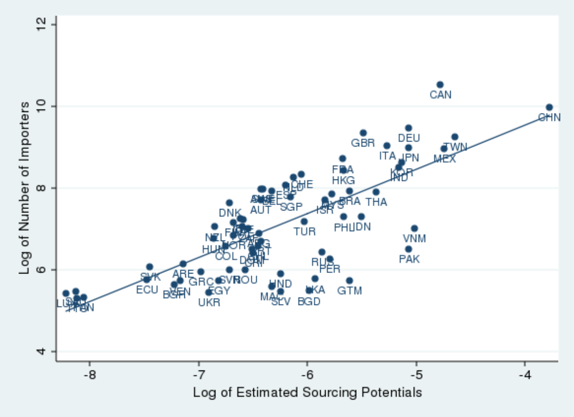
$$\Pi(\mathcal{J},\varphi,f_{ij}^{n}) = \varphi^{\sigma-1}\left(\sum_{j=1}^{j\in\mathcal{J}} \overset{\text{Step 1}}{T_j(\tau_{ij}w_j)^{-\theta}}\right)^{\overset{\text{Step 2}}{(\sigma-1)/\theta}} \overset{\text{Step 3}}{\widetilde{B} - \sum_{j\in\mathcal{J}} f_{ij}^{n}}$$

Step 1: Estimate country sourcing potential

- Define country potential $\xi_j = T_j \left(\tau_{ij} w_j\right)^{-\theta}$
- Normalize firm share from j: $\chi_{ij}^n / \chi_{ii}^n = \frac{T_j(\tau_{ij} w_j)^{-\theta}}{\Theta_i^n} / \frac{T_i(\tau_{ii} w_i)^{-\theta}}{\Theta_i^n}$
- Log-Linearize: $\log \chi_{ij}^n - \log \chi_{ii}^n = \log \xi_j + \epsilon_j^n$
- Estimate via OLS

Sourcing potential versus number of firms

Figure 2: Country sourcing potential parameters and the extensive margin



Step 2: Estimate elasticity of demand and dispersion of productivities

- Estimate elasticity of demand using model's predicted mark-up
  - Median manufacturing firm's mark-up is 1.35
  - Implies $\sigma = 3.85$
- Project $\hat{\xi}_j = T_j \widehat{(\tau_{ij} w_j)}^{-\theta}$ on country variables
  - Wages (human capital adjusted)
  - Country controls for technology and bilateral trade frictions
  - Instrument using population

$$
\begin{aligned}
\log \hat{\xi}_j = & \beta_r \log \mathsf{R\&D}_j + \beta_k \log \mathsf{capital}_j + \beta_C \mathsf{control\ corruption}_j \\
& + \beta_n \log \mathsf{no\ of\ firms} - \theta \log w_j \\
& - \theta \left(\log \beta_c + \beta_d \log \mathsf{distance}_{ij} + \mathsf{language}_{ij} \log \beta_l \right) + \iota_j
\end{aligned}
$$

Step 2b: Estimate dispersion of productivities

Table 4: Estimation of firm and aggregate trade elasticities

	$\log \xi$		log aggregate imports		
	OLS	IV	OLS	IV	IV
log HC adjusted wage	-0.537	-1.789	-0.643	-4.544	-1.268
	(0.184)	(0.696)	(0.390)	(1.844)	(0.768)
log distance	-0.341	-0.621	-0.859	-1.733	-0.650
	(0.197)	(0.294)	(0.418)	(0.779)	(0.333)
log R&D	0.352	0.524	0.763	1.298	0.251
	(0.068)	(0.125)	(0.144)	(0.332)	(0.176)
log capital/worker	-0.184	0.425	-0.264	1.633	0.308
	(0.175)	(0.390)	(0.370)	(1.033)	(0.421)
common language	0.105	0.146	0.354	0.479	0.137
	(0.223)	(0.289)	(0.471)	(0.764)	(0.317)
control corrupt	0.156	0.621	0.365	1.816	0.414
	(0.151)	(0.312)	(0.319)	(0.826)	(0.350)
log no. of firms	0.108	-0.020	0.031	-0.369	-0.062
	(0.086)	(0.130)	(0.183)	(0.345)	(0.142)
log domestic purchases					2.392
					(0.327)
Constant	-7.250	-11.068	14.499	2.600	-37.389
	(0.922)	(2.323)	(1.952)	(6.156)	(6.573)
Observations	57	57	57	57	57

Notes: Standard errors in parentheses. In the IV specifications, the human-capital-adjusted wage is instrumented by population. HC adjusted wage is country wage adjusted for differences in human capital. Domestic purchases is total purchases of U.S. inputs by firms sourcing from a country. First-stage F-statistic on the excluded instrument is 6.49. First-stage regression results are in the Appendix.

Implications of first two steps

- Sourcing from all countries, relative to only domestic sourcing
  - 9 percent lower input costs
  - 32 percent larger sales

- Result: $\frac{\sigma-1}{\theta} > 1$ (p-value: 0.06)
  - Complements case from model
  - Increasing differences of the profit function in the sourcing set

Step 3: Estimate fixed costs and residual demand

- Fix the shape parameter of Pareto distribution $\kappa = 4.25$
- Estimate 6 parameters via Simulated Method of Moments
  - Firm-country-specific fixed costs (cons, distance, lang, control of corruption, disp)
  - Residual demand

- Use 69 moments
  - Share of importing firms (24%), share of importers with firm sales below median (8.4%)
  - Share of firms that sources from each country
  - Share of firms sourcing less than 50th percentile from the U.S.

- Solve firm's problem
  - 2^{67} or about 10^{20} possible choices
  - Exploit complementarities in profit function
  - Build on algorithm in Jia (2008)

Marginal benefit of country j

- Profits of a sourcing strategy $\mathcal{J}$ for a firm
  - given productivity φ and fixed cost f_{ij}^n

$$\Pi\left(\mathcal{J}, \varphi, f_{ij}^n\right) = \varphi^{\sigma-1} B \left(\left(\gamma \Theta_i\left(\mathcal{J}\right)\right)^{(\sigma-1)/\theta}\right) - \sum_{j \in \mathcal{J}} f_{ij}^n,$$

- Marginal benefit of adding country j given φ and $\mathcal{J} \setminus j$

$$\varphi^{\sigma-1} \gamma^{(\sigma-1)/\theta} B \left(\Theta_i\left(\mathcal{J}\right)^{(\sigma-1)/\theta} - \Theta_i\left(\mathcal{J} \setminus j\right)^{(\sigma-1)/\theta}\right) - f_{ij}^n$$

Solve firm's problem using Jia (2008) algorithm

- Define mapping $V : \{0,1\}^N \to \{0,1\}^N$
  - $V_j(\mathcal{J}) = 1$ if marginal benefit of j given $\mathcal{J}$ is positive
- Increasing differences in profit function imply $V()$ is an increasing function
- Start from set $\mathcal{J}^0$ and use iterative application of V-operator to obtain lower bound for sourcing strategy
- Start from set $\mathcal{J}^1$ and use iterative application of V-operator to obtain upper bound for sourcing strategy
- If bounds do not overlap, evaluate all combinations between them

▸ Statistics on Performance

Parameter Estimates

Table 5: Estimated parameters

B	β_c^f	β_d^f	β_l^f	β_C^f	β_{disp}^f
0.122	0.022	0.193	0.872	-0.393	0.934
(0.004)	(0.002)	(0.018)	(0.024)	(0.012)	(0.018)

Notes: Table reports coefficients and standard errors from estimating the model via simulated method of moments Standard errors based on 25 bootstrap samples drawn with replacement.

- Fixed costs 13 percent lower if common language
- Fixed costs increasing in distance with elasticity of .19 percent
- Median fixed cost estimates range from 10,000 to 56,000 USD

Counterfactual

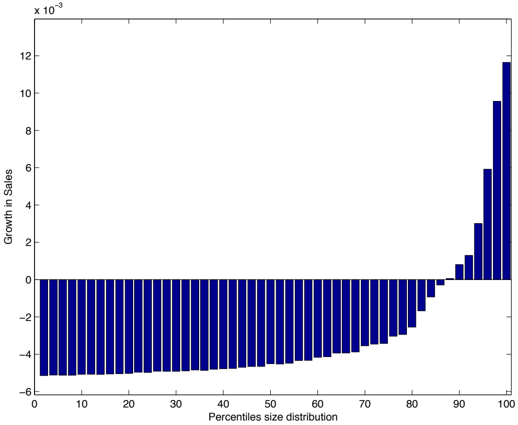
- Shock to China's sourcing potential large enough to explain 178% increase in Chinese share of US imports between 1997 and 2007.
- Resolve for the equilibrium price index and the mass of entering firms
- Compare
  - Baseline
  - Alternative parameter values that imply univeral importing or independent entry decisions
- Focus on
  - Third market effects and sourcing from the U.S.
  - Gross versus net changes in sourcing
  - Size distribution

Baseline

Chinese import status	Change sourcing from US	Change Sourcing from other countries	Share of firms
Entrants	1.008	1.015	0.053
Exiters	-	-	0
Continuers	1.001	1.001	0.027
Others	0.995	0.987	0.920

- Aggregate sourcing from the U.S. is reduced by 0.53 percent
- For every 10 domestic manufacturing jobs destroyed, 2 new jobs are created.

