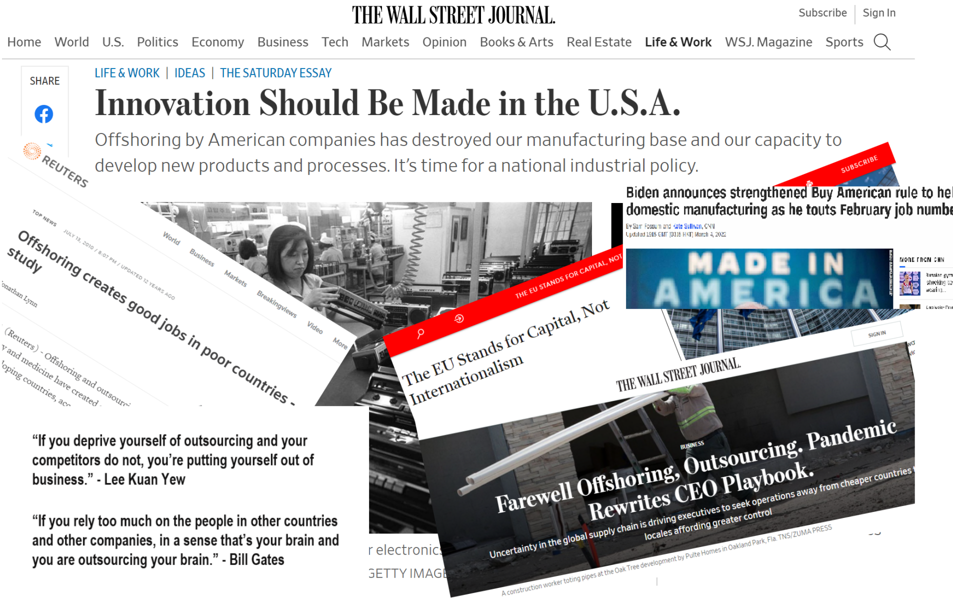
Measuring Advanced Manufacturing and Process Innovation: Applications to Productivity and Growth

Leo Liu, Elvira Sojli, Wing Wah Tham

University of New South Wales



"If you deprive yourself of outsourcing and your competitors do not, you're putting yourself out of business." - Lee Kuan Yew

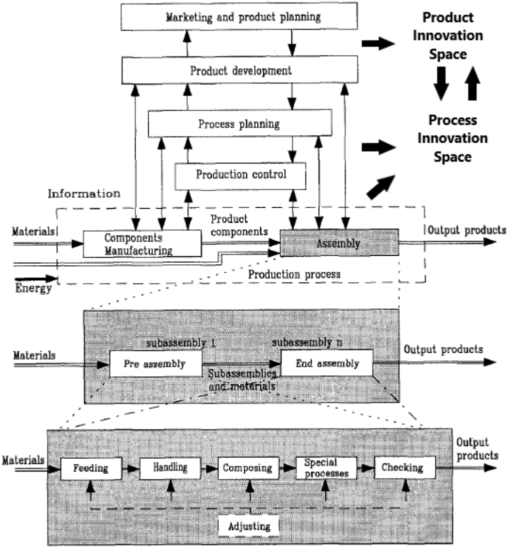
"If you rely too much on the people in other countries and other companies, in a sense that's your brain and you are outsourcing your brain." - Bill Gates

From invention to product through manufacturing

- Converting a great idea into a product requires multiple stages and cross-disciplinary interaction

  R&D $\rightarrow$ design $\rightarrow$ manuf. & production $\rightarrow$ assembly $\rightarrow$ marketing
- Production and manufacturing are especially important for product improvement and creation of new products (Pisano and Shih, 2012)

From invention to product through manufacturing



The Production Process

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  - + Cost reduction $0.58 per $1 on outsourced jobs
  - - Unemployment
  - - Decrease in industrial commons
  - - Separate product and process

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  - Decrease in industrial commons
  - Separate product and process
- **Understanding advanced manufacturing and process innovation has implications for firm growth, trade outcomes, and government policies**

The challenge

- Lack of consistent firm information on advanced manufacturing and products
  - Across industries
  - With large cross-section
  - Long time series
  - International coverage (especially important for offshoring analysis)
- Prior work mainly based on intermittent industry-specific surveys

This paper

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    - US
    - Cross-country convergence

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  - Firm
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    - Process and product innovation complementarity
  - Aggregate economic growth
    - US
    - Cross-country convergence
- Documents differential role of process and product innovation and existence of complementarity

  $\longrightarrow$ affects policy and welfare decisions at firm and economy level

The how

Innovation

Is the implementation of a new or significant improved product (good or service), or process, a new marketing method, or a new org. method in business practice.

