DO BOARD INTERLOCKS INCREASE INNOVATION?
EVIDENCE FROM NATURAL EXPERIMENTS IN INDIA

Christian HELMERS §  Manasa PATNAM ‡  Raghavendra RAU ‡

§ Santa Clara University
‡ CREST (ENSAE)
‡ JBS, University of Cambridge
WHAT DO WE DO?

▶ Large literature on how knowledge is transmitted across companies both intentionally and unintentionally (Jaffe et al. 1993; Audretsch and Feldman 1996)
WHAT DO WE DO?

- Large literature on how knowledge is transmitted across companies both intentionally and unintentionally (Jaffe et al. 1993; Audretsch and Feldman 1996)
- But what is the mechanism through which information flows between companies?
- Specifically, what role do corporate networks play in information sharing?
WHAT DO WE DO?

- Large literature on how knowledge is transmitted across companies both intentionally and unintentionally (Jaffe et al. 1993; Audretsch and Feldman 1996)
- But what is the mechanism through which information flows between companies?
- Specifically, what role do corporate networks play in information sharing?
- Even more specifically: What is the impact of corporate network size on innovation and patenting?
WHAT DO WE DO?

- What is the impact of corporate network size on innovation and patenting?
- Effect of network size on
WHAT DO WE DO?

► What is the impact of corporate network size on innovation and patenting?

► Effect of network size on

  1. R&D investment (current and capital)
  2. Patenting (international & domestic)
WHAT DO WE DO?

- What is the impact of corporate network size on innovation and patenting?
- Effect of network size on
  1. R&D investment (current and capital)
  2. Patenting (international & domestic)
- Construct networks from director board interlocks among Indian listed companies
WHAT DO WE DO?

- What is the impact of corporate network size on innovation and patenting?
- Effect of network size on
  1. R&D investment (current and capital)
  2. Patenting (international & domestic)
- Construct networks from director board interlocks among Indian listed companies
- Identification through two natural experiments:
WHAT DO WE DO?

▶ What is the impact of corporate network size on innovation and patenting?

▶ Effect of network size on
  1. R&D investment (current and capital)
  2. Patenting (international & domestic)

▶ Construct networks from director board interlocks among Indian listed companies

▶ Identification through two natural experiments:
  ▶ Corporate governance reform to explore network size effect
    ▶ ITT effect: Required board restructuring that affects network size
What do we do?

- What is the impact of corporate network size on innovation and patenting?
- Effect of network size on
  1. R&D investment (current and capital)
  2. Patenting (international & domestic)
- Construct networks from director board interlocks among Indian listed companies
- Identification through two natural experiments:
  - Corporate governance reform to explore network size effect
    - ITT effect: Required board restructuring that affects network size
  - TRIPS patent reform that affects patentability for a subset of peer firms
    - Mechanisms of network size effect: Why does network size influence innovation and patenting?
WHAT DO WE DO?

- What is the impact of corporate network size on innovation and patenting?
- Effect of network size on
  1. R&D investment (current and capital)
  2. Patenting (international & domestic)
- Construct networks from director board interlocks among Indian listed companies
- Identification through two natural experiments:
  - Corporate governance reform to explore network size effect
  - ITT effect: Required board restructuring that affects network size
  - TRIPS patent reform that affects patentability for a subset of peer firms
  - Mechanisms of network size effect: Why does network size influence innovation and patenting?
- We find:
  - Positive effect of network size on short-term R&D and patenting
  - Positive peer effects from networked firm on R&D
**WHY SHOULD WE CARE?**

- Literature on inter-*firm* networks and innovation/patenting
  - Strategic alliances (Schilling & Phelps, 2007)
  - (In)formal research collaboration (Hagedoorn et al., 2000)
  - Business groups (Belenzon & Berkovitz, 2010)
Why should we care?

