Motivation

• Does openness to trade promote productivity?

• Exports and firm productivity are correlated
  
  • Selection: robust finding
  • Learning-by-Exporting: mixed evidence

• A reflection of a new mechanism: endogenous innovation?
  
  • Aw, Roberts, and Winston (2007): R&D and exporting correlated.
• Recent macro/trade models of joint decisions of R&D and export: Atkeson and Burstein (2008), Costantini and Melitz (2007).

• **Interdependent** R&D and exporting at firm-level
  • Exporting → larger market → more R&D incentive
  • Selection
  • R&D → higher expected future productivity → re-inforce selection

• **market size effect** depend on
  • domestic/exporting profitability
  • innovation process
  • costs assoicated with each activity
• Document firm-level R&D and export dynamics in Taiwanese Electronics Industry.

• Estimate an empirical structural model and quantify how

• **Optimal R&D and export decisions** depend on
  • expectation of future productivity/export demand
  • fixed/sunk costs associated with choices

• Decompose **correlated** R&D and Export dynamics by
  • selection on unobservables
  • state dependence

• To be done: quantify how large is the market size effect, i.e. how does R&D respond to trade cost reduction?
• Productivity in response to both R&D and exporting.
• Impact of R&D is larger.
• But, relatively low exporting cost makes it a more important channel.
• The **interdependence** of R&D and exporting is dominated by selection: stable export demand.
• To be done: what if a trade liberalization?
• 2000-2004 Taiwan Annual Manufacturing Survey.

• Product classes: consumer electronics, telecommunication equipment, computers and storage equipment, electronics parts and components.

• Most dynamic industry in Taiwanese manufacturing sector
  - **Export participation** .39 - compete with low-margins
  - **R&D performers** .17 - major focus on process innovation
  - Significant cross-sectional heterogeneity in productivity and activities.
  - Sustained productivity growth, 3.6% annual in 80s and 90s.

• Key variables: Revenue-domestic and export, Physical capital stocks (size), R&D expenditure, Variable costs-material, labor, energy
• **Transition** pattern of R&D and exporting

<table>
<thead>
<tr>
<th>Status year t</th>
<th>Status Year t+1</th>
<th>All Firms</th>
<th>Neither</th>
<th>only R&amp;D</th>
<th>only Export</th>
<th>Both</th>
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<tbody>
<tr>
<td>All Firms</td>
<td></td>
<td>.563</td>
<td>.036</td>
<td>.255</td>
<td>.146</td>
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<tr>
<td>only Export</td>
<td></td>
<td>.213</td>
<td>.010</td>
<td>.708</td>
<td>.070</td>
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<tr>
<td>Both</td>
<td></td>
<td>.024</td>
<td>.062</td>
<td>.147</td>
<td>.767</td>
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</tr>
</tbody>
</table>

• **Persistence** in the status: (1) high sunk costs (2) high degree of persistence in the underlying profit heterogeneity.

• Exporting is more **common** than R&D investment.

• Undertaking one of the activities in year \( t \rightarrow \) more likely to add the other in year \( t + 1 \), less likely to drop the other in year \( t + 1 \)
Technology:

- Short-run marginal cost:
  \[ \ln c_{it} = \ln c(k_{it}, w_t) - x_{it} = \beta_0 + \beta_k \ln k_{it} + \beta_w \ln w_t - x_{it} \]

- \( k_{it} \) capital stock, \( w_t \) variable input price, \( x_{it} \) productivity

- Differs across firms, but not a function of output

- Two sources of heterogeneity: capital-observable, productivity-not observable by researchers.
Demand:

- Demand for the firm’s output in domestic market (Dixit -Stiglitz)

\[ q_{it}^D = Q_t^D \left( \frac{p_{it}^D}{P_t^D} \right)^{\eta_D} = \frac{I_t^D}{P_t^D} \left( \frac{p_{it}^D}{P_t^D} \right)^{\eta_D} = \Phi_t^D (p_{it}^D)^{\eta_D} \]

- All aggregates are combined into \( \Phi_t^D \).

