How Do Factories Get Smarter?:
Implication for Innovation Policy

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“Smart factory” is a manifestation of digital transformation in manufacturing.

- Coined by German growth initiative, Industrie 4.0 (the 4th industrial revolution)

Korea initiated so-called the Manufacturing Innovation 3.0. in 2014.

- Smart factory is the core strategy.

The Korea Smart Factory Association (KOSF) has been launched.

- Public-private partnership
  - Partly funded by large firms; knowledge transfer from large firms to SMEs.
  - Platform where supplier and demander are matched.
Main Projects of MOSF

1. Supports firms to adopt digital technologies.
   ▶ Covers up to 50% of the cost (with a certain limit).
   ▶ SMEs are the main target.
   ▶ Specifically, it aims to build 30,000 smart factories by 2022.
     ★ There are about 69,000 manufacturing plants with 10 or more employees.
     ★ About 36,000 plants have less than 20 employees.
   ▶ An independent coordinator is assigned to each case to monitor the process.
     ★ Well experienced, and usually retired expert.

2. Supports R&D for smart factory technologies, including standardization.

3. Promotes interactions btw. large firms and SMEs.

4. Provides training programs for factory workers.
Key Questions in Chung and Kim (2021)

(Q1) What is smart factory and how “smart” a factory is?

(Q2) What happens when a factory gets smarter?

(Q3) How do factories get smarter?
What is Smart Factory (Manufacturing)?

- Basic idea
  - Came from the lean manufacturing system in Toyota (Womack et al., 1990).
    - Reduces complexity and avoids wastes (e.g., JIT).
    - Networks, communication, self-coordinating work teams (e.g., Kanban)
  - Why not lean in planning and technologies (Zuehlke, 2010)
    - Current production system is often too complex and inefficient.

- Technically, we can define a smart factory as follows:

**Definition**

A factory that digitizes and networks all processes, products, and resources (Kagermann et al., 2013; Bitkom e.V. et al., 2016).
Toyota’s Kanban
An Exemplary Case

- Nobilia, a German kitchen furniture maker (PC Control, 2014)
  - Kitchen furniture is customized in nature (Lot-size of one).

- Automatic ordering and assembly of all pieces to build furniture.

- Digitizes all information about the process and uses them for value creation.
  - **DW** records and manages the locations of holes to assemble pieces.
  - Information from drilling is transferred to a **MES** to optimize the process.
    - motor power, vibration, etc.
  - **IoT-enabled machines** scan the **RFID** attached to all pieces in real-time.
    - Used to decide the order of production and monitor the process.

- Production schedule is managed by the dispatch department.
  - Best aligned with the delivery schedule.
“Automation applied to an inefficient operation will magnify the inefficiency.”

– Bill Gates (The Road Ahead 1995) –

“Excessive automation at Tesla was a mistake... Humans are underrated.”

– Elon Musk (Tweeted on 13 Apr 2018) –
Key Features of Smart Factory

- We consider the following two key features:
  
  (1) **IT & OT based System Integration**
   
   1. Vertical integration of production system
   2. Horizontal integration of the product value chain

  (2) **Data Share and Use**
   
   1. Sharing (digitized) data as the lifeblood
   2. Using the data for decision-making

- These features are not new.

- Recently, however, there have been significant improvements in...
  
  1. System integration of shop-floor (OT) & HQ office (IT)
  2. Data availability and data-handling technologies
Figure: Horizontal and Vertical Integration of Factory System

Horizontal Integration (across Production Phases)

Level 4 Enterprise (ERP)

Level 3 Manufacturing Plant (MES)

Level 2 Control & Monitoring (SCADA, PLC)

Level 1 Devices & Raw Materials (IoT, Sensor, RFID)

Vertical Integration (Manufacturing Phase)

Planning (PLM) → Design (CAD, CPS) → Purchasing (SCM) → Manufacturing (CPS, FEMS) → Inspection (Sensor) → Shipment (SCM) → Marketing (Big Data)
Economic Interpretation

- Smartness of a factory as a particular form of *organizational capital*.
  - System integration needs substantial coordinations (more than ever).
    - Even a single ERP can fail to work for various reasons *(Davenport, 1998)*.
    - Technology adoption needs complimentary investments and adjustment *(Milgrom and Roberts, 1995)*.
  - Data share and use are (transitionally) organizational practices.
    - Again, time and efforts are needed *(Brynjolfsson and McElheran, 2019)*.
  - These two jointly form a factory-specific capital called the *smartness*.

- In this sense, factory accumulates—not installs—the smartness.
  - We specifically call the accumulation of smartness “smartization”
    - smartization vis-a-vis automation and robotization
Survey Data

- Survey questionnaire
  1. Production type: types of output and production process
  2. Automation: level of automation, robot adoptions
  3. Smartness: level of system integration, level of data share & uses, adoption status of (12 types of) enabling digital technologies, government subsidies
  4. Organization: management practices (production & incentive management), existence of ICT division, CEO preferences
  5. Worker & task characteristics: labor and task demand by skill-type
  6. Establishment characteristics: financial, production, employment information

- Survey asks for 2015 and 2017 values to construct a panel data.

- Target 1,000 sample factories across 8 industries and 4 size categories.
  - Stratified sampling by industry and factory size.
  - Final sample size is 939 of which 82% is factories with less than 100 employees.
Figure: Trend in Digital Technology Adoption

New Tech: BigData analytics, Cloud Computing, CPS, and AI
Measure of the Factory Smartness

- **System Integration (SI)**
  - Questions on degrees of horizontal and vertical integration (C5 and C6)
  - The level of SI is calculated as the average of the two answers.
    - After adjusted to a 0–1 scale.