- Literature on inter-firm networks and innovation/patenting
  - Strategic alliances (Schilling & Phelps, 2007)
  - (In)formal research collaboration (Hagedoorn et al., 2000)
  - Business groups (Belenzon & Berkovitz, 2010)
- Another direct measure: interlocking boards of directors
**WHY SHOULD WE CARE?**

- Literature on inter-	extbf{firm} networks and innovation/patenting
  - Strategic alliances (Schilling & Phelps, 2007)
  - (In)formal research collaboration (Hagedoorn et al., 2000)
  - Business groups (Belenzon & Berkovitz, 2010)

- Another direct measure: interlocking boards of directors

- Role of directors:
  - Provision of information & advice to CEO and top management
  - Influence corporate strategy
  - Decide on Intellectual Property policy & strategy
WHY SHOULD WE CARE?
WHY SHOULD WE CARE?

- Literature on board interlocks:
  - Motivation for board interlocks (Mizruchi, 1996)
  - Profitability (Baysinger and Butler, 1985; Burt, 1983)
  - CEO pay (Guedj and Barnea, 2009)
  - Mutual fund/Private equity investment (Cohen et al., 2008; Stuart and Yim, 2010)
  - Venture capital firm performance (Hochberg et al., 2007)
Why should we care?

- Literature on board interlocks:
  - Motivation for board interlocks (Mizruchi, 1996)
  - Profitability (Baysinger and Butler, 1985; Burt, 1983)
  - CEO pay (Guedj and Barnea, 2009)
  - Mutual fund/Private equity investment (Cohen et al., 2008; Stuart and Yim, 2010)
  - Venture capital firm performance (Hochberg et al., 2007)

- Channel for information transmission between companies
IDENTIFICATION OF NETWORK SIZE EFFECT: SUMMARY

- **Objective:** analyze impact of firm (board) network size on patenting and R&D expenditure

- **Challenge:** Endogeneity of network formation
  - Endogeneity of network size
IDENTIFICATION OF NETWORK SIZE EFFECT: SUMMARY

- **Objective:** analyze impact of firm (board) network size on patenting and R&D expenditure

- **Challenge:** Endogeneity of network formation
  - Endogeneity of network size

- **Solution:** Corporate governance reform: subset of listed firms forced to re-structure boards
  - Exploit change in network size induced by restructuring
Identification of Network Size Effect: Reform

- Year 2001: Security and Exchange Board of India (SEBI) introduced changes to Clause 49.
IDENTIFICATION OF NETWORK SIZE EFFECT: REFORM

- Year 2001: Security and Exchange Board of India (SEBI) introduced changes to Clause 49
- Required changes in the composition of the board of directors:
  - Combination of executive and non-executive directors with \( \geq 50\% \) non-executive directors
Identification of Network Size Effect: Reform

- Year 2001: Security and Exchange Board of India (SEBI) introduced changes to Clause 49

- Required changes in the composition of the board of directors:
  - Combination of executive and non-executive directors with ≥50% non-executive directors

- Reform not applicable to all listed companies
IDENTIFICATION OF NETWORK SIZE EFFECT: REFORM

- ‘Eligible’ firms (based on net-worth or paid-up share capital):
  - Group ‘A’ (comply by March 2001): paid up share capital of $\geq$ Rs. 25 crores
  - Group ‘B’ (comply by March 2002): paid up share capital of Rs. 10 crores $\geq$ Rs. 25 crores
  - Group ‘C’ (comply by March 2003): paid up share capital of Rs. 3 crores $\geq$ Rs. 10 crores

- ‘Non-eligible’ firms:
  - Firms with paid up share capital of <$ Rs. 3 crores at any time in history of entity were not required to comply
  - Effective implementation only in 2003 (penalties for violations only in 2003)
  - In our analysis: phased ‘compliance period’ (by A, B and C)
IDENTIFICATION OF NETWORK SIZE EFFECT: REFORM

