# Al and Firm performance: Evidence from Japan

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## Motivation

- Growing attention on AI, machine learning, ChatGPT, and their impacts on the performances of firms and economy
- Brynjolfsson, Rock, and Syverson, 2019
  - Despite the widening introduction of AI, productivity is stagnant.
  - Only some firms may be able to enjoy the positive impact of AI, while others may not.
  - It takes a longer time for AI to contribute to the productivity of the economy.
- Much concern on the impact of AI on Labor demand
  - Replacement effect (-) vs. Productivity effect (+)

## Motivation

- An increasing number of research investigates the economic impact of AI on firm performances.
  - Community Innovation Survey (Rammer et al. [2022], Europe)
  - Annual Business Survey (Zolas et al. [2018], US)
  - Firm Survey (Czarnitzki et al. [2023], Germany)
  - Information on patents (e.g. Yang [2022], Taiwan, Silva Marioni et al. [2024], 15 European Countries)
- This study utilizes
  - Patent data
  - Inter-firm transaction relation data
  - Press release data
  - to figure out AI technology and introduction of it
  - to research the impact of AI on
    - Firm-level productivity
    - Labor demand
  - To study the spill-over effect of AI

#### Data

- Basic Survey of Japanese Business Structure and Activity (Ministry of Economy, Trade and Industry)
  - all the firms in manufacturing, trade, and some service industry
  - with 50+ employees and 30+ mill. Yen of capital
  - 1991, 1994~2019
- IIP patent database (Institute of Intellectual Property)
  - All the patents applied in Japan between 1960~2018
  - Information on the applicant, inventor, technology field, and citation
- TSR (Tokyo Shoko Research)
  - Inter-firm relationship on transaction and equity holding
  - Reports transaction partners up to 30
    - => Construct data from the customer side and supplier side
  - 2007~2021

## What is AI? How to figure out AI?



Application

Aria

(2) Al-applied inventions: Technologies such as image processing, speech processing, natural language processing, device control/robotics, diagnosis/detectio n/prediction/optimi zation systems, etc. X Inventions characterized by the application of Al core inventions

## How to figure out AI?

- AI invention = the patent application of A | B | C
- Set A: IPC, classified to <u>G06N</u> (Computer system based on specific calculation model)
- Set B: Classified to the Al-related
   <u>File Index</u>
- Set C: Al-related <u>Keywords</u> in the abstract or descriptions of the patent application (Keywords from Methodology in *WIPO Technology Trends Artificial Intelligence*)



## Set B using FI (File Index)

#### 45 Tech fields for Al Set B

Examples

XA unique patent classification adopted by the Japanese Patent Office for the purpose of facilitating the use of IPC

XAn example of IPC classification: "G" is for section, "06" is for class, "N" is for subclass, and "17/30" is for group

| AI-related FI   | Description  |
|-----------------|--|
| A61B1/045,614   | Machine learning, data mining or statistical analysis, e.g.          |
|                 | Extracting lesions using artificial intelligence; extracting lesions |
|                 | by cluster analysis  |
| B23Q15/00,301@C | Knowledge accumulation, programming by inference                     |
| B60T8/174       | Characterized by the use of special control theories, e.g. Fuzzy     |
|                 | theory   |
| F02D41/14,310@H | Learning control   |
| F24H1/10,302@N  | Fuzzy control, e.g. Neural nets                                      |
| G05B13/02@L     | Learning control   |
| G05B13/02@M     | AI, using inference  |
| G05B13/02@N     | Fuzzy control  |
| G05B19/4155@V   | Inference, learning  |
| G06F7/02,630    | Adaptation, e.g. Self-learning                                       |
| G06F11/14,676   | In neural nets   |
| G06F11/22,657   | Those that use expert systems  |

## Set C using keywords for AI

- machine-learning
- (learning+algorithm+learning+model)
- (supervised+supervised+supervised),(learning+training+training)
- (unsupervised+unsupervised),(learning+training+training)
- (semi-supervised+semi-supervised+semi-supervised+semisupervised),(Learning+Training+Training)
- (neural+neural),(net+network)
- multilayer,perceptron
- neocognitron
- (connectionist+connectionism)
- back, propagation
- (over-fitting+over-learning+over-fitting+over-learning)
- (sigmoid+activation), function
- (deep+deep),(learning+learning+learning)