Baseline - Size distribution and price index



- Price index falls by .2 %.

Alternative parameters: Universal importing

- No fixed costs of foreign sourcing

Chinese import status	Change sourcing from US	Change Sourcing from other countries	Share of firms
Entrants	-	-	0
Exiters	-	-	0
Continuers	0.987	0.987	1
Others	-	-	0

- All type of firms descrease sourcing from the U.S. and from third markets by the same amount

Alternative parameters: Independent entry decisions

- Set $\theta = \sigma - 1$

Chinese import status	Change sourcing from US	Change Sourcing from other countries	Share of firms
Entrants	0.997	0.994	0.053
Exiters	-	-	0
Continuers	0.997	0.996	0.027
Others	0.997	0.992	0.920

- All firms decrease sourcing from the U.S. by the same amount
- No gross increases of sourcing

AFT (2014): Summary

- New framework for firm sourcing in a multi-country world
  - Interdependencies in firms' extensive margin decisions
  - Distinguish between country potential and fixed costs
- Counterfactual implications
  - Third market effects
  - Heterogeneous effects across firms
  - Gross changes versus net changes
- Framework and methodology can be applied to other problems

Arkolakis and Eckert (2018)

- Develop an algorithm that applies also to the substitutes case
- Suppose the profit function is submodular
- Algorithm:
  - Consider $\max \mathbf{I} = \{1, ..., 1\} \in \mathbf{I}$
    - Largest amount of negative complementarity $\implies$ Any choice with $MV > 0$ fixed to 1 in **I***
  - Consider $\min I = \{0, ..., 0\} \in \mathbf{I}$
    - Least amount of negative complementarity $\implies$ Any choice with $MV < 0$ fixed to 0 in **I***
  - Iterate on ambiguous entries until reach fixed point **I***
  - Delivers $I^{\text{max}} = \max$ **I*** and $I^{\text{min}} = \min$ **I*** (optimal decision inside these bounds)

What to do when upper and lower bound do not overlap?

1. Evaluate all combinations in between
   - Worked in the AFT example. Maybe infeasible in other cases
2. Arkolakis and Eckert propose to run their algorithm repeatedly for a subset of choices
   - Does not work well in the worst case
3. Heuristics / Greedy algorithm
   - See Appendix of TKMD (2018) for some suggestions

Concluding remarks

- Assuming independence between discrete choices ignores a lot of interesting economic trade-offs
- Putting structure on the problem can help to cover interesting cases with super-modularity or sub-modularity
- A mixed case (not strictly super- or sub-modular) is pretty hard
- More work to be done and more applications to be explored!

Appendix

Gravity - universal importing

- Special case 1: Very low fixed cost of offshoring

$$M_{ij} = \tau_{ij}^{-\theta} \frac{Ei}{\Theta_i} \frac{Q_j}{\sum_k \tau_{kj}^{-\theta} \frac{E_k}{\Theta_k}}$$

- Familiar from Eaton and Kortum (2002)
- Trade elasticity is given by θ
- Extensive margin effect at the *product-level*

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Gravity - general case

- General case

$$M_{ij} = \tau_{ij}^{-\theta} \Lambda_{ij} \frac{E_i}{P_i^{1-\sigma}/N_i} \frac{Q_j}{\sum_k \tau_{kj}^{-\theta} \Lambda_{kj} \frac{E_k}{P_j^{1-\sigma}/N_j}}$$

where

$$\Lambda_{ij} = \int_{\tilde{\varphi}_{ij}}^{\infty} I_{ij}\left(\varphi\right)\left(\Theta_i\left(\varphi\right)\right)^{(\sigma-1-\theta)/\theta} \varphi^{\sigma-1} dG_i\left(\varphi\right),$$

- Λ_{ij} yields
  - Extensive margin effect at the *firm-level* in addition to the *product-level*
  - Third market effects

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Gravity - independent entry decisions

- Special case 2: $(\sigma-1)/\theta = 1$ and core efficiency Pareto

$$M_{ij} = \tau_{ij}^{-\kappa} f_{ij}^{1-\kappa/(\sigma-1)} \Psi_i \frac{E_i}{P_i^{-\kappa}} \frac{Q_j}{\sum_k \tau_{kj}^{-\kappa} f_{kj}^{1-\kappa/(\sigma-1)} \Psi_k \frac{E_k}{P_k^{-\kappa}}},$$

- Trade elasticity as in Chaney (2008)
- Extensive margin effect
- No third market effects

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Statistics on Jia Algorithm Performance

Cardinality of difference in bounds	0	1	2	3	4	5	6	7	8	9-25	≥ 26
Number of occasions	11220190126	0	918094	84695	6693	376	16	0	0	0	0

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