- ‘Eligible’ firms (based on net-worth or paid-up share capital):
  - Group ‘A’ (comply by March 2001): paid up share capital of ≥ Rs. 25 crores
  - Group ‘B’ (comply by March 2002): paid up share capital of Rs. 10 crores ≥ Rs. 25 crores
  - Group ‘C’ (comply by March 2003): paid up share capital of Rs. 3 crores ≥ Rs. 10 crores

- ‘Non-eligible’ firms:
  - Firms with paid up share capital of < Rs 3 crores at any time in history of entity were not required to comply
IDENTIFICATION OF NETWORK SIZE EFFECT: REFORM

- ‘Eligible’ firms (based on net-worth or paid-up share capital):
  - Group ‘A’ (comply by March 2001): paid up share capital of $\geq$ Rs. 25 crores
  - Group ‘B’ (comply by March 2002): paid up share capital of Rs. 10 crores $\geq$ Rs. 25 crores
  - Group ‘C’ (comply by March 2003): paid up share capital of Rs. 3 crores $\geq$ Rs. 10 crores

- ‘Non-eligible’ firms:
  - Firms with paid up share capital of $<\ Rs 3$ crores at any time in history of entity were not required to comply

- Effective implementation only in 2003 (penalties for violations only in 2003)
IDENTIFICATION OF NETWORK SIZE EFFECT: REFORM

- ‘Eligible’ firms (based on net-worth or paid-up share capital):
  - Group ‘A’ (comply by March 2001): paid up share capital of ≥ Rs. 25 crores
  - Group ‘B’ (comply by March 2002): paid up share capital of Rs. 10 crores ≥ Rs. 25 crores
  - Group ‘C’ (comply by March 2003): paid up share capital of Rs. 3 crores ≥ Rs. 10 crores

- ‘Non-eligible’ firms:
  - Firms with paid up share capital of < Rs 3 crores at any time in history of entity were not required to comply

- Effective implementation only in 2003 (penalties for violations only in 2003)

- In our analysis: phased ‘compliance period’ (by A, B and C)
IDENTIFICATION OF NETWORK SIZE EFFECT

- Exploit differential impact of reform applicable to a subset of eligible firms
IDENTIFICATION OF NETWORK SIZE EFFECT

- Exploit differential impact of reform applicable to a subset of eligible firms

- Firms that did not meet the board structure requirement before the reform period had to restructure
IDENTIFICATION OF NETWORK SIZE EFFECT

- Exploit differential impact of reform applicable to a subset of eligible firms

- Firms that did not meet the board structure requirement before the reform period had to restructure
IDENTIFICATION OF NETWORK SIZE EFFECT

- Identifying instrument interaction of:
IDENTIFICATION OF NETWORK SIZE EFFECT

- Identifying instrument interaction of:
  - An eligible firm ($E_i$)
  - Reform period ($R_t$) (varies by listing group)
  - And firms that were below board structure requirement prior to the reform ($B_i$)
IDENTIFICATION OF NETWORK SIZE EFFECT

- Identifying instrument interaction of:
  - An eligible firm ($E_i$)
  - Reform period ($R_t$) (varies by listing group)
  - And firms that were below board structure requirement prior to the reform ($B_i$)

- Control for direct effect of reform shock and eligibility on outcome:
  - Account for potential direct effect of reform (Dharmapala & Khanna)
  - Account for size-based eligibility
EMPIRICAL SPECIFICATION

- Naive specification:

\[ y_{it} = \alpha + \beta N_{it} + \gamma x_{it} + \mu_i + \gamma_t + u_{it} \]  

- \( y_{it} \) firm specific outcome measure: patents/R&D
- \( N \) corporate network size
- Above spec. subject to endogeneity
Empirical Specification

- Naive specification:

\[ y_{it} = \alpha + \beta N_{it} + \gamma x_{it} + \mu_i + \gamma t + u_{it} \]  

  - \( y_{it} \) firm specific outcome measure: patents/R&D
  - \( N \) corporate network size
  - Above spec. subject to endogeneity

- IV approach exploiting reform:

\[ N_{it} = \alpha (B_i \times E_i \times R_t) + \gamma^f x_{it} + \mu_i^f + \varsigma^f t + \eta_{it} \]  

\[ y_{it} = \beta \hat{N}_{it} + \gamma x_{it} + \mu_i + \varsigma t + u_{it} \]  

- ITT: Triple interaction term \((B_i \times E_i \times R_t)\) identifying instrument
EMPIRICAL SPECIFICATION

- Alternative Strategy: Exploit requirement thresholds, RDD approach; two thresholds:
  - Board structure threshold: \( PROP_{it} \) as the observed proportion of non-executives
    - \( B_{it} \): whether firm was below the required board composition criteria
  - Listing Categories threshold: \( MP_{i} \) amount of paidup share capital for a given firm
    - \( MP_{i}^A \) and \( MP_{i}^B \): firm is group A or a group B firm
EMPIRICAL SPECIFICATION

- Alternative Strategy: Exploit requirement thresholds, RDD approach; two thresholds:
  - Board structure threshold: $PROP_{it}$ as the observed proportion of non-executives
    - $B_{it}$: whether firm was below the required board composition criteria
  - Listing Categories threshold: $MP_i$ amount of paidup share capital for a given firm
    - $MP_i^A$ and $MP_i^B$: firm is group A or a group B firm
  - Can rewrite first-stage as RDD spec.:
    \[
    N_{it} = \alpha_{1}^{ITT} (B_{it} \times MP_i^A) + \alpha_{2}^{ITT} (B_{it} \times MP_i^B) + \alpha_{3}^{ITT} (B_{it}) + \alpha_{4}^{ITT} (MP_i^A) + \alpha_{5}^{ITT} (MP_i^B)
    \]
    Instruments
    \[
    + f_B(PROP_{it}, \gamma_1) + f_{MP}(MP_{it}, \gamma_2) + f_{B,MP}(PROP_{it} \times MP_i, \gamma_3) + \varsigma t + \eta_{it}
    \]
    Conditioning Polynomials
COMPANY INFORMATION

- Accounting Data from Prowess:
  - Panel of all listed Indian private sector firms (BSE & NSE) 1997-2008
  - CMIE classification of firms into group and non-group firms
  - Industry Affiliation by NIC classification
COMPANY INFORMATION

▶ Accounting Data from Prowess:
  ▶ Panel of all listed Indian private sector firms (BSE & NSE) 1997-2008
  ▶ CMIE classification of firms into group and non-group firms
  ▶ Industry Affiliation by NIC classification

▶ Corporate Networks:
  ▶ Prowess: Detailed information on all directors on board (dynamic)
BACKGROUND: INDIAN PATENT SYSTEM

- 2 significant changes in opposite directions since 1947
BACKGROUND: INDIAN PATENT SYSTEM

- 2 significant changes in opposite directions since 1947

- 1970 Patents Act: no patentability of pharmaceutical *products* (although *process* patentable)

- 1995 WTO accession and TRIPS: 3 major amendments to the 1970 Patents Act
BACKGROUND: INDIAN PATENT SYSTEM

- 2 significant changes in opposite directions since 1947

- 1970 Patents Act: no patentability of pharmaceutical *products* (although *process* patentable)

- 1995 WTO accession and TRIPS: 3 major amendments to the 1970 Patents Act

- Allowed pharmaceutical product patents — but 10-year transition period

- Between 1995-2005 pharmaceutical product patent applications through ‘pipeline’ system
PATENT DATA

- Patent filings by Indian residents
**Patent data**

- Patent filings by Indian residents
- International filings (USPTO & EPO): EPO PATSTAT
Patent data

- Patent filings by Indian residents
- International filings (USPTO & EPO): EPO PATSTAT
- Serious under-reporting in PATSTAT of Indian filings
PATENT DATA

