Staggered Adjustment and Trade Dynamics

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Motivation

• Are new empirical trade models helpful for open economy macro?

• A fundamental incompatibility:
  • Open economy macro models need
    a small trade elasticity to explain short-run responses to changes in relative cost
  • Trade models need
    a large trade elasticity to explain long-run responses to changes in tariffs

• See the problem in performance of a typical trade model over time
Motivation II

- Bilateral trade share:

\[
\pi_{ni}^t = \frac{X_{ni}^t}{X_n^t} = \frac{T_i^t (w_i^t d_{ni}^t)^{-\theta}}{\sum_k T_k^t (w_k^t d_{nk}^t)^{-\theta}}
\]

- Compare \(i\)'s and \(j\)'s shipments to market \(n\):

\[
\ln \frac{X_{ni}^t}{X_{nj}^t} = \ln \frac{T_i^t}{T_j^t} - \theta \ln \frac{w_i^t}{w_j^t} - \theta \ln \frac{d_{ni}^t}{d_{nj}^t}
\]

- What do changes in relative wages explain?
Motivation II

• Bilateral trade share:

\[ \pi^t_{ni} \equiv \frac{X^t_{ni}}{X^t_n} = \frac{T^t_i (w^t_i d^t_{ni})^{-\theta}}{\sum_k T^t_k (w^t_k d^t_{nk})^{-\theta}} \]

• Compare i’s and j’s shipments to market n:

\[ \ln \frac{X^t_{ni}}{X^t_{nj}} = \ln \frac{T^t_i}{T^t_j} - \theta \ln \frac{w^t_i}{w^t_j} - \theta \ln \frac{d^t_{ni}}{d^t_{nj}} \]

• Specify a regression in changes

\[ \ln \frac{\hat{X}^t_{ni}}{\hat{X}^t_{nn}} = -\theta \ln \frac{\hat{W}^t_i}{\hat{W}^t_n} + \varepsilon^t_{ni} \]
Motivation III: Pooled Regressions (Annual Differences):

- Explanatory power of the wage changes

\[
\ln \frac{\hat{X}_{ni}^t}{\hat{X}_{nn}^t} = -\theta \ln \frac{\hat{w}_i^t}{\hat{w}_n^t} + \epsilon_{ni}^t
\]

\(-\hat{\theta} = 0.4 \text{ (s.e. 0.04)} \quad R^2 = 0.21\)

- Explanatory power of encompassing source effect \((S_i^t = T_i^t(w_i^t)^{-\theta})\)

\[
\ln \frac{\hat{X}_{ni}^t}{\hat{X}_{nn}^t} = \ln \frac{\hat{S}_i^t}{\hat{S}_n^t} + \epsilon_{ni}^t
\]

\(R^2 = 0.47\)
Our Goal

- Develop a model that works well at different frequencies
  - Open economy model exploiting information in bilateral trade
- Sacrifice optimizing behavior to make it easier to take to the data
Line of Attack: Staggered Adjustment by Consumers

- Basic idea: consumers are slow to switch sources of supply
  - Consistent with evidence on “Customer Loyalty” (Reichheld & Teal ’96)
  - Like firms changing prices in Calvo model

- Analysis inspired by Ruhl ’05, related to Drozd & Nosal ’12
  - Common feature: slow adjustment
  - Ruhl and DN: forward looking decisions by firms (pay sunk cost, build customer base)
  - AEK: passive (staggered) adjustment by consumers
Main Idea in a Nutshell

- A continuum of goods
  - Consumer can search for cheapest supplier only for a fraction of goods each period
    - Sluggish adjustment at the extensive margin (consistent with Baier et al ’11)
    - Standard CES Dixit-Stiglitz demand at the intensive margin

- Firms perfectly competitive
  - Take prices as given
Main Idea: Prices over time
Main Idea: Prices over time & Consumer Choice

Note: Red denotes the chosen supplier.
The Model
Theoretical Framework

- Our model encompasses empirical Ricardian and Armington models

- Adds just one parameter to EK '02, $\lambda$: fraction of consumers adjusting
  - $\lambda = 0$ delivers Armington
  - $\lambda = 1$ delivers EK
  - In between is where trade dynamics get interesting
Basics

- Perfect competition, continuum of goods $j \in [0, 1]$, integer $I$ countries (denoted $n$ when importing and $i$ when exporting)