• • • •

## International comparison

### Patent applications classified into G06N



## Al related patent application in Japan



## Matched patent (BSJBSA & AI and non-AI patent app.)



## What impact of AI (mechanism)

- 1. of AI for the own production
  - mainly developed in-house (←patent)
  - to enhance productivity
- 2. of AI for a product
  - mainly developed in-house (
     —patent)
  - Al-imbedded products => enhance price
  - e.g. self-driving cars, Al-supported database (Oracle, Amazon), Al-supported software (Microsoft)
- 3. of AI as a product
  - mainly developed in-house (
     —patent)
  - Al itself is a product => enhance price
  - e.g. ChatGPT, DeepL, Google Bard
- 4. of AI as a business tool
  - mainly introduced from outside (
     —patent)
  - to enhance productivity
  - Firms introducing AI-supported database software from e.g. Oracle, DeepL

## **Productivity index**

#### TFP (Total Factor Productivity) index following Good, Nadiri and Sickles (1997)

$$\ln TFP_{f,t} = \left(\ln Q_{f,t} - \overline{\ln Q_{f,t}}\right) - \sum_{i} \frac{1}{2} \left(S_{f,i,t} + \overline{S_{i,t}}\right) \left(\ln X_{f,i,t} - \overline{\ln X_{i,t}}\right), \quad for \ t = 1994,$$

$$\ln TFP_{f,t} = \left(\ln Q_{f,t} - \overline{\ln Q_t}\right) - \sum_{i} \frac{1}{2} \left(S_{f,i,t} + \overline{S_{i,t}}\right) \left(\ln X_{f,i,t} - \overline{\ln X_{i,t}}\right) + \sum_{s=1}^{t} \left(\overline{\ln Q_s} - \overline{\ln Q_{s-1}}\right) - \sum_{s=1}^{t} \sum_{i} \frac{1}{2} \left(\overline{S_{i,s}} + \overline{S_{i,s-1}}\right) \left(\overline{\ln X_{i,s}} - \overline{\ln X_{i,s-1}}\right) \quad for \ t \ge 1995.$$

Q: Gross output, S: cost share, X: Inputs (capital, labor, and intermediate input)

## Summary of TFP

-

 Firms without patent < with patent < with AI patent < with core-AI patent

| InTFP                           | Obs     | Mean   | Std. dev. | Min    | Max   |
|---------------------------------|---------|--------|-----------|--------|-------|
|                                 |         |        |           |        |       |
| 3SJBSA                          | 716,678 | -0.018 | 0.250     | -3.587 | 1.496 |
| firms with patent application   | 297,760 | 0.050  | 0.206     | -2.317 | 1.496 |
| with AI patent application      | 16,369  | 0.159  | 0.228     | -1.238 | 1.437 |
| with Al-core patent application | 6,965   | 0.199  | 0.242     | -1.238 | 1.277 |
|                                 |         |        |           |        |       |
|                                 |         |        |           |        |       |

firms with press release

| on Productivity                  | In(cum |
|----------------------------------|--------|
| <ul> <li>Fixed effect</li> </ul> | In(cu  |
| estimation                       |        |

 AI contributes to the productivity

 Al patent contributes to productivity more than non-Al patent

 Similar to Yang (2022)

|  | InTFP, t                        |                                 |                                 |                                 |                                 |                                 |
|--|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|  | (1)                             | (2)                             | (3)                             | (4)                             | (5)                             | (6)                             |
| In(cumulated # pat. App. Non-Al, t-1)        |                                 |                                 |                                 | <b>0.00562***</b>               |                                 |                                 |
| In(cumulated # pat. App. AI, t-1)            | <b>0.0290***</b><br>[0.00287]   |                                 |                                 | 0.0259***<br>[0.00289]          |                                 |                                 |
| In(cumulated # citation, Non-AI, t-1)        |                                 |                                 |                                 |                                 | 0.00465***<br>[0.000551]        |                                 |
| In(cumulated # citation, AI, t-1)            |                                 | <b>0.0159***</b><br>[0.00194]   |                                 |                                 | <b>0.0144***</b> [0.00195]      |                                 |
| In(5-year cumulated # citation, Non-AI, t-1) |                                 |                                 |                                 |                                 |                                 | 0.00918***<br>[0.000576]        |
| In(5-year cumulated # citation, AI, t-1)     |                                 |                                 | 0.0219***<br>[0.00233]          |                                 |                                 | <b>0.0176***</b><br>[0.00234]   |
| In(#employee、t-1)                            | -0.0242***<br>[0.00101]         | - <b>0.0242***</b><br>[0.00101] | - <b>0.0242***</b><br>[0.00101] | - <b>0.0251***</b><br>[0.00102] | - <b>0.0249***</b><br>[0.00101] | - <b>0.0255***</b><br>[0.00101] |
| In(R&D、t-1)                                  | <b>0.00149***</b><br>[0.000259] | 0.00150***<br>[0.000259]        | <b>0.00149***</b><br>[0.000259] | 0.00130***<br>[0.000260]        | 0.00134***<br>[0.000259]        | 0.00114***<br>[0.000260]        |
| Foreign capital ratio, t-1                   | <b>0.0472***</b><br>[0.00381]   | <b>0.0477***</b><br>[0.00381]   | <b>0.0473***</b><br>[0.00381]   | <b>0.0467***</b><br>[0.00381]   | <b>0.0471***</b><br>[0.00381]   | <b>0.0461***</b><br>[0.00381]   |
| In(Firm age, t)                              | <b>0.0710***</b><br>[0.00270]   | <b>0.0709***</b><br>[0.00270]   | <b>0.0711***</b><br>[0.00270]   | <b>0.0670***</b><br>[0.00275]   | <b>0.0676***</b><br>[0.00273]   | <b>0.0662***</b><br>[0.00272]   |
| Observation                                  | 251,675                         | 251,675                         | 251,675                         | 251,675                         | 251,675                         | 251,675                         |
| Adj. R2                                      | 0.063                           | 0.063                           | 0.063                           | 0.063                           | 0.063                           | 0.064                           |
| ρ  | 0.741                           | 0.742                           | 0.742                           | 0.738                           | 0.738                           | 0.736                           |
| Av. Group size                               | 12.2                            | 12.2                            | 12.2                            | 12.2                            | 12.2                            | 12.2                            |

## on Productivity after 2009

| <ul> <li>After financial</li> </ul>  |
|--------------------------------------|
| crisis                               |
| <ul> <li>Stronger impacts</li> </ul> |
| of AI on                             |
| productivity after                   |
| 2009                                 |

 partly explain the recent surge of AI patent

|  | (1)        | (2)        |
|--|------------|------------|
|  |            |            |
| In(#employee、t-1)                        | -0.0241*** | -0.0241*** |
|  | [0.00101]  | [0.00101]  |
| In(R&D、t-1)                              | 0.00146*** | 0.00146*** |
|  | [0.000259] | [0.000259] |
| Foreign capital ratio, t-1               | 0.0444***  | 0.0446***  |
|  | [0.00381]  | [0.00381]  |
| In(Firm age, t)                          | 0.0730***  | 0.0729***  |
|  | [0.00271]  | [0.00271]  |
| In(cumulated # pat. App. Al, t-1)        | 0.00415**  |            |
|  | [0.00206]  |            |
| In(cumulated # pat. App. Al, t-1)        | 0.0137***  |            |
| ×1 (Year≥2009)                           | [0.000804] |            |
| In(5-year cumulated # citation, AI, t-1) |            | 0.00708*** |
|  |            | [0.00251]  |
| In(5-year cumulated # citation, AI, t-1) |            | 0.0156***  |
| ×1 (Year≥2009)                           |            | [0.000996] |
|  |            |            |
| Observation                              | 251,675    | 251,675    |
| Adj. R2                                  | 0.064      | 0.064      |
| ρ  | 0.744      | 0.743      |
| Av. Group size                           | 12.2       | 12.2       |

InTFP, t

|  |                                       |            | InTFP, t   |            |
|--|---------------------------------------|------------|------------|------------|
| on Productivity by   |                                       | Low TFP    | Medim TFP  | High TFP   |
| Office to the second se |                                       | (1)        | (2)        | (3)        |
| <ul> <li>Fixed effect</li> </ul>   | In(cumulated # pat. App. Non-Al, t-1) | 0.00828*** | 0.0106***  | 0.00302*** |
| estimation   |                                       | [0.00139]  | [0.000744] | [0.000867] |
| Commation  | In(cumulated # pat. App. Al, t-1)     | -0.0278**  | 0.0407***  | 0.0273***  |
| I ow productivity  |                                       | [0.0110]   | [0.00473]  | [0.00277]  |
|  | In(#employee、t-1)                     | 0.00652*** | -0.0170*** | -0.0354*** |
| firms may not  |                                       | [0.00183]  | [0.00115]  | [0.00141]  |
| opiov productivity   | In(R&D, t-1)                          | 0.000897*  | 0.00017    | 0.000526   |
| enjoy productivity-  |                                       | [0.000509] | [0.000280] | [0.000329] |
| enhancing effect   | Foreign capital ratio, t-1            | 0.0148     | 0.0154***  | 0.0365***  |
|  |                                       | [0.00992]  | [0.00500]  | [0.00403]  |
| OT AI  | In(Firm age, t)                       | 0.106***   | 0.0476***  | 0.0352***  |
| <ul> <li>Same results with _</li> </ul>  |                                       | [0.00645]  | [0.00332]  | [0.00321]  |
| oumulativa aitatian  | Observation                           | 67,351     | 85,320     | 99,004     |
| cumulative citation  | Adj. R2                               | 0.062      | 0.174      | 0.063      |
| or 5-vear citation   | ρ                                     | 0.658      | 0.588      | 0.649      |
| e. e jear entation   | Av. Group size                        | 5.3        | 5.4        | 7.0        |

High TFP

#### InTFP, t

Medium TFP

 Fixed effect estimation

 Low productivity firms may not enjoy productivityenhancing effect of Al

 Same results with cumulative citation or 5-year citation

|  | (1)                          | (2)                            | (3)                            |  |
|--|------------------------------|--------------------------------|--------------------------------|--|
| In(5-year cumulated # citation, Non-AI, t-1) | <b>0.0119***</b>             | <b>0.0121***</b>               | <b>0.00556***</b>              |  |
| In(5-year cumulated # citation, AI, t-1)     | -0.0314***                   | 0.0358***                      | 0.0204***                      |  |
| ln(#employee、t-1)                            | [0.00998]<br>0.00621***      | [0.00357]<br>-0.0169***        | [0.00225]<br>-0.0358***        |  |
| In(R&D, t-1)                                 | [0.00182]<br>0.000799        | [0.00115]<br>0.0000871         | [0.00141]<br>0.000365          |  |
| Foreign capital ratio, t-1                   | [0.000508]<br>0.014          | [0.000279]<br><b>0.0149***</b> | [0.000330]<br><b>0.0362***</b> |  |
| In(Firm age, t)                              | [0.00991]<br><b>0.106***</b> | [0.00499]<br><b>0.0492***</b>  | [0.00403]<br><b>0.0344***</b>  |  |
|  | [0.00641]                    | [0.00329]                      | [0.00318]                      |  |
| Observation                                  | 67,351                       | 85,320                         | 99,004                         |  |
| Adj. R2                                      | 0.063                        | 0.176                          | 0.064                          |  |
| ρ  | 0.660                        | 0.592                          | 0.647                          |  |
| Av. Group size                               | 5.3                          | 5.4                            | 7.0                            |  |

Low TFP

#### AI and firm performance

| -   | InT   | FP, t       |            |             |            |
|---|---|-------------|------------|-------------|------------|
| Transaction and S                           | Spill-over of Al                                      |             | Low TFP    | Medium TFP  | High TFP   |
|   |   | (1)         | (2)        | (3)         | (4)        |
| <ul> <li>If a firm's transaction</li> </ul> | In(cumulative patent app., non-Al, t-1)               | 0.00551***  | 0.00295    | 0.00854***  | 0.000976   |
| partner introduce AI,                       |   | [0.00198]   | [0.00405]  | [0.00170]   | [0.00246]  |
| is the firm's                               | In(cumulative patent app., Al, t-1)                   | 0.0132      | -0.0842*   | 0.00719     | 0.00292    |
| productivity                                |   | [0.00973]   | [0.0431]   | [0.00981]   | [0.00925]  |
| enhanced?                                   | In(cumulative patent app., Al, <b>supplier</b> , t-1) | 0.000666*   | 0.000612   | -0.000216   | -0.000238  |
| (by introducing AI-                         |   | [0.000396]  | [0.000766] | [0.000327]  | [0.000511] |
| supported software or                       | In(cumulative patent app., Al, <b>customer</b> , t-1) | 0.00032     | -0.000905  | 0.000828*** | 0.000835*  |
| production system)                          |   | [0.000355]  | [0.000641] | [0.000294]  | [0.000485] |
| • Weak positive spill-                      | ln(#employee, t-1)                                    | -0.0206***  | 0.0109***  | -0.0112***  | -0.0280*** |
| over from suppliers                         |   | [0.00217]   | [0.00390]  | [0.00198]   | [0.00315]  |
|   | In(R&D, t-1)  | -0.00184*** | -0.00189*  | -0.000401   | -0.000718  |
| <ul> <li>Positive spill-over</li> </ul>     |   | [0.000490]  | [0.00102]  | [0.000416]  | [0.000594] |
| from customers, but                         | Foreign capital ratio, t-1                            | 0.0257***   | 0.0162     | 0.000511    | 0.00565    |
| only to medium and                          |   | [0.00711]   | [0.0175]   | [0.00707]   | [0.00765]  |
| high TFP firms                              | In(Firm age, t)                                       | 0.0296***   | 0.00733    | 0.0102      | 0.00793    |
| • No identification as to                   |   | [0.00678]   | [0.0165]   | [0.00654]   | [0.00753]  |
| whether the firm                            |   |             |            |             |            |
| whether the firm the                        | Observation   | 89,062      | 25,174     | 30,551      | 33,337     |
| introduced AF from the                      | Adj. R2   | 0.093       | 0.122      | 0.387       | 0.066      |
| transaction partners.                       | ρ   | 0.817       | 0.692      | 0.639       | 0.732      |
|   | Av. Group size  | 6.2         | 3.5        | 3.2         | 4.0        |

## Al and Innovation using Press release data

- Price data not available => investigate the effect on innovation
- Data on new product announcements by companies:
  - Nihon Keizai Shimbun Press Release Database.
  - From December 13, 2016 to December 28, 2022.
  - Approximately 20,000 articles each year
  - Total of about 30,000 companies were matched with company data
- Follow Ikeuchi (2017) methodology: based on keywords
  - <u>Product innovation</u>: launch, commercialize, start offering, start selling, productize, launch, sell, launch, offer, service, open, commercialize, renew, renewal, change, improve, add, expand, enlarge, launch, enter, commercialize, launch, ship, publish
  - Process innovation: introduction, operation, build
  - <u>Technological innovation</u>: success, development, discovery, clarification, demonstration, practical application, prototype

## AI and Innovation

| Press release                          | ln(#prod. Inn.), t |          | In(#proc. Inn.), t |           |           | ln(#tech. inn), t |           |           |           |
|--|--------------------|----------|--------------------|-----------|-----------|-------------------|-----------|-----------|-----------|
|  | (1)                | (2)      | (3)                | (4)       | (5)       | (6)               | (7)       | (8)       | (9)       |
|  |                    |          |                    |           |           |                   |           |           |           |
| In(employee, t-1)                      | -0.0134            | 0.00157  | 0.00171            | 0.00774*  | 0.0102**  | 0.0103**          | -0.000857 | 0.00304   | 0.0031    |
|  | [0.0150]           | [0.0151] | [0.0151]           | [0.00454] | [0.00454] | [0.00454]         | [0.00689] | [0.00690] | [0.00690] |
| In(cum. Patent app., non-AI, t-1)      | 0.327***           |          |                    | 0.0709*** |           |                   | 0.0795*** |           |           |
|  | [0.0229]           |          |                    | [0.00693] |           |                   | [0.0105]  | _         |           |
| In(cum. Patent app., Al, t-1)          | 0.572***           |          |                    | 0.0841*** |           |                   | 0.164***  |           |           |
|  | [0.0308]           |          |                    | [0.00932] |           |                   | [0.0141]  | J         |           |
| In(cum. #citation, non-Al, t-1)        |                    | 0.574*** |                    |           | 0.243***  |                   |           | 0.104**   |           |
|  |                    | [0.0913] |                    |           | [0.0274]  |                   |           | [0.0417]  |           |
| In(cum. #citation, Al, t-1)            |                    | 0.823*** |                    |           | 0.0979    |                   |           | 0.0163    |           |
|  |                    | [0.219]  |                    |           | [0.0660]  |                   |           | [0.100]   |           |
| In(5-year cum. #citation, non-Al, t-1) |                    |          | 0.521***           |           |           | 0.204***          |           |           | 0.0865**  |
|  |                    |          | [0.0811]           |           |           | [0.0244]          |           |           | [0.0371]  |
| In(5-year cum. #citation, AI, t-1)     |                    |          | 0.901***           |           |           | 0.112*            |           |           | 0.0366    |
|  |                    |          | [0.192]            |           |           | [0.0577]          |           |           | [0.0876]  |
|  |                    |          |                    |           |           |                   |           |           |           |
| Observation                            | 49,653             | 49,653   | 49,653             | 49,653    | 49,653    | 49,653            | 49,653    | 49,653    | 49,653    |
| Adj. R2                                | -0.306             | -0.327   | -0.327             | -0.375    | -0.381    | -0.381            | -0.365    | -0.373    | -0.373    |
| ρ                                      | 0.904              | 0.972    | 0.962              | 0.823     | 0.982     | 0.972             | 0.721     | 0.797     | 0.723     |
| Av. Group size                         | 3.6                | 3.6      | 3.6                | 3.6       | 3.6       | 3.6               | 3.6       | 3.6       | 3.6       |