Oslo Manual, OECD 2005

The how

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  Requirements of novelty and the inventive step or non-obviousness criteria

- Process patents capture frontier advanced manufacturing processes capable of industrial applications

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- Process patents capture frontier advanced manufacturing processes capable of industrial applications
- But how to classify patents?

Classifying patents

United States Patent [19]
Mullis

[11] **Patent Number:** **4,683,202**
[45] **Date of Patent:** * **Jul. 28, 1987**

[54] **PROCESS FOR AMPLIFYING NUCLEIC ACID SEQUENCES**

[75] Inventor: **Kary B. Mullis,** Kensington, Calif.

[73] Assignee: **Cetus Corporation,** Emeryville, Calif.

[*] Notice: The portion of the term of this patent subsequent to Jul. 28, 2004 has been disclaimed.

[21] Appl. No.: **791,308**

[22] Filed: **Oct. 25, 1985**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 716,975, Mar. 28, 1985, abandoned.

[51] **Int. Cl.**[4] **C12P 19/34;** C12N 15/00; C12N 1/00; C07H 21/04; C07H 21/02

[52] **U.S. Cl.** **435/91;** 435/177.3; 435/317; 536/27; 536/28; 536/29; 935/17; 935/18; 935/16

[58] **Field of Search** 435/91, 172.3, 317; 536/27, 28, 29; 935/17, 18

[56] **References Cited**

mentary DNA for Cloning", J. Theor. Biol. 95: 679 (1982).

Caton and Robertson, *Nucleic Acids Research*, vol. 7, pp. 1445–1456 (1979).

Rossi et al., *J. Biol. Chem.*, 257, 9226–9229 (1982).

Primary Examiner—James Martinell
Attorney, Agent, or Firm—Janet E. Hasak; Albert P. Halluin

[57] **ABSTRACT**

The present invention is directed to a process for amplifying any desired specific nucleic acid sequence contained in a nucleic acid or mixture thereof. The process comprises treating separate complementary strands of the nucleic acid with a molar excess of two oligonucleotide primers, and extending the primers to form complementary primer extension products which act as templates for synthesizing the desired nucleic acid sequence. The steps of the reaction may be carried out stepwise or simultaneously and can be repeated as often as desired.

Classifying patents

What is claimed is:

1. A process for amplifying at least one specific nucleic acid sequence contained in a nucleic acid or a mixture of nucleic acids wherein each nucleic acid consists of two separate complementary strands, of equal or unequal length, which process comprises:

(a) treating the strands with two oligonucleotide primers, for each different specific sequence being amplified, under conditions such that for each different sequence being amplified an extension product of each primer is synthesized which is complementary to each nucleic acid strand, wherein said primers are selected so as to be sufficiently complementary to different strands of each specific sequence to hybridize therewith such that the extension product synthesized from one primer, when it is separated from its complement, can serve as a template for synthesis of the extension product of the other primer;

(b) separating the primer extension products from the templates on which they were synthesized to produce single-stranded molecules; and

(c) treating the single-stranded molecules generated from step (b) with the primers of step (a) under conditions that a primer extension product is synthesized using each of the single strands produced in step (b) as a template.

2. The process of claim 1, wherein steps (b) and (c) are repeated at least once.

3. The process of claim 1, wherein said step (b) is accomplished by denaturing.

4. The process of claim 3, wherein said denaturing is caused by heating.

5. The process of claim 1, wherein said step (b) is accomplished using the enzyme helicase.

6. The process of claim 1, wherein steps (a) and (c) are accomplished using an enzyme.

7. The process of claim 6, wherein said enzyme is selected from the group consisting of *E. coli* DNA poly-

temperature of reaction during steps (a) and (c).