- Wage $w_i^t$, aggregate productivity $A_i^t$, iceberg trade costs $d_{ni}^t$
  - Unit cost of $i$’s labor for supplying $n$:
    \[ c_{ni}^t \equiv \frac{w_i^t d_{ni}^t}{A_i^t} \]

- A technology for making good $j$ in country $i$ with efficiency $z$ implies price in $n$ of:
  \[ p_{ni}^t(z) = \frac{c_{ni}^t}{z} \]
Technologies

- New technologies rain down, independently across countries, as in EK’01

- For any good, the number of techniques with efficiency better than $z$ is distributed Poisson ($T_i^t z^{-\theta}$)
  - Each country more than one available techniques to produce good $j$
Old EK: Full Adjustment

- Only the best technologies are used in each country, efficiency $z_{i}^{a,t}(j)$.

- Probability that no technique better than $z$ has arrived (Poisson evaluated at 0) yields Fréchet:

$$\Pr[z_{i}^{a,t}(j) \leq z] = e^{-T_{i}^{t}z^{-\theta}}$$
Old EK: Results

- Price distribution for lowest cost in $n$:

\[
\Pr[p_{n,t}^a(j) \leq p] = G_{n,t}^a(p) = 1 - e^{-\Phi_{n,t} p^\theta}
\]

- How countries contribute to $n$: 
  \[
  \Phi_{n,t} = \sum_k T_{t,k} (c_{nk}^t)^{-\theta}
  \]

- Distribution same for all $i$ conditional on $n$ buying from $i$

- Share of goods for which $i$ is lowest cost in $n$:

\[
\bar{\pi}_{n,i}^a = \frac{T_{i,t} (c_{ni}^t)^{-\theta}}{\Phi_{n,t}}
\]
New AEK: Staggered Adjustment

- Consumer: With probability $\lambda$ looks everywhere for the lowest-cost supplier, otherwise buys good from same supplier as last year.

- Producers: perfectly competitive
  - If $T_i^t = T_i$ (constant technologies) consumer buys country’s lowest cost supplier.
  - If $T_i^t$ increases consumer may buy from producers with dominated technologies.

- We assume that consumers do not observe location of supplier
  - Price by itself does not reveal information for source country (as in EK).
  - Given this environment, optimal to pick cheapest supplier when adjusting.
New AEK: Staggered Adjustment

- Fraction of goods $n$ buys from $i$ evolves as:
  \[ \bar{\pi}_{ni}^t = \lambda \bar{\pi}_{ni}^{a,t} + (1 - \lambda) \bar{\pi}_{ni}^{t-1} \]

- Price distribution for goods purchased from country $i$ evolves as:
  \[ G_{ni}^t(p) = \frac{\lambda \bar{\pi}_{ni}^{a,t}}{\bar{\pi}_{ni}^t} G_{ni}^{a,t}(p) + \frac{(1 - \lambda) \bar{\pi}_{ni}^{t-1}}{\bar{\pi}_{ni}^t} G_{ni}^{t-1} \left( \frac{p}{c_{ni}^t / c_{ni}^{t-1}} \right) \]

  (not the same for all $i$)
New AEK: Staggered Adjustment

- Fraction of goods $n$ buys from $i$ evolves as:

$$\bar{\pi}_{ni}^t = \lambda \bar{\pi}_{ni}^{a,t} + (1 - \lambda) \bar{\pi}_{ni}^{t-1}$$

- Price distribution for goods purchased from country $i$ evolves as:

$$G_{ni}^t(p) = \frac{\lambda \bar{\pi}_{ni}^{a,t}}{\bar{\pi}_{ni}^t} G_{ni}^{a,t}(p) + \frac{(1 - \lambda) \bar{\pi}_{ni}^{t-1}}{\bar{\pi}_{ni}^t} G_{ni}^{t-1} \left( \frac{p}{c_{ni}^t / c_{ni}^{t-1}} \right)$$

Note: We haven’t talked yet about consumer demand.
Consumer Preferences

- Standard Dixit-Stiglitz preferences as in EK

\[ x_n^t (p) = \left( \frac{p}{P_n^t} \right)^{-(\sigma-1)} X_n^t \]  \hspace{1cm} (1)

with price index

\[ (P_n^t)^{-(\sigma-1)} = \sum_i \pi_{ni}^t (P_{ni}^t)^{-(\sigma-1)} \]

where

\[ P_{ni}^t = \left[ \int_0^\infty p^{-(\sigma-1)} dG_{ni}^t (p) \right]^{-1/(\sigma-1)} \]
Trade Shares