## AI and Innovation

AI effects are significant and larger in the long term.

| Press release                          | ln(#prod. lnn., t+2) |           |           | ln(#proc. Inn., t+2) |           |           | In(#tech. inn., t+2) |           |           |
|--|----------------------|-----------|-----------|----------------------|-----------|-----------|----------------------|-----------|-----------|
|  | (1)                  | (2)       | (3)       | (4)                  | (5)       | (6)       | (7)                  | (8)       | (9)       |
|  |                      |           |           |                      |           |           |                      |           |           |
| In(employee, t-1)                      | 0.0142*              | 0.0167**  | 0.0161*   | -0.00218             | -0.00187  | -0.00191  | -0.00426             | -0.00409  | -0.00422  |
|  | [0.00845]            | [0.00844] | [0.00844] | [0.00273]            | [0.00273] | [0.00273] | [0.00388]            | [0.00387] | [0.00387] |
| In(cum. Patent app., non-Al, t-1)      | 0.0438***            |           |           | 0.000578             |           |           | 0.00614              |           |           |
|  | [0.0106]             |           |           | [0.00341]            |           |           | [0.00484]            |           |           |
| In(cum. Patent app., Al, t-1)          | 0.175***             |           |           | 0.0738***            |           |           | 0.0400***            |           |           |
|  | [0.0199]             |           |           | [0.00643]            |           |           | [0.00914]            |           |           |
| In(cum. #citation, non-Al, t-1)        |                      | 0.0843*** |           |                      | 0.0173**  |           |                      | 0.0298**  |           |
|  |                      | [0.0254]  |           |                      | [0.00819] |           |                      | [0.0116]  |           |
| In(cum. #citation, Al, t-1)            |                      | 0.389***  |           |                      | 0.161***  |           |                      | 0.109**   |           |
|  |                      | [0.0969]  |           |                      | [0.0313]  |           |                      | [0.0444]  |           |
| In(5-year cum. #citation, non-Al, t-1) |                      |           | 0.108***  |                      |           | 0.0170**  |                      |           | 0.0325*** |
|  |                      |           | [0.0235]  |                      |           | [0.00760] |                      |           | [0.0108]  |
| In(5-year cum. #citation, AI, t-1)     |                      |           | 0.334***  |                      |           | 0.142***  |                      |           | 0.108***  |
|  |                      |           | [0.0814]  |                      |           | [0.0263]  |                      |           | [0.0373]  |
|  |                      |           |           |                      |           |           |                      |           |           |
| Observation                            | 75,259               | 75,259    | 75,259    | 75,259               | 75,259    | 75,259    | 75,259               | 75,259    | 75,259    |
| Adj. R2                                | -0.200               | -0.202    | -0.201    | -0.236               | -0.238    | -0.238    | -0.231               | -0.232    | -0.231    |
| ρ                                      | 0.670                | 0.755     | 0.744     | 0.416                | 0.695     | 0.601     | 0.473                | 0.541     | 0.522     |
| Av. Group size                         | 5.1                  | 5.1       | 5.1       | 5.1                  | 5.1       | 5.1       | 5.1                  | 5.1       | 5.1       |

## Conclusions

- Growing interests in AI
- This study analyzes the impact of AI on the firm performances such as productivity by defining introduction of AI as AI-related inventions and matching the IIP Patent DB with the Basic Survey of Japanese Business Structure and Activity.
- (1) The introduction of Al-related technologies is positively correlated with firms' total factor productivity (TFP).
- (2) After 2009, the relationship between AI-related patent applications and firm productivity has strengthened.
- (3) AI-related patents contribute to productivity mainly in firms with intermediate or higher productivity. For firms with low
  productivity, AI-related patent applications may not necessarily lead to higher productivity.
- (4) Only weakly significant impact of the AI-related patents by supplier firms is found.
- (5) The AI-related patents by the customer firms has a positive spillover effect on the productivity of the firms, but only with middle and high productivity
- (6) AI contributes to the product and process innovations of the firm. The effects are significant and larger in the long term.

#### **Challenges and future works:**

Resolving the problem of endogeneity