- Patent filings by Indian residents
- International filings (USPTO & EPO): EPO PATSTAT
- Serious under-reporting in PATSTAT of Indian filings
- Indian filings:
  - 1995-2004 *EKASWA* (Gazette) by Patent Facilitating Centre (PFC)
  - 2005-2008 *iPairs* (Journal) online search facility by CGPDT
  - Complement with *BigPatents India*
VARIABLES

- Variables - Outcome:
  - International patent filings: USPTO & EPO
  - Domestic patent filings: CGPDT
  - R&D Expenditure: Total outlay of the company on research and development during the year on both its current and capital account.
VARIABLES

- Variables - Outcome:
  - International patent filings: USPTO & EPO
  - Domestic patent filings: CGPDT
  - R&D Expenditure: Total outlay of the company on research and development during the year on both its current and capital account.
**VARIABLES**

- **Variables - Outcome:**
  - International patent filings: USPTO & EPO
  - Domestic patent filings: CGPDT
  - R&D Expenditure: Total outlay of the company on research and development during the year on both its current and capital account.

- Firm level controls: Assets, Exports/Sales
- Business group: Patenting propensity
- Industry: Patenting propensity
## First Stage Explanation

### Network Size Changes

<table>
<thead>
<tr>
<th></th>
<th>Total Network Size</th>
<th>Network gain from</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre Reform (1)</td>
<td>Post reform (2)</td>
</tr>
<tr>
<td>Above Threshold</td>
<td>7.138</td>
<td>12.268</td>
</tr>
<tr>
<td>Below Threshold</td>
<td>5.649</td>
<td>10.094</td>
</tr>
<tr>
<td>Difference</td>
<td><strong>1.489</strong></td>
<td><strong>2.174</strong></td>
</tr>
</tbody>
</table>
**FIRST STAGE EXPLANATION**

## Network Size Changes

<table>
<thead>
<tr>
<th></th>
<th>Total Network Size</th>
<th>Network gain from hires - fires</th>
<th>remaining (Post-Pre) difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre Reform (1)</td>
<td>Post reform (2)</td>
<td></td>
</tr>
<tr>
<td>Above Threshold</td>
<td>7.138</td>
<td>12.268</td>
<td>0.091</td>
</tr>
<tr>
<td>Below Threshold</td>
<td>5.649</td>
<td>10.094</td>
<td>0.117</td>
</tr>
<tr>
<td>Difference</td>
<td>1.489**</td>
<td>2.174**</td>
<td>-0.026</td>
</tr>
</tbody>
</table>
### Results: First Stage Validity

**Balancing Test**

Average firm-level characteristics for firms appointing directors post-reform

<table>
<thead>
<tr>
<th></th>
<th>Below required proportion</th>
<th>Above required proportion</th>
<th>t-statistic</th>
<th>Wilcoxon z-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D (log)</td>
<td>0.222</td>
<td>0.251</td>
<td>1.196</td>
<td>1.474</td>
</tr>
<tr>
<td>Current R&amp;D</td>
<td>0.180</td>
<td>0.198</td>
<td>0.838</td>
<td>1.600</td>
</tr>
<tr>
<td>Capital R&amp;D</td>
<td>0.074</td>
<td>0.088</td>
<td>1.128</td>
<td>1.228</td>
</tr>
<tr>
<td>Total Patent Count</td>
<td>0.226</td>
<td>0.230</td>
<td>0.048</td>
<td>-0.275</td>
</tr>
<tr>
<td>Domestic Patent Count</td>
<td>0.189</td>
<td>0.196</td>
<td>-0.114</td>
<td>-0.634</td>
</tr>
<tr>
<td>International Patent Count</td>
<td>0.029</td>
<td>0.040</td>
<td>0.418</td>
<td>-0.563</td>
</tr>
<tr>
<td>Patent Propensity (total)</td>
<td>0.150</td>
<td>0.222</td>
<td>0.775</td>
<td>-0.266</td>
</tr>
<tr>
<td>Patent Propensity (domestic)</td>
<td>0.142</td>
<td>0.209</td>
<td>0.727</td>
<td>-0.780</td>
</tr>
<tr>
<td>Patent Propensity (int.)</td>
<td>0.007</td>
<td>0.012</td>
<td>0.707</td>
<td>0.785</td>
</tr>
<tr>
<td>Assets (log)</td>
<td>4.486</td>
<td>4.453</td>
<td>-0.384</td>
<td>0.182</td>
</tr>
<tr>
<td>Exports by sales (log)</td>
<td>0.104</td>
<td>0.094</td>
<td>-0.905</td>
<td>0.562</td>
</tr>
</tbody>
</table>
## Results: R&D expenditure