- Multiplying each side of (1) by $\bar{\pi}_{ni}^t$, then integrating over $G_{ni}(p)$ gives the observed trade share:

$$\pi_{ni}^t = \bar{\pi}_{ni}^t \left( \frac{P_{ni}^t}{P_n^t} \right)^{-(\sigma-1)}$$

- For $\lambda$ low, $\bar{\pi}_{ni}^t$ responds slowly to a change in costs, but its long-run elasticity is always $\theta$.

- For $\lambda$ low, the price index $P_{ni}^t$ moves nearly in proportion to costs, hence affecting the trade share with an elasticity $\sigma - 1$, but in the long run $P_{ni}^t \rightarrow P_n^t$. 
Three Key Parameters

- Elasticity of substitution $\sigma$
- Elasticity of the extensive margin $\theta$
- Speed of adjustment $\lambda$

Their roles:

- In Armington $\sigma - 1$ is the trade elasticity
- In EK $\theta$ is the trade elasticity
- For us, $\sigma - 1$ matters for the short run and $\theta$ for the long run, with $\lambda$ governing the arrival of the long run
Closing the Model

- Static equilibrium allowing for exogenous trade deficits $D^t_n$
- Labor supply $L^t_i$ is also exogenous
- Labor market equilibrium requires:

$$w^t_i L^t_i = \sum_{n=1}^{l} \pi^t_{ni} (w^t_n L^t_n + D^t_n)$$

- Want to include a non-traded sector and intermediates, but keep it simple for now.
Model Implications

- Trade elasticity
  \[
  \frac{\partial \pi_{ni}^t}{\partial w_i} \frac{w_i}{\pi_{ni}^t} = - \left[ \lambda \theta + (1 - \lambda)(\sigma - 1) \right] (1 - \pi_{ni}^t).
  \]

- Insensitivity of trade shares to wages (if \(\lambda\) and \(\sigma\) are low) makes wages more sensitive to a shock, such as a change in \(D\).

- Real wage (letting \(Z_n^t = T_n^t (A_n^t)^\theta\) combine the two productivity terms):
  \[
  \frac{w_n^t}{P_n^t} = \gamma^{-1} \left( Z_n^t \right)^{1/\theta} \left( \nu_n^t \right)^{1/(\sigma-1)} \left( \bar{\pi}_{nn}^a,t \right)^{-1/\theta}
  \]
Numerical Illustrations
Parameters, Initial Conditions, and Shocks

- Benchmark parameters $\Theta = \{\theta, \sigma, \lambda\}$
  - $\theta = 4$: long-run elasticity estimates (Simonovska Waugh '10, Caliendo Parro '10)
  - $\sigma = 0.5$: short-run elasticity estimates (Reinert '92, Bloningen Wilson '99)
  - $\lambda = 0.05$, $\lambda = 0.20$, or $\lambda = 1$: marketing case studies ($\approx 0.15$)

- Full-adjustment initial conditions: $\pi_{ni}^0 = \pi_{ni}^0$ and $\nu_{ni}^0 = \nu_{ni}^0$, $\pi_{ni}^0 = \pi_{ni}^0$
- Assume $T_i$ and $L_i$ constant
- Model gives a difference in equation on past trade shares (&changes in technology etc)
  - Use it to solve for equilibrium recursively
Data

- Bilateral trade in manufactures among G6 countries and ROW
- Annual 1991-2006
- Manufacturing gross production for $Y_i$
Experiment I: Balancing Trade

- Start from initial condition in 2006, then permanently adjust to balanced trade
- Japan starts in surplus; United Kingdom and the United States in deficit
- Show outcomes for \( i = J, UK, USA \):
  1. Wage \( w^t_i \) (relative to world manufacturing production)
  2. Real wage \( w^t_i / P^t_i \)
  3. Terms of trade (export price over import price)
  4. Domestic share, \( \pi^t_{ii} \)
Experiment I: Trade Balance after 2006

Net Exports to GDP

-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2

FRA
GER
ITA
JAP
UK
USA
Figure 2: Balanced Trade with High Lambda (DEK)
Figure 3: Balanced Trade with Medium Lambda

- Wages (Relative to World GDP)
- Real Wages
- Terms of Trade
- Share on Domestic Spending
Figure 4: Balanced Trade with Low Lambda

- Wages (Relative to World GDP)
  - Japan
  - UK
  - USA
- Real Wages
- Terms of Trade
- Share on Domestic Spending

Years from Initial Steady State
Experiment II: Trade Liberalization

• Start from initial condition in 2006, then $\hat{d}_{ni}^{2007} = 1/(1.1)$ for all $n \neq i$
• Set $\lambda = 0.05$
• Outcomes for $i = J, UK, USA$:
  1. Wage $w_i^t$ (relative to world manufacturing production)
  2. Real wage $w_i^t / P_i^t$
  3. Terms of trade (export price over import price)
  4. Domestic share, $\pi_{ii}^t$
Figure 5: Trade Liberalization Outcomes
Trade Liberalization: Welfare Loss due to Slow Adjustment

![Graph showing the ratio of welfare over time for Japan, UK, and USA. The x-axis represents years from the initial steady state, ranging from 0 to 10. The y-axis shows the ratio, ranging from 0.99 to 1.01. The graph indicates a decline and eventual recovery for each country, with Japan, UK, and USA shown as separate lines.](image)

- **Japan**
- **UK**
- **USA**

The graph illustrates the impact of trade liberalization on welfare, highlighting the slow adjustment period and the resulting welfare loss.
Experiment III: Estimate Trade Elasticities

- Simulate using actual deficits 1992-2006
- Productivity shocks log normal: mean and std. deviation of growth 0.01
- Generate 100 separate data sets by repeatedly simulating the model
- Run the following short-run regression on both the simulated and the actual data:

\[
\ln \frac{\hat{\pi}_{ni}}{\hat{\pi}_{nn}} = \varepsilon S \ln \frac{\hat{W}_{ni}}{\hat{W}_{nn}} + u_{ni} \text{ for all } t, n, i \neq n
\]
Short-Run Regression Results

<table>
<thead>
<tr>
<th></th>
<th>$\lambda = 0.05$</th>
<th>$\lambda = 0.2$</th>
<th>$\lambda = 1$</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>0.384</td>
<td>−0.017</td>
<td>−1.17</td>
<td>0.41</td>
</tr>
<tr>
<td>std. deviation</td>
<td>0.003</td>
<td>0.017</td>
<td>0.239</td>
<td>0.04</td>
</tr>
<tr>
<td>model elasticity</td>
<td>0.275</td>
<td>−0.400</td>
<td>−4.00</td>
<td></td>
</tr>
</tbody>
</table>
Long-Run Regression

- Simulate permanent removal of a 10% tariff on ROW imports, in 1992
- Captured by $\hat{d}_{ni}^{1992} = 1/(1.1)$ when $n = \text{ROW}$
- We also include the same shocks to deficits and productivity as in the previous exercise
- Construct the Head and Ries '01 index
  \[ H_{ti} = \frac{\pi_{tn}^t}{\pi_{nn}^t} \frac{\pi_{in}^t}{\pi_{ii}^t} \]

- Run the long-run regression:
  \[ \ln \left( \frac{H_{ni}^{2006}}{H_{ni}^{1991}} \right) = \varepsilon_L \ln \left( \hat{d}_{ni}^{1992} \hat{d}_{in}^{1992} \right) + u_{ni} \text{ for all } n, i \leq n \]

- Mean OLS estimate is $-3.62$ when $\lambda = 0.05$ (long-run elasticity would have been $\theta = 4$)
Towards Estimation
Equations for Estimation

Let $\tau^t_i = \ln \hat{Z}^t_i$ and $\varepsilon^t_{ni} = -\theta \ln \hat{d}^t_{ni}$ be random shocks:

$$\hat{\pi}^{a,t}_{ni} = \frac{\exp (\tau^t_i + \varepsilon^t_{ni}) (\hat{w}^t_i)^{-\theta}}{\sum_k \hat{\pi}^{a,t-1}_{ni} \exp (\tau^t_k + \varepsilon^t_{nk}) (\hat{w}^t_k)^{-\theta}}$$