15. The process of claim 1, wherein the two primers in steps (a) and (c) are each present in a molar ratio of at least 1000:1 primer:complementary strand.

16. The process of claim 1, wherein the nucleic acid sequence(s) to be modified is contained in a mixture of nucleic acids resulting from a chemical synthesis.

17. The process of claim 1, wherein at least one primer contains at least one nucleotide which is not complementary to the specific sequence to be amplified.

18. The process of claim 17 wherein one primer comprises an oligonucleotide with 20 complementary nucleotides and, at its 5′ end, a T7 promoter containing 26 noncomplementary nucleotides.

19. A process for amplifying a specific nucleic acid sequence contained in double-stranded DNA which process comprises:

(a) separating the strands of the DNA by physical, chemical or enzymatic means;

(b) treating the single strands with two oligodeoxyribonucleotide primers, in a molar excess of primer: its complementary strand, under conditions such that an extension product of each primer is synthesized, using *E. coli* DNA polymerase I or Klenow fragment thereof, which extension product is complementary to each DNA strand, wherein said primers are selected so as to be sufficiently complementary to different strands of each specific sequence to hybridize therewith such that the extension product synthesized from one primer, when it is separated from its complement, can serve as a template for synthesis of the extension product of the other primer;

(c) separating the primer extension products from the templates on which they are synthesized to produce single-stranded molecules by physical, chemical or enzymatic means; and

(d) treating the single-stranded molecules generated from step (c) with the two primers of step (b) in a

Classifying patents

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Classifying patents

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- However
  - Cannot do manually for millions of patents - need to automate process (natural language processing)
  - Claim data is missing or poorly digitised for various data samples

Data challenges

- US patent information digitised in structured format from 1976 (Bena and Simitzi, 2021; Bena et al., 2022)

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$\longrightarrow$ Time series not sufficient for analysis of mid and long-term growth

$\longrightarrow$ No cross-section information for cross-country analysis

Addressing data challenges - Patent titles

- The title should clearly describe main subject of invention
- Should be consistent with claims

Guidelines for the Wording of Titles of Invention, from World Intellectual Property Organization (WIPO) require:
"*The patent title should clearly, concisely and as specifically as possible indicate the main subject to which the invention relates. If the patent document contains claims in different categories (product, process, apparatus, use), this should be evident from the title.*"

USPTO 606 Title of Invention [R-10.2019]
"*The title should be brief but technically accurate and descriptive*"*... if "The title of the invention is not descriptive. A new title is required that is clearly indicative of the invention to which the claims are directed.*"

- Consistent/comparable information across time and patent offices from 1850-2019

Data

US data

- Google USPTO patents - 1850 to 2019, 10.5 mio
  - all firms (public and private), universities, individuals
- US publicly-listed firms (CRSP) - 1926 to 2019, 2.95 million patents
  - use sample from 1929-2019
- Firm information from CRSP-Compustat merged file sample - 1950 to 2019

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International data

- PATSTAT patents - 1833 to 2018, 46.9 million patents
  - all patents
  - sample with 10 years of English patent titles and GDP
- GDP and macro data from Penn tables

Classification methods

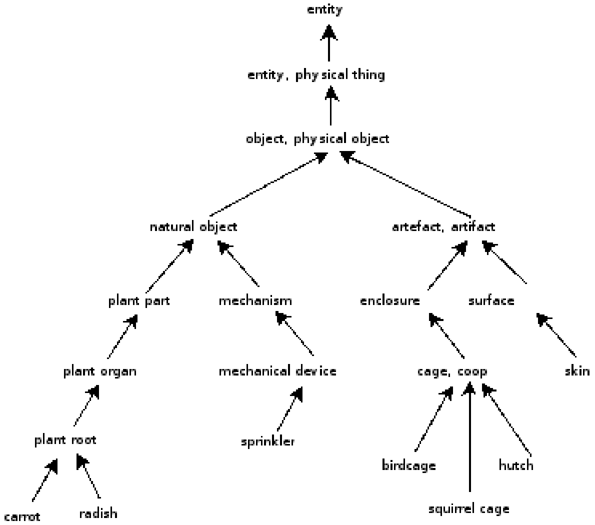
- Rule-based $\rightarrow$ define a number of textual analysis steps to classify (main focus)
  - Both titles and claims (first claim, only independent claims, all claims)
- Deep-learning based $\rightarrow$ use DeBERTa to learn from claim-based classification and generate classifications based on title