- Similarly, demand for the firm’s output in export market:

\[ q_{it}^X = z_{it} \frac{I_t^X}{P_t^X} \left( \frac{p_{it}^X}{P_t^X} \right)^{\eta_X} = \Phi_t^X z_{it} (p_{it}^X)^{\eta_X} \]

- \( z_{it} \): firm-specific demand shock in export market. Heterogeneity between export and domestic market for each firm.
• These assumptions imply domestic and export revenue function as:

\[
\ln r_{it}^D = (\eta_D + 1) \ln \left( \frac{\eta_D}{\eta_D + 1} \right) + \ln \Phi_t^D + (\eta_D + 1) \ln c_{it} \\
\ln r_{it}^X = (\eta_X + 1) \ln \left( \frac{\eta_X}{\eta_X + 1} \right) + \ln \Phi_t^X + (\eta_X + 1) \ln c_{it} + z_{it}
\]

• Profits: directly relate revenue to unobservables \( x_{it} \) and \( z_{it} \).

\[
\pi_{it}^D = (-1/\eta_D) r_{it}^D (\Phi_t^D, k_{it}, x_{it}) \\
\pi_{it}^X = (-1/\eta_X) r_{it}^X (\Phi_t^X, k_{it}, x_{it}, z_{it})
\]

• Finally, total cost \( tvc_{it} = r_{it}^D (1 + \frac{1}{\eta_D}) + r_{it}^X (1 + \frac{1}{\eta_X}) \)
Transition of State Variables

• Productivity $x_{it}$ evolves **endogenously**, depending on R&D $d_{it-1}$ and exporting $e_{it-1}$:

$$x_{it} = g(x_{it-1}, d_{it-1}, e_{it-1}) + \xi_{it}$$

• $d_{it-1}$: learning-by-investing. $e_{it-1}$: learning-by-exporting. $d, e$: discrete (0/1) or continuous.

• Export demand shock $z_{it}$ evolves **exogenously** as a first order markov process:

$$z_{it} = \rho_z z_{it-1} + \mu_{it}, \mu_{it} \sim N(0, \sigma^2_{\mu})$$

• Firm size measure capital $k_i$: short time series dimension with very little variation over time.
Sources of dynamics:

- \( e \) and \( d \) affect evolution of future \( x \), \( z \) is persistent over time
- Beginning each activity involves one-time sunk cost.

Sequence of Information and Decisions:

1. Begin period \( t \) with productivity and export demand shock \((x_{it}, z_{it})\).
2. Random fixed cost \( \gamma^F_{it} \) of exporting and sunk cost \( \gamma^S_{it} \rightarrow \) export decision.
3. Maximize static profits \( \pi^D_{it} \) and, if exporting, \( \pi^X_{it} \).
4. Random fixed cost of R&D \( \gamma^I_{it} \) and sunk cost \( \gamma^D_{it} \rightarrow \) R&D decision.
5. End of period \( t \), new states \((x_{it+1}, z_{it+1})\) realized.
Dynamic Decisions - Value Functions

• Let $s_{it} = (z_{it}, x_{it}, k_{i}, e_{it-1}, d_{it-1}, \Phi_t)$

• Firm’s integrated value function in year $t$

$$V_{it}(s_{it}) = \int \pi^D_{it} + \max_{e_{it} \in (0,1)} \{ \pi^X_{it} - e_{it-1} \gamma^F_{it} - (1 - e_{it-1}) \gamma^S_{it} + V^E_{it}, V^D_{it} \} dG^\gamma$$

• Firm’s future value of exporting:

$$V^E_{it}(s_{it}) = \int \max_{d_{it} \in (0,1)} \{ \delta E_t V^{}_{it+1}(s_{it+1} | \cdot, e_{it} = 1, d_{it} = 1) - \gamma^l_{it} d_{it-1} \}
- \gamma^D_{it} (1 - d_{it-1}), \delta E_t V^{}_{it+1}(s_{it+1} | \cdot, e_{it} = 1, d_{it} = 0) \} dG^\gamma$$

• Firm’s future value when it chooses not to export:

$$V^D_{it}(s_{it}) = \int \max_{d_{it} \in (0,1)} \{ \delta E_t V^{}_{it+1}(s_{it+1} | \cdot, e_{it} = 0, d_{it} = 1) - \gamma^l_{it} d_{it-1} \}
- \gamma^D_{it} (1 - d_{it-1}), \delta E_t V^{}_{it+1}(s_{it+1} | \cdot, e_{it} = 0, d_{it} = 0) \} dG^\gamma$$
Finally, the expected future value conditional on different choices $e_{it}$ and $d_{it}$:

$$E_t V_{it+1} = \int \int \int V_{it+1}(s_{it+1}) dF(x'|x_{it}, e_{it}, d_{it}) dF(z'|z_{it}) dG(\Phi'|\Phi_t)$$

**Three mechanisms** that exporting and R&D are correlated:

- **Selection**: probability of $e_{it}$ and $d_{it}$ increasing in $x_{it}$ and $z_{it}$.

- **MBD**($s_{it}$) = $E_t V_{it+1}(\cdot|e_{it}, d_{it} = 1) - E_t V_{it+1}(\cdot|e_{it}, d_{it} = 0)$
  - export sunk cost $\gamma^S_{it}$
  - knowledge production $g(x_{it}, e_{it}, d_{it})$.

- **MBE**($s_{it}$) = $\pi^X_{it} + V^E_{it}(\cdot, d_{it-1}) - V^D_{it}(\cdot, d_{it-1})$
  - R&D sunk cost $\gamma^D_{it}$
  - knowledge production $g(x_{it}, e_{it}, d_{it})$. 
Set of parameters:

- **Domestic Demand and Cost Parameters**
  - \((\Phi^D, \beta_0, \beta_k)\): domestic revenue equation-recover unobserved productivity \(x_{it}\).
  - Productivity evolution equation
  \[
  x_{it} = \alpha_0 + \alpha_1 x_{it-1} + \alpha_2 (x_{it-1})^2 + \alpha_3 (x_{it-1})^3 + \alpha_4 d_{it-1} + \alpha_5 e_{it-1} + \alpha_6 d_{it-1} e_{it-1} + \xi_{it}
  \]

- \((\eta_X, \eta_D)\): total cost equation

- **Dynamic Parameters**
  - \((\rho_Z, \sigma_\mu, \Phi_X)\): export revenue equation-only observed for exporters.
  - \(G^\gamma\): firm’s conditional choice probabilities
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Discrete R&amp;D</th>
<th>Continuous R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 + 1/\eta_D$</td>
<td>.8432 (.0195)*</td>
<td>.8432 (.0195)*</td>
</tr>
<tr>
<td>$1 + 1/\eta_X$</td>
<td>.8361 (.0164)*</td>
<td>.8361 (.0164)*</td>
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<td>$\beta_k$</td>
<td>-.0633 (.0052)*</td>
<td>-.0636 (.0051)*</td>
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<td>$\alpha_0$</td>
<td>.0879 (.0198)*</td>
<td>.0866 (.0194)*</td>
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<td>$\alpha_1$</td>
<td>.5925 (.0519)*</td>
<td>.5982 (.0511)*</td>
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<td>$\alpha_2$</td>
<td>.3791 (.0915)*</td>
<td>.3777 (.0912)*</td>
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<td>$\alpha_3$</td>
<td>-.1439 (.0585)*</td>
<td>-.1592 (.0588)*</td>
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<td>$\alpha_4$</td>
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<td>.0067 (.0012)*</td>
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<td>$\alpha_5$</td>
<td>.0196 (.0046)*</td>
<td>.0197 (.0045)*</td>
</tr>
<tr>
<td>$\alpha_6$</td>
<td>-.0118 (.0115)</td>
<td>-.0022 (.0014)</td>
</tr>
</tbody>
</table>

| $SE(\xi_{it})$    | .1100                 | .1098                  |
| sample size       | 3703                  | 3703                   |