Let $g_T = \hat{T}^t_i$:

$$\nu^t_{ni} = \lambda \hat{\pi}^{a,t}_{ni} + (1 - \lambda) \left( \frac{\hat{\pi}^{a,t}_{ni}}{g_T} \right)^{\frac{\sigma-1}{\theta}} \nu^{t-1}_{ni}$$

Given full-adjustment initial conditions at $t = 0$ and observed wage changes $\hat{w}^t_i$, want to perfectly fit data on bilateral trade shares over time:

$$\pi^t_{ni} = \frac{\nu^t_{ni}}{\sum \nu^t_{nk}}$$
Moment Conditions

- To identify the parameters $\Theta = \{\theta, \sigma, \lambda, g_T\}$ impose orthogonality conditions between the shocks and observed deficits $D^t_n$
- Gives a vector of moments $f(\tau, \varepsilon)$ that should be close to zero
- The identification power of deficits comes from the labor market equilibrium conditions, which imply that running a larger deficit raises a country’s wage
A Procedure

- Want to exploit recent work on structural estimation using Mathematical Programming with Equilibrium Constraints (MPEC): Su Judd ’10
- Our model fits nicely into the setting explored by Dube Fox Su ’09:

\[
\min_{\Theta, \tau, \varepsilon} f(\tau, \varepsilon)'\Omega f(\tau, \varepsilon) \\
\text{subject to } \pi(\tau, \varepsilon; \Theta) = \Pi
\]

- Note I: since \( \pi \) is a constraint, we also fit wages by labor market clearing
- Note II: trade shares are like market shares in BLP
- Its just a big constrained minimization problem
Appendix
Motivation II

- Bilateral trade share:
  \[
  \frac{X_{ni}^t}{X_n^t} = \pi_{ni}^t = \frac{T_i^t (w_i^t d_{ni}^t)^{-\theta}}{\sum_k T_k^t (w_k^t d_{nk}^t)^{-\theta}}
  \]

- Compare i’s and j’s shipments to market n:
  \[
  \ln \frac{X_{ni}^t}{X_{nj}^t} = \ln \frac{T_i^t}{T_j^t} - \theta \ln \frac{w_i^t}{w_j^t} - \theta \ln \frac{d_{ni}^t}{d_{nj}^t}
  \]

- What do changes in relative wages explain?
- Set: United Kingdom (i), Japan (j), each G6 country (n’s)
Motivation III

- UK/Japan wage (falls then rises). Manufacturing shipments (UK vs. Japan) to G6 destinations:

![Graphs by Country](image)

**Destination**

- France
- Germany
- Italy
- Japan
- United Kingdom
- United States

**Time**

- 1990
- 1995
- 2000
- 2005

**Graphs by Country**

- ireltrade
- irelwage
Three Key Equations for Simulation

- Letting $\hat{Z}_i^t = \hat{T}_i^t (\hat{A}_i^t)^\theta$ capture productivity change (where $\hat{x}^t = x^t / x^{t-1}$):

  $$\hat{\pi}_{ni}^{a,t} = \frac{\hat{Z}_i^t (\hat{\nu}_i^t \hat{d}_{ni}^t)^{-\theta}}{\sum_k \hat{\pi}_{ni}^{a,t-1} \hat{Z}_k^t (\hat{\nu}_k^t \hat{d}_{nk}^t)^{-\theta}}$$

- Letting $\nu_{ni}^t = \pi_{ni}^t \left( \frac{P_n^t}{P_n^{a,t}} \right)^{-(\sigma-1)}$ so that trade shares are

  $$\pi_{ni}^t = \nu_{ni}^t / \sum \nu_{nk}^t$$

  $$\hat{\nu}_{ni}^t = \lambda \hat{\pi}_{ni}^{a,t} \frac{\hat{\pi}_{ni}^{a,t-1}}{\nu_{ni}^{t-1}} + (1 - \lambda) \left( \frac{\hat{\pi}_{ni}^{a,t}}{\hat{T}_i^t} \right)^{\frac{\sigma-1}{\theta}}$$

- Letting $Y_i^t = w_i^t L_i^t$ we have:

  $$\hat{w}_i^t \hat{L}_i^t Y_i^{t-1} = \sum_{n=1}^l \pi_{ni}^t (\hat{w}_n^t \hat{L}_n^t Y_n^{t-1} + D_n^t)$$
Experiment I: Trade Balance after 2006
Trade Liberalization: Welfare Loss due to Slow Adjustment