Rule-based classification

- Heuristic separation between process and product patents where claims/titles referring to
  - an activity (process, method or use) are classified as process-related words
  - a physical entity (product or apparatus) are classified as product-related words

- Textual analysis of title and claims using expanding (self learning) corpus of generic terms (hypernyms) related to "activity" and "physical entities"
- Does not depend on specific (subjective) or pre-defined words/lists

Hypernyms - WordNet Stanford project



Rule-based classification

1. Extract the keyword
2. Classify the keyword

- Claims

$\underbrace{\text{A method}}_{\text{preamble}} \quad \underbrace{\text{of}}_{\text{transitional phrase}} \quad \underbrace{\text{making a thin film semiconductor...}}_{\text{content}}$

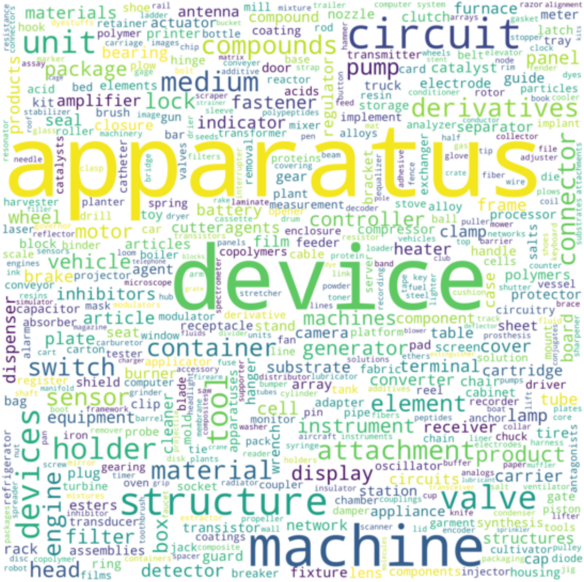
method $\rightarrow$ *Process*

- Title

$\underbrace{\text{Methods}}_{\text{keyword}} \quad \underbrace{\text{of}}_{\text{transitional phrase}} \quad \underbrace{\text{making a thin film semiconductor}}_{\text{content}}$