- Markups average 1.18 for domestic and 1.20 for exports
- Steady state values of $x$ (relative to $d = e = 0$): Export only 1.34, R&D only 2.00, Both 2.22.
## Dynamic Parameter Estimates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>St Error</th>
<th>Parameter</th>
<th>Estimate</th>
<th>St Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_I$ (Innov FC)</td>
<td>67.606</td>
<td>3.930</td>
<td>$\gamma^1_I$ (size 1)</td>
<td>46.265</td>
<td>7.038</td>
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<tr>
<td>$\gamma_I$ (Innov FC)</td>
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<td></td>
<td>$\gamma^2_I$ (size 2)</td>
<td>66.596</td>
<td>3.423</td>
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<tr>
<td>$\gamma_D$ (Innov SC)</td>
<td>354.277</td>
<td>31.377</td>
<td>$\gamma^1_D$ (size 1)</td>
<td>381.908</td>
<td>66.521</td>
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<td>$\gamma_D$ (Innov SC)</td>
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<td></td>
<td>$\gamma^2_D$ (size 2)</td>
<td>388.715</td>
<td>41.959</td>
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<tr>
<td>$\gamma_F$ (Export FC)</td>
<td>11.074</td>
<td>0.389</td>
<td>$\gamma^1_F$ (size 1)</td>
<td>5.733</td>
<td>0.295</td>
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<tr>
<td>$\gamma_F$ (Export FC)</td>
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<td>$\gamma^2_F$ (size 2)</td>
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<td>0.704</td>
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<tr>
<td>$\gamma_S$ (Export SC)</td>
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<td>3.483</td>
<td>$\gamma^1_S$ (size 1)</td>
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<td>6.046</td>
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<tr>
<td>$\gamma_S$ (Export SC)</td>
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<td>$\gamma^2_S$ (size 2)</td>
<td>67.401</td>
<td>6.676</td>
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<tr>
<td>$\Phi_X$ (Export Rev Intercept)</td>
<td>3.813</td>
<td>0.063</td>
<td>$\Phi_X$</td>
<td>3.873</td>
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<tr>
<td>$\rho_Z$ (Export Rev AR process)</td>
<td>0.773</td>
<td>0.014</td>
<td>$\rho_Z$</td>
<td>0.763</td>
<td>0.015</td>
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<tr>
<td>$\log \sigma_\mu$ (Export Rev Std Dev)</td>
<td>-0.287</td>
<td>0.018</td>
<td>$\log \sigma_\mu$</td>
<td>-0.289</td>
<td>0.021</td>
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</table>
Marginal Benefit of Exporting (millions of NT dollars)

<table>
<thead>
<tr>
<th>$x_t$</th>
<th>$d_{t-1} = 1$</th>
<th>$d_{t-1} = 0$</th>
<th>$d_{t-1} = 1$</th>
<th>$d_{t-1} = 0$</th>
<th>$d_{t-1} = 1$</th>
<th>$d_{t-1} = 0$</th>
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<tr>
<td>-0.02</td>
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<tr>
<td>0.49</td>
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<tr>
<td>0.67</td>
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<td>362.9</td>
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<td>69.1</td>
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<tr>
<td>1.18</td>
<td>1911.3</td>
<td>1790.0</td>
<td>1834.0</td>
<td>1695.3</td>
<td>565.7</td>
<td>583.2</td>
</tr>
</tbody>
</table>

- increasing in productivity: selection
- $V^E > V^D$: sunk costs/LBE
- $MBE(d_{t-1} = 1) < MBE(d_{t-1} = 0)$: sunk R&D is overwhelmed by tech substitution ($\alpha_6$)
## Costs of Exporting and R&D (millions of NT dollars)

<table>
<thead>
<tr>
<th>$x_t$</th>
<th>Mean Exporting Costs&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mean R&amp;D Costs&lt;sup&gt;b&lt;/sup&gt;</th>
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</thead>
<tbody>
<tr>
<td>-0.02</td>
<td>Fixed 1.61</td>
<td>Sunk 1.80</td>
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<tr>
<td>0.67</td>
<td>8.50</td>
<td>21.06</td>
</tr>
<tr>
<td>1.18</td>
<td>10.67</td>
<td>43.54</td>
</tr>
</tbody>
</table>

**a.** For plants with $d_{t-1} = 1$

**b.** For plants with $e_t = 1$
Extensions of this framework (subject to better data):

- Quality improvement vs. cost reduction
- Industry Equilibrium
- Knowledge externality