- **Data Share and Use (DSU)**
  - Questions on degrees of data share (C11) and use (C10)
  - The level of DSU is the average of all answers of 10 sub-questions.
    - Again, adjusted to a 0–1 scale.

- Factory smartness is measured by the average of SI and DSU.
C5. What best describes the **manufacturing phase** at this establishment?

1. (Check) Manual check of production logs or checklists, or simple planning using EXCEL program. (0)

2. (Monitoring) Operations are systematically managed so that production history can be traceable at any time. (1/4)

3. (Control) Problems in operations are automatically identifiable through real-time data and resolvable by remote controller. (2/4)

4. (Optimization) Big data and technology solutions can control and optimize the entire process, and anticipate problems in advance. (3/4)

5. (Autonomous operation) Optimized factory can control and solve problems in case of abnormalities with little human intervention. (1)

C6. From sales forecasting to production, inventory management and logistics phases, what best describes the **utilization of ICT** at this establishment?

1. No ICT is used in any production phase. (0)

2. ICTs are applied to management system at some production phases. (e.g., design, operation, inventory, accounting) (1/4)

3. ICT-based management systems at some production phases are partially linked with one another in real-time. (e.g., ordering information \(\Rightarrow\) production planning) (2/4)

4. ICT-based management systems at each production phases are linked with one another in real-time. (e.g., sales \(\leftrightarrow\) design \(\leftrightarrow\) manufacturing \(\leftrightarrow\) resource management) (3/4)

5. All information generated at all production phases is linked through ICTs. (1)
C11. At what level and scope were the data that are collected or analyzed from each production activity shared?

<table>
<thead>
<tr>
<th>Type of Activity</th>
<th>Year</th>
<th>① Not shared at all (0)</th>
<th>② Occasionally shared as needed (1/4)</th>
<th>③ Shared by an agreed scope (2/4)</th>
<th>④ Shared by an agreed scope, plus as needed (3/4)</th>
<th>⑤ Always shared in real-time (1)</th>
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<tbody>
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<td>(1) Between workers within the divisions</td>
<td>2015</td>
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<td>(2) Between divisions within the establishment</td>
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<td>(3) Between establishments within the affiliated firms</td>
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<td>(4) Between suppliers or buyers in the supply chains</td>
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C10. How frequently did your establishment apply data analysis results into the following activities?

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<tr>
<th>Type of Activity</th>
<th>Year</th>
<th>¹ Real-time (1)</th>
<th>² Daily (3/4)</th>
<th>³ Weekly (2/4)</th>
<th>⁴ Monthly (1/4)</th>
<th>⁵ Yearly or not used (0)</th>
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<td>(1) Optimization of manufacturing process</td>
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<td>(2) Higher product quality and lower defect rate</td>
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<td>(3) Anticipation of failures of production facilities</td>
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<td>(4) Development of new products or services</td>
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<td>(5) Supply chain (supplier or customer) management</td>
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<td>(6) Product demand forecast and marketing strategies</td>
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Figure: Distribution of Factory Smartness: 2015 vs. 2017

Mean: 0.31 → 0.37; Median: 0.30 → 0.36; S.D.: 0.118 → 0.123
Figure: Smartization ($=\Delta$Smartness)
Figure: Relationship between Smartness and Other Variables
Effects of Factory Smartization

Factory smartization improves overall productivity.
  ➤ in terms of both daily output and sales.
  ➤ If the bottom 10% factory in smartness was raised to the median level (50%),
    the daily output would improve approximately 9.1%p.

Digital technology does not guarantee productivity gains.
  ➤ Unless technology adoption improves smartness, there’s no productivity gain.

Effects are heterogeneous depending on the type of production process.
  ➤ Batch and job shop: increases product variety and number of clients
  ➤ Assembly line: reduces defect rate
  ➤ Continuous process: reduces leadtime

Smartization has no significant effect on employment, at least in a short run.
What Makes Factories Smarter?

- Adoption of enabling digital technologies is clearly important for smartization.
  - However, it is neither sufficient nor necessary condition.
    - Recall the case of Toyota in 1950s

- Technology-induced smartization is conditional.
  - Due to the strong complementarity btw. DT adoption and incentive management (Bloom et al., 2012).
  - Factory with the lowest incentive management quality did not get smarter despite the technology adoption.

- Other important drivers include
  - CEO’s leadership and interest in the technology (Galasso and Simcoe, 2011)
  - Existence of ICT division or related workers
Summary of the Findings

Digital Technologies
Information Technology + Operation Technology

Factory Smartness (=System Integration + Data Share & Use) as Organization Capital

Heterogeneous Performances
Productivity, Efficiency, Product Variety

Incentive Management & CEO Leadership

Manufacturing Processes
Batch, Assembly Line, Continuous
Implications for Innovation Policy

- Our findings explain why subsidy for technology adoptions may be inefficient.
  - Incentive management quality in Korea is much poorer the U.S. (Chung, 2020).
  - Quantity-based target can make policy practitioners to forget the ultimate goal.

- Innovation policies need to be more balanced btw. technology and management.
  - Oslo manual clearly states that there are two broad kinds of innovation.
    - technological innovation and managerial innovation
  - Smart manufacturing is the outcome of the combination of the two.
  - Packaged policy can create a synergy.

- This lesson is more emphasized for catching-up economies.
  - Factories in these economies are even less likely to be well managed.
  - Financial wherewithal is more limited.
References


PC Control (2014) Nobilia, Germany: Series production with lot-size-1 flexibility demonstrates the true potential of Industry 4.0, No. 4, pp. 28–33.