method $\rightarrow$ *Process*

Product and process word clouds



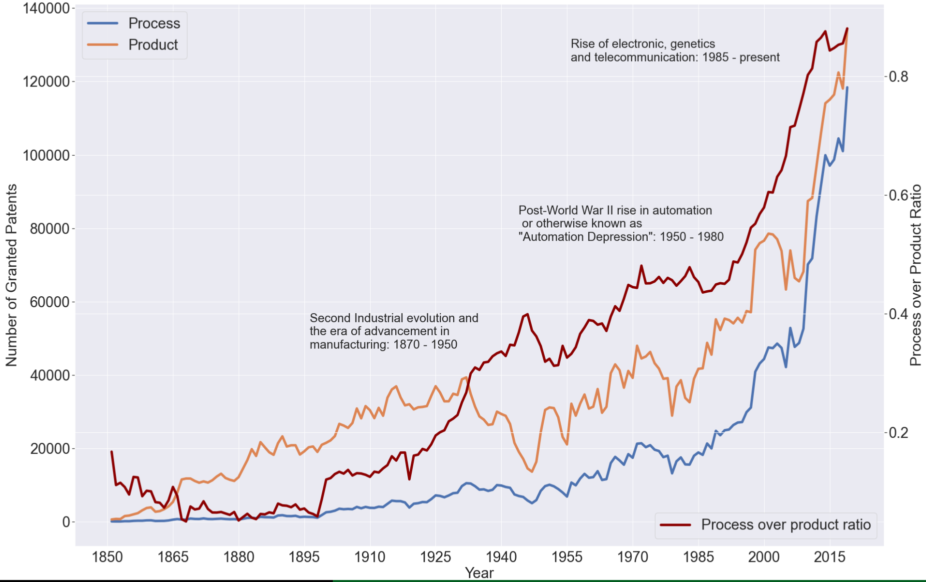
Product and process word clouds

Industry variation

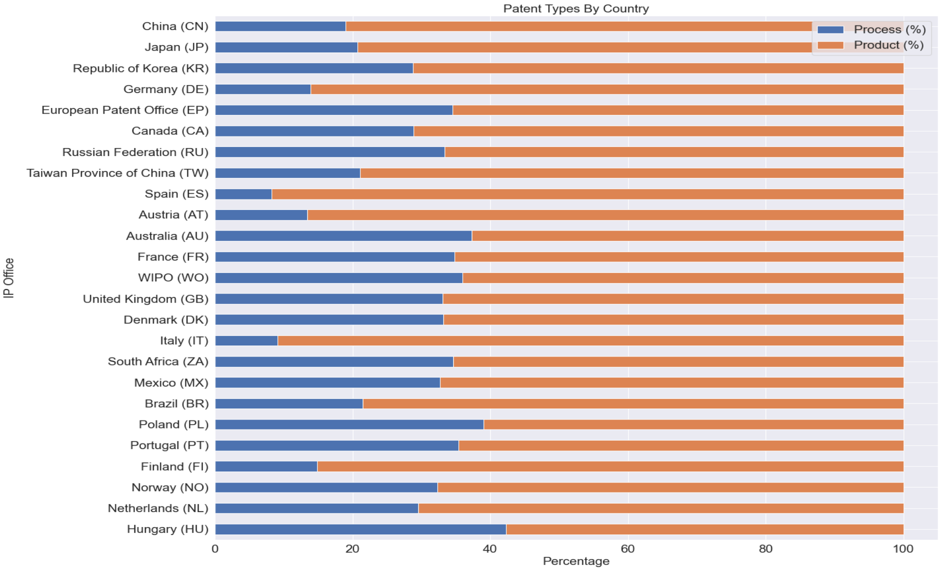
Fama-French industries

	Process	Product	Total
Business Equipment	54%	46%	1,101,208
Chemicals and Allied Products	38%	62%	197,131
Consumer Durables	37%	63%	347,117
Consumer NonDurables	34%	66%	39,204
Finance	56%	44%	41,482
Healthcare, Medical Equipment, and Drugs	35%	65%	212,317
Manufacturing	37%	63%	606,416
Oil, Gas, and Coal Extraction and Products	56%	44%	123,179
Other	52%	48%	62,171
Telephone and Television Transmission	48%	52%	122,124
Utilities	55%	45%	3,584
Wholesale, Retail, and Some Services	45%	55%	56,499

Time-series variation



International variation (US=40%)



Patent metrics

Scope, Citations, Value

- Relative comparison between process and product patents within same year and tech class (4-digit level)
- Patent level regression of patent metric on process patent dummy
- Standard errors clustered at tech class (4-digit level)

	Claims	Scope	Backward	Originality	Forward	Generality	$\ln(\xi)$
Process	0.083***	0.002	0.118***	0.012***	0.112***	0.014***	0.157***
	(58.35)	(1.35)	(10.12)	(28.32)	(15.77)	(14.29)	(29.25)
IPC4×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	5,341,881	5,341,881	5,341,838	4,989,354	5,288,423	3,753,626	1,895,274
Adj. R^2				0.12		0.14	0.18

Process innovation in practice

Firm's R&D investment decision

- Endogenous growth models (Romer 1990; Klette and Kortum 2004) imply that firm growth is related to process and product innovation through effect of technology on
  - how to produce new product variety
  - how to increase product quality
  - how to reduce production costs
- Choice of process and/or product innovation is an important strategic firm investment decision
  - Increase firm/product demand at expense of competitors
    - Creation of new products - product variety
    - Improve product quality
  - Process innovation
    - Efficiency gains in production - lower production costs
    - Shift product frontier, process-product complementarity

