Inventing while you work:
Knowledge generality, visibility and non-R&D innovation

You-Na LEE and John P. WALSH
Georgia Institute of Technology

Funding provided by NSF (SciSIP) Grant #1261418

YN Lee, JP Walsh. 2016. . "Inventing while you work: Knowledge, non-R&D learning and innovation." Research Policy 45 (1), 345-359

Introduction

- **The economics of innovation** as the canonical view
- Adopt insights from **sociology of work** and **organizational learning**
- How are innovations generated from different work practices in firms?
- Focus on the relation between **knowledge** characteristics and **learning, in R&D and outside-R&D work (NRD)**
- Ground models of innovation in firm practices
  - Incorporate both R&D and non-R&D innovation

Contributions

- Understanding the fundamental drivers of innovation
  - More broadly conceived
- Understanding how the organization of work, and choice in technology, can affect organizational learning and innovation
  - Help build learning organizations to promote innovation economy.

Examples of non-R&D innovations

- A salesman for an industrial supply company discovered a need for a new cleaning system for fiber-optics connectors.
- After being rebuffed by R&D department ("Concentrate on your sales work"), he started a one-man skunkworks, spending time at GT's library to get technical information, and working in his basement.
- He developed a new patented cleaning system, that became a major line of business at his firm.

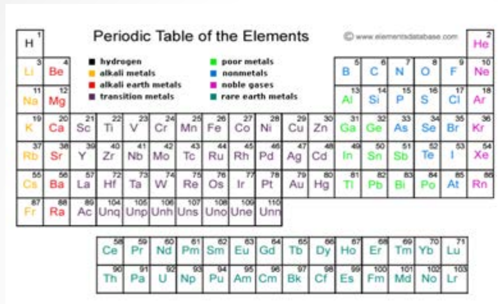
Examples of non-R&D innovations

- A technical service rep at a specialty chemicals firm noticed that there was a need for a greener chemical for use as ship coating.
- Drawing on his chemical engineering education, he invented a new, patented coating that was compatible with new environmental regulations
- The new product replaced existing product that was incompatible with new tougher regulations and helped firm gain market share on competitors using old technology

Nature of knowledge, work and learning in R&D vs. non-R&D

- R&D and non-R&D employees have different work practices and modes of learning
  (Jensen et al., 2007; Malerba, 1992; Stinchcombe, 1990)
  - Broad external search vs. targeted search
  - Simulation and lab analyses vs. learning by working
- Nature of knowledge will affect different intensities of two modes of learning (Jensen et al., 2007; McIver et al., 2013).

Generality of knowledge



General

Sticky

Generality of knowledge and R&D vs. non-R&D learning and innovation

- The knowledge base of an industry strongly shapes the innovation processes of the different activities in firms (Asheim and Coenen, 2006; Pavitt, 1984; Winter, 1984).
  - Analytical vs. synthetic knowledge
  - Explicit, global knowledge vs. implicit, local knowledge
- A general knowledge environment (i.e., high mobility/transferability of knowledge) better matches work practices by R&D than those by non-R&D workers.

H1: **Generality** increases innovati0n productivity given **R&D** work compared to that given non-R&D work.

Visibility of knowledge

High Visibility

↕

Low Visibility

Visibility of knowledge and R&D vs. non-R&D learning and innovation

- More visible problems or impact of inputs on outputs provide more opportunities for utilizing learning in working (Seymore, 2009; Stinchcombe, 1965; Zuboff, 1988).
  - Organizational structures/practices (e.g., Toyota Production System)
  - Technology choice (e.g., paper mills pre- and post- automation)

- Greater effectiveness of learning (Brown and Duguid, 1989).

H2: **Visibility** increases innovation productivity given **non-R&D** work compared to that given R&D work.