<table>
<thead>
<tr>
<th></th>
<th>(1) R&amp;D (OLS)</th>
<th>(2) Network Size (IV I)</th>
<th>(3) R&amp;D (IV II)</th>
<th>(4) Current R &amp; D (IV II)</th>
<th>(5) Capital R&amp;D (IV II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Size</td>
<td>0.002**</td>
<td></td>
<td>0.009</td>
<td>0.014**</td>
<td>0.002</td>
</tr>
<tr>
<td>(0.001)</td>
<td></td>
<td>(0.006)</td>
<td>(0.005)</td>
<td>(0.004)</td>
<td>(0.003)</td>
</tr>
<tr>
<td>Reform × Below Threshold</td>
<td></td>
<td></td>
<td>-2.680**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixed Effects</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>11,358</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First-Stage F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## RESULTS: R&D expenditure

<table>
<thead>
<tr>
<th></th>
<th>(1) R&amp;D (OLS)</th>
<th>(2) Network Size (IV I)</th>
<th>(3) R&amp;D (IV II)</th>
<th>(4) Current R &amp; D (IV II)</th>
<th>(5) Capital R&amp;D (IV II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Size</td>
<td>0.002**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reform × Below Threshold</td>
<td></td>
<td>-2.680***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.555)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>11,358</td>
<td>11,358</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First-Stage F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Results: R&D Expenditure

<table>
<thead>
<tr>
<th></th>
<th>(1) R&amp;D (OLS)</th>
<th>(2) Network Size (IV I)</th>
<th>(3) R&amp;D (IV II)</th>
<th>(4) Current R &amp; D (IV II)</th>
<th>(5) Capital R&amp;D (IV II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Size</td>
<td>0.002**</td>
<td>0.009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.006)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reform × Below Threshold</td>
<td>-2.680***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.555)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>11,358</td>
<td>11,358</td>
<td>11,358</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First-Stage F</td>
<td></td>
<td></td>
<td></td>
<td>23.27</td>
<td></td>
</tr>
</tbody>
</table>
## RESULTS: R&D EXPENDITURE

<table>
<thead>
<tr>
<th>Source</th>
<th>(1) R&amp;D Network Size (OLS)</th>
<th>(2) R&amp;D Network Size (IV I)</th>
<th>(3) R&amp;D Current R &amp; D Capital (IV II)</th>
<th>(4) R&amp;D Capital R&amp;D (IV II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Size</td>
<td>0.002**</td>
<td>0.009</td>
<td>0.014**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.006)</td>
<td>(0.005)</td>
<td></td>
</tr>
<tr>
<td>Reform × Below Threshold</td>
<td></td>
<td>-2.680***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.555)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>N</td>
<td>11,358</td>
<td>11,358</td>
<td>11,358</td>
<td>11,358</td>
</tr>
<tr>
<td>First-Stage F</td>
<td></td>
<td></td>
<td>23.27</td>
<td>23.27</td>
</tr>
</tbody>
</table>
## Results: R&D expenditure

<table>
<thead>
<tr>
<th></th>
<th>(1) R&amp;D (OLS)</th>
<th>(2) Network Size (IV I)</th>
<th>(3) R&amp;D (IV II)</th>
<th>(4) Current R &amp; D (IV II)</th>
<th>(5) Capital R&amp;D (IV II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Size</td>
<td>0.002**</td>
<td>0.009</td>
<td>0.014**</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.006)</td>
<td>(0.005)</td>
<td>(0.004)</td>
<td></td>
</tr>
<tr>
<td>Reform × Below Threshold</td>
<td>-2.680***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.555)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>N</td>
<td>11,358</td>
<td>11,358</td>
<td>11,358</td>
<td>11,358</td>
<td>11,358</td>
</tr>
<tr>
<td>First-Stage F</td>
<td>23.27</td>
<td>23.27</td>
<td>23.27</td>
<td>23.27</td>
<td>23.27</td>
</tr>
</tbody>
</table>
## RESULTS: PATENTS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(OLS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Size</td>
<td>0.013*</td>
<td>0.093*</td>
<td>0.058</td>
<td>0.035**</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
<td>(0.055)</td>
<td>(0.039)</td>
<td>(0.017)</td>
</tr>
<tr>
<td>Reform × Below Threshold</td>
<td>-2.680***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.555)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Firm Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>11,358</td>
<td>11,358</td>
<td>11,358</td>
<td>11,358</td>
</tr>
<tr>
<td>First-Stage F</td>
<td>23.27</td>
<td>23.27</td>
<td>23.27</td>
<td>23.27</td>
</tr>
</tbody>
</table>

**Notes:**
- Standard errors are in parentheses.
- ***p < 0.01, **p < 0.05, *p < 0.10.
# Results: RDD Results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Size</td>
<td>0.030***</td>
<td>0.027***</td>
<td>0.083**</td>
<td>0.053*</td>
<td>0.030**</td>
</tr>
<tr>
<td></td>
<td>(0.005)</td>
<td>(0.004)</td>
<td>(0.042)</td>
<td>(0.029)</td>
<td>(0.015)</td>
</tr>
<tr>
<td>Polynomials Net Worth (Eligibility)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Polynomials Prop. NE (Requirement)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Polynomials Eligibility × Requirement</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>$N$</td>
<td>13,773</td>
<td>13,773</td>
<td>13,773</td>
<td>13,773</td>
<td>13,773</td>
</tr>
<tr>
<td>First-Stage F</td>
<td>24.577</td>
<td>24.577</td>
<td>24.577</td>
<td>24.577</td>
<td>24.577</td>
</tr>
</tbody>
</table>
NETWORK SIZE: MECHANISMS

- How does network size affect innovation: Peer Effects?
Network Size: Mechanisms

- How does network size affect innovation: Peer Effects?

\[ y_{it} = \alpha + \beta \bar{y}_{jt-1}^N + \gamma x_{it} + \mu_i + \gamma t + u_{it} \]

- Exploit TRIPS reform which affected patentability for pharmaceutical firms
**Network Size: Mechanisms**

- How does network size affect innovation: Peer Effects?

\[
y_{it} = \alpha + \beta \bar{y}_{jt-1}^N + \gamma x_{it} + \mu_i + \gamma_t + u_{it}
\]

- Exploit TRIPS reform which affected patentability for pharmaceutical firms
- Peer effect \(\bar{y}_{jt-1}^N\) is endogenous but can be predicted, instrument using:
  
  \(\text{TRIPS} \times \text{Clause 49A reform} \times \text{Proportion of Pharma firms in peer group}\)
**NETWORK SIZE: MECHANISMS**

- How does network size affect innovation: Peer Effects?

\[ y_{it} = \alpha + \beta \bar{y}_{jt-1} + \gamma x_{it} + \mu_i + \gamma_t + u_{it} \]

- Exploit TRIPS reform which affected patentability for pharmaceutical firms

- Peer effect \( \bar{y}_{jt-1} \) is endogenous but can be predicted, instrument using:

  \[ \text{TRIPS} \times \text{Clause 49A reform} \times \text{Proportion of Pharma firms in peer group} \]