Firm growth

$$log(\frac{Y_{i,t+\tau}}{Y_{i,t}}) = \beta_0 + \beta_1\theta_{proc,i,t} + \beta_2\theta_{prod,i,t} + \gamma X_{i,t} + \alpha_{sic3} + \delta_t + \epsilon_{i,t},$$

- Profits: growth rate in firm gross profits (sale-cogs, CPI deflated)
- Sales: firm sales
- Capital: firm capital stock (ppegt NIPA equipment price deflated)
- Employment: firm employment (emp);
- TFP: firm-level TFP as in Olley & Pakes (E'ca, 1996) & Imrohorouglu & Tuzel (MS, 2014)

Exclude finance and utility firms, as they are in heavily regulated/different industrial organisation setting
$\theta_{proc(prod),i,t}$ is market value of process and product patents scaled by total assets
$X_{i,t}$: log value of capital stock, log number of employees, and firm yearly idiosyncratic volatility $\sigma_{i,t}$ (sum of squared daily abnormal returns)

Firm growth

	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Panel A. Profits										
Process (θ)	0.138***	0.289***	0.335***	0.33***	0.309***	0.385***	0.374***	0.343***	0.355***	0.364***
	(3.34)	(4.46)	(4.79)	(3.97)	(3.51)	(3.76)	(3.73)	(3.32)	(2.75)	(2.75)
Product (θ)	0.073**	0.097*	0.142**	0.181*	0.259**	0.236*	0.296**	0.352**	0.371**	0.434**
	(2.04)	(1.94)	(2.09)	(1.89)	(2.18)	(1.72)	(2.1)	(2.3)	(1.96)	(2.36)
Panel B. Sales										
Process (θ)	0.138***	0.289***	0.336***	0.331***	0.311***	0.387***	0.376***	0.346***	0.358***	0.367***
	(3.34)	(4.46)	(4.8)	(3.98)	(3.52)	(3.77)	(3.74)	(3.34)	(2.76)	(2.76)
Product (θ)	0.073**	0.096*	0.142**	0.181*	0.260**	0.238*	0.298**	0.354**	0.374**	0.437**
	(2.04)	(1.93)	(2.09)	(1.9)	(2.19)	(1.73)	(2.11)	(2.31)	(1.97)	(2.37)

Firm growth results

- Process innovation related to more sales and higher profits in short to medium run than product innovation
- Where do the effects come from?
  1. Direct effect
     - Process is related to cost reduction in a competitive market
     - Higher sales and *increased markups*
  2. Indirect effect
     - Stimulating new product innovation
     - Process and product innovation complementarity

Patent complementarities

1. Process-driven product innovation has higher value and better quality
2. Accumulation effect
3. Process-driven products are primary drivers of firm profit and sales