Data

- Ideally, want a large sample of R&D and non-R&D activities and measure innovation productivity of each: *Unobservable*
- So, start with a large sample of inventions, across different industries (knowledge environments)
  - Project level (not firm-level) [cf. EU studies, NSF BRDIS]
- Inventor Survey
  - A survey of **US inventors on 2000-2003 priority date triadic patents** (filed in Japan and the EPO and granted by the USPTO)
  - 1919 responses (response rate: 31.8%)
  - 1738 responses for analyses, limiting to inventors in firms
  - Categorize inventions as coming from R&D v. non-R&D work
  - Link other datasets (Private, NSF, Census data)

Empirical model (Linking observables to hypotheses)

by Bayes' theorem

$$\frac{P(RD|invention)}{P(NRD|invention)} = \frac{\frac{P(RD)\,P(invention|RD)}{P(invention)}}{\frac{P(NRD)\,P(invention|NRD)}{P(invention)}} = \frac{P(RD)P(invention|RD)}{P(NRD)P(invention|NRD)}$$

$$\ln\left(\frac{P(RD|invention)}{P(NRD|invention)}\right) = \ln\left(\frac{P(RD)}{P(NRD)}\right) + \ln\left(\frac{P(invention|RD)}{P(invention|NRD)}\right)$$

Observed ratio — Control relative sizes — Hypothesized ratio

$$\ln(P(invention|RD)) = \ln\theta_R = \alpha_R GEN + \beta_R VIS + \boldsymbol{\gamma_R X} + \epsilon_R$$
$$\ln(P(invention|NRD)) = \ln\theta_N = \alpha_N GEN + \beta_N VIS + \boldsymbol{\gamma_N X} + \epsilon_N$$

$$\ln\left(\frac{P(invention|RD)}{P(invention|NRD)}\right) = \ln\left(\frac{\theta_R}{\theta_N}\right) = \ln\theta_R - \ln\theta_N$$
$$= (\alpha_R - \alpha_N)GEN + (\beta_R - \beta_N)VIS + (\boldsymbol{\gamma_R} - \boldsymbol{\gamma_N})\boldsymbol{X} + (\epsilon_R - \epsilon_N)$$
$$= \alpha GEN + \beta VIS + \boldsymbol{\gamma X} + \epsilon$$

H1 implies $\alpha_R > \alpha_N$, and hence α is positive.
H2 implies $\beta_R < \beta_N$ and hence β is negative.

Measures

- **R&D and non-R&D invention** at the project level
- A composite measure of the type of employees and their creative process in generating the invention
  - In robustness checks, we test alternative categorizations

	Location of the Inventor				
Creative process	Independent R&D unit or its subunit	R&D subunit attached to a non-R&D unit	Manufacturing	Software development	Other (e.g., sales)
Targeted achievement of an R&D project					
Unexpected by-product of an R&D project			R&D invention		
Expected by-product of an R&D project					
Related to your normal job (not inventing)					
Pure inspiration/creativity			Non-R&D invention		

Size of non-R&D innovation in economy

- In our data, **12%** of triadically patented inventions are **non-R&D**

	GT Inventor Survey	NSF BRDIS	Arora et al. (2016) innovation survey
Population	Triadically patented inventions	US patented inventions	New-to-market innovations
% non-R&D innovation	12%	6%	11%
NRD defined at	Project	Firm	Project

Share of non-R&D inventions (firms with 15+ inventions)

Firm	% Non-R&D invention
A	16.1
B	15.2
C	13.8
D	13.5
E	13.0
F	4.3
G	3.1
H	0.0
I	0.0
J	0.0
All	8.7

Share of non-R&D inventions, by industry

NAICS		N	% non-R&D inventions
311-312	Food, beverage and tobacco product	5	0.0
313-316	Textile mills, textile product, apparel, and leather	10	21.4
321-323	Wood product, paper, and printing	21	20.8
325	Chemical (except pharmaceutical and medicines)	257	4.1
3254	Pharmaceutical and medicine	56	4.5
326	Plastics and rubber products	78	9.1
327	Nonmetallic mineral product	36	11.9
331	Primary metal	16	10.5
332	Fabricated metal product	74	19.5
333	Machinery	266	18.6
334	Computer and electronic (except semiconductor)	441	12.9
3344	Semiconductor and other electronic component	177	11.7
335	Electrical equipment, appliance, and component	121	11.5
336	Transportation equipment	63	9.5
337-339	Furniture and related product, and miscellaneous	117	14.8
	All	1738	12.1

Measures

- **Generality of knowledge**
  - Mobility/Transferability of knowledge
  - A sum of the standardized values of three dimensions
  - Industry scores of importance in each dimension from a survey of US R&D units in 1994, linked to the focal dataset through NAICS

Codifiable knowledge
+
Basic knowledge = General knowledge
+
University-driven knowledge

Measures

- **Visibility of knowledge**
  - Tight links between actions and outcomes
  - Two criteria: **Organizational forms** by Stinchcombe (1965) and **use of mechanical knowledge** in industry (Seymore, 2009)