  Instrument ↑

  ↓

  \( \bar{y}_{jt-1} \) ↑
Network Size: Mechanisms

- How does network size affect innovation: Peer Effects?

\[ y_{it} = \alpha + \beta \bar{y}_{jt-1} + \gamma x_{it} + \mu_i + \gamma_t + u_{it} \]

- Exploit TRIPS reform which affected patentability for pharmaceutical firms

- Peer effect \( \bar{y}_{jt-1} \) is endogenous but can be predicted, instrument using:
  
  \[ \text{TRIPS} \times \text{Clause 49A reform} \times \text{Proportion of Pharma firms in peer group} \]

  Instrument ↑

  ↓

  \( \bar{y}_{jt-1} \) ↑

- Results show that

- A 1% increase in network average R&D increases own firm’s R&D by 1.051%
NETWORK EFFECTS: INNOVATION OR STRATEGY

- Two competing explanations
  - Innovation Effect: Transmission of genuinely new knowledge
  - Strategic Effect: Patenting an existing innovation

To examine this:
- Patent Equivalents: filing existing patents in different countries
  - An increase in network size leads to the filing foreign patent on an existing domestic patent
- However, current R&D is also affected by network:
  - Exploratory in nature so part of the effect could also be innovation driven
  - Analysis of long-run data needed to explore this issue further (beyond the scope of this paper)
Two competing explanations

- Innovation Effect: Transmission of genuinely new knowledge
- Strategic Effect: Patenting an existing innovation

To examine this:

- Patent Equivalents: filing existing patents in different countries
**NETWORK EFFECTS: INNOVATION OR STRATEGY**

- Two competing explanations
  - Innovation Effect: Transmission of genuinely new knowledge
  - Strategic Effect: Patenting an existing innovation

- To examine this:
  - Patent Equivalents: filing existing patents in different countries
    - An increase in network size leads to the filing foreign patent on an existing domestic patent
NETWORK EFFECTS: INNOVATION OR STRATEGY

- Two competing explanations
  - Innovation Effect: Transmission of genuinely new knowledge
  - Strategic Effect: Patenting an existing innovation

- To examine this:
  - Patent Equivalents: filing existing patents in different countries
    - An increase in network size leads to the filing of a foreign patent on an existing domestic patent
  - However, current R&D is also affected by network:
    - Exploratory in nature so part of the effect could also be innovation driven
NETWORK EFFECTS: INNOVATION OR STRATEGY

- Two competing explanations
  - Innovation Effect: Transmission of genuinely new knowledge
  - Strategic Effect: Patenting an existing innovation

- To examine this:
  - Patent Equivalents: filing existing patents in different countries
    - An increase in network size leads to the filing of foreign patents on an existing domestic patent
  - However, current R&D is also affected by network:
    - Exploratory in nature so part of the effect could also be innovation driven
NETWORK EFFECTS: INNOVATION OR STRATEGY

▶ Two competing explanations

▶ Innovation Effect: Transmission of genuinely new knowledge

▶ Strategic Effect: Patenting an existing innovation

▶ To examine this:

▶ Patent Equivalents: filing existing patents in different countries

▶ An increase in network size leads to the filing foreign patent on an existing domestic patent

▶ However, current R&D is also affected by network:

▶ Exploratory in nature so part of the effect could also be innovation driven

▶ Analysis of long-run data needed to explore this issue further (beyond the scope of this paper)
CONCLUSIONS

- Interlocking boards increase innovation and patenting.
CONCLUSIONS

- Interlocking boards increase innovation and patenting.

- The impact on R&D is attributable to an innovation effect induced by information transmission through interlocks.

- The effect on patenting is driven by a strategic effect.
CONCLUSIONS

- Interlocking boards increase innovation and patenting.
- The impact on R&D is attributable to an innovation effect induced by information transmission through interlocks.
- The effect on patenting is driven by a strategic effect.
- Firms are more likely to extend patent protection by patenting inventions abroad that they have already patented in India.