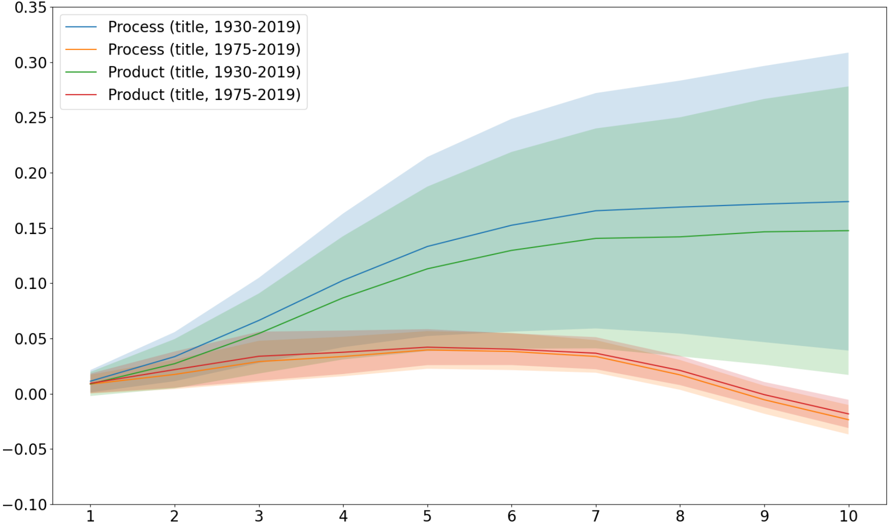
Profit Growth

	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Process (θ)	0.118*	0.305**	0.371**	0.347*	0.572***	0.714***	0.549**	0.579**	0.560*	0.545**
	(1.71)	(2.53)	(2.3)	(1.84)	(2.66)	(3.06)	(2.11)	(2.05)	(1.82)	(1.98)
Product (θ, Process based)	0.158**	0.158	0.321*	0.391*	0.408**	0.419**	0.474**	0.605***	0.659***	0.646***
	(2.44)	(1.03)	(1.87)	(1.94)	(2.23)	(2.24)	(2.44)	(2.9)	(3.07)	(2.87)
Product (θ, non-Process based)	0.047	0.091	0.051	0.06	0.046	-0.079	-0.016	-0.082	-0.07	-0.045
	(0.83)	(0.96)	(0.48)	(0.43)	(0.33)	(-0.56)	(-0.11)	(-0.54)	(-0.44)	(-0.29)
Obs.	154,172	138,508	124,747	112,677	102,092	92,739	84,337	76,755	69,883	63,662

Aggregate economic growth

- Endogenous growth models argue that product variety can play an important role in economic growth
  - Garcia-Marcia et al. (E'ca '19) show implicit role of products for economic growth
  - Kogan et al. (2017) show role of patents for growth
- Role of process and product innovation contingent on level of variety and productivity (Yorukoglu 2000)
- Employ setting of Kogan et al. (2017) to calculate relation of process and product innovation with aggregate growth and productivity

Growth: GDP


Process (title, 1930-2019)
Process (title, 1975-2019)
Product (title, 1930-2019)
Product (title, 1975-2019)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
1
2
3
4
5
6
7
8
9
10

International convergence

a la Aghion et al. (QJE 2005)

Theoretically, there will be growth convergence as technology propagates across countries

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$$g_i - g_1 = \beta_0 + \beta_p ln(P_i) + \beta_y \times (ln(y_i^0) - ln(y_1^0)) + \beta_{py} \times ln(P_i) \times (ln(y_i^0) - ln(y_1^0)) + \epsilon_i,$$

	GDP	GDP-Labor		TFP	TFP-Labor	
		High	Low		High	Low
	(1)	(2)	(3)	(4)	(5)	(6)
P (Proc./Prod.)	0.203	-0.327	1.196	0.033	-0.118	0.125
	(0.52)	(-1.54)	(1.12)	(0.25)	(-0.68)	(0.49)
$ln(y_i^0) - ln(y_1^0)$	0.129	-1.043***	0.973			
	(0.25)	(-3.40)	(0.99)			
$P \times (ln(y_i^0) - ln(y_1^0))$	1.036**	0.491	1.893**			
	(2.13)	(1.71)	(2.14)			
$ln(y_i^0) - ln(y_1^0)$				-3.272***	-3.349***	-3.262***
				(-12.94)	(-10.71)	(-6.56)
$P \times (ln(y_i^0) - ln(y_1^0))$				-1.345***	-1.838**	-1.383**
				(-3.16)	(-2.43)	(-2.60)
Obs.	51	29	22	51	29	22
R^2	0.13	0.42	0.23	0.82	0.88	0.73

Conclusion

- Provide a firm-level long term and cross-country measure of manufacturing and process innovation
  - Allows for test of models on growth, trade, industrial organisation
- Advanced manufacturing and process innovation is as important as product innovation for firms and the economy
- Process-driven products are very important innovations at the firm level $\rightarrow$ separation of R&D and production likely to be harmful for firms and economies
- For countries with low labor costs, it is product innovation that increases likelihood of growth convergence

International sample

Patent Office	Process (%)	Product (%)	Total Patents	Missing Title (%)	Claims Information	Year First	Year Last
China	20.53	79.47	10187203	0.26	Not Reported	1985	2018
Japan	27.86	72.14	4430275	30.07	Not Reported	1971	2018
Republic of Korea	31.90	68.10	2170231	5.22	Not Reported	1978	2018
Canada	35.85	64.15	1315897	0.00	Not Reported	1954	2018
United Kingdom	30.56	69.44	1223077	2.24	Not Reported	1954	2018
Taiwan	23.14	76.86	976130	2.58	Not Reported	1991	2018
Russian Federation	50.92	49.08	585932	0.31	Not Reported	1994	2018
Australia	40.28	59.72	583091	1.47	Not Reported	1954	2018
Germany	24.71	75.29	411346	5.77	Not Reported	1969	2016
South Africa	39.60	60.40	276084	0.12	Not Reported	1969	2017
France	23.41	76.59	267989	12.97	Not Reported	1965	2016
Poland	42.24	57.76	142110	6.66	Not Reported	1978	2018
Mexico	45.13	54.87	115364	0.07	Not Reported	1989	2018
Hungary	50.40	49.60	81993	9.31	Not Reported	1974	2018
Ukraine	46.64	53.36	59930	2.43	Not Reported	1997	2018
Israel	53.32	46.68	59130	0.01	Not Reported	1978	2018
Malaysia	43.41	56.59	54121	0.03	Not Reported	1959	2018
Czech Republic	26.45	73.55	52805	3.54	Not Reported	1994	2018
Portugal	45.82	54.18	50134	0.03	Not Reported	1972	2018
Switzerland	23.86	76.14	50107	8.33	Not Reported	1962	2014
Greece	36.95	63.05	45885	25.09	Not Reported	1961	2018
Italy	20.81	79.19	40557	0.04	Not Reported	1978	2003
Ireland	36.74	63.26	38688	0.01	Not Reported	1954	2018
Bulgaria	40.89	59.11	34281	20.10	Not Reported	1977	2017
Spain	26.77	73.23	33309	0.01	Not Reported	1979	2015
Romania	41.97	58.03	31902	9.14	Not Reported	1978	2018
Philippines	37.18	62.82	27316	0.20	Not Reported	1975	2018
Netherlands	29.31	70.69	25197	7.58	Not Reported	1957	2018
China, Hong Kong SAR	29.04	70.96	23501	0.02	Not Reported	1976	2017
Slovakia	43.93	56.07	13755	0.53	Not Reported	1994	2018
Egypt	45.97	54.03	13695	0.05	Not Reported	1976	2016
Singapore	32.53	67.47	10498	0.01	Not Reported	1983	1995
Austria	25.74	74.26	10034	0.11	Not Reported	1975	2011
Sweden	28.68	71.32	9516	2.40	Not Reported	1979	2018
Slovenia	29.59	70.41	8775	0.01	Not Reported	1994	2018
Belgium	24.20	75.80	7261	34.44	Not Reported	1957	2008
Lithuania	42.08	57.92	7080	0.04	Not Reported	1994	2018
Finland	45.86	54.14	6742	0.35	Not Reported	1975	2018
Serbia	33.94	66.06	6625	0.24	Not Reported	2006	2018
Denmark	34.47	65.53	6560	0.20	Not Reported	1975	2018
Republic of Moldova	53.46	46.54	5699	0.00	Not Reported	1994	2018
Croatia	33.80	66.20	5644	0.07	Not Reported	1994	2018
Latvia	43.81	56.19	4649	0.04	Not Reported	1994	2018
Zambia	45.43	54.57	2722	0.33	Not Reported	1968	1994
Zimbabwe	40.70	59.30	2637	0.08	Not Reported	1980	1995
Jordan	39.91	60.09	2102	0.00	Not Reported	1971	2016
Kenya	38.74	61.26	1350	0.00	Not Reported	1975	1989
Luxembourg	37.97	62.03	878	76.57	Not Reported	1983	2016
Norway	53.24	46.76	469	5.86	Not Reported	2004	2018
Estonia	29.39	70.61	309	0.02	Not Reported	1998	2018
Iceland	41.67	58.33	28	0.34	Not Reported	2000	2018