		Organizational forms	
		Prefactory/early	Railroad age/Modern
Mechanical knowledge	High	**High visibility (=1)**	
	Low		**Low visibility (=0)**

- **R&D intensity**
  - Relative size of R&D to non-R&D

Descriptive statistics: R&D v. non-R&D invention

	Invention type		
	R&D inv (N=1519)	Non-R&D inv (N=219)	t
Inventor characteristics			
Age at first patent application	34	37	-5.2 ***
Age at highest degree	28	27	2.0 *
Highest degree = PhD	48%	24%	7.6 ***
Highest degree major = Science/Engineering	98%	92%	2.8 ***
Invention process			
No. of information sources (university, customer, supplier etc., max= 11)	5.1	4.5	2.6 ***
Invention output			
Product (vs. Process) invention	79%	80%	-0.2
Value of invention			
Any commercialization (Inhouse, start-up, or licensed)	53%	64%	-2.8 ***
No. of claims	23.2	22.6	0.5
Forward citation	3.2	3.4	-0.8

*** at .01, ** at .05, * at .10

Knowledge environment and non-R&D invention

- Logistic regression models predicting ratio of R&D to non-R&D inventions
- H1: More general knowledge → relatively more R&D invention
- H2: More visible knowledge → relatively more non-R&D invention
- Control for relative size of R&D v. non-R&D [RDI, firm size, industry growth]; patent propensity
- Also test using firm dummies (alternative controls)

Results

	R&D invention vs. non-R&D invention					
	Full sample					Product inv only
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Generality of knowledge	0.151 **				0.141 **	0.150 **
	(0.065)				(0.066)	(0.073)
Codifiable		0.210 *				
		(0.119)				
Basic			0.433 **			
			(0.183)			
University-driven				0.198 **		
				(0.098)		
Visibility of knowledge	-0.704 ***	-0.713 ***	-0.550 ***	-0.757 ***	-0.724 ***	-0.960 ***
	(0.203)	(0.203)	(0.204)	(0.208)	(0.205)	(0.238)
Inv. patent propensity	0.003	0.003	0.003	0.003	0.003	0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)
Industry annual growth	0.105 **	0.102 **	0.055	0.088 **	0.113 **	0.115 **
	(0.051)	(0.050)	(0.041)	(0.041)	(0.053)	(0.055)
Firm size	0.111	0.113	0.100	0.108	0.102	0.125
	(0.094)	(0.095)	(0.095)	(0.094)	(0.098)	(0.108)
Log R&D intensity					0.010	0.054
					(0.105)	(0.121)
Observations	1384	1384	1384	1384	1370	1101

*** at .01, ** at .05, * at .10

H1

H2

Hypothesis Tests

	R&D invention (=1) vs. non-R&D invention (=0)	
	Logit	
Variables	**Full sample**	**Product invention only**
Generality (H1)	**0.141****	**0.150****
	(0.066)	**(0.073)**
Visibility (H2)	**-0.724*****	**-0.960*****
	(0.205)	**(0.238)**
Relative size of R&D to non-R&D	0.010	0.054
	(0.105)	(0.121)
Controls	Yes	Yes
Obs	1370	1101

*** at .01, ** at .05, * at .10

Results (using firm dummies)

	R&D invention vs. non-R&D invention		
	Logit		
Variables	(1)	(2)	(3)
Generality of knowledge	0.141 **	0.215 **	0.030
	(0.066)	(0.108)	(0.104)
Visibility of knowledge	-0.724 ***	-0.881 ***	-0.810 **
	(0.205)	(0.332)	(0.397)
Inv. patent propensity	0.003	0.005	0.009 *
	(0.003)	(0.005)	(0.005)
Industry annual growth	0.113 **	0.129	0.143
	(0.053)	(0.089)	(0.101)
Firm size	0.102	0.025	
	(0.098)	(0.219)	
Log R&D intensity	0.010	-0.215	
	(0.105)	(0.236)	
Firm dummies	No	No	Yes
Observations	1370	444	444

*** at .01, ** at .05, * at .10

Drivers of R&D v. non-R&D

- General knowledge environments associated with increase in rate of R&D invention (H1)
- Knowledge visibility associated with increase in rate of non-R&D (H2)
- Including firm dummies, results similar (although general knowledge becomes n.s.)
- Results robust to different operationalizations of R&D v. non-R&D (although sig. levels sometimes change)

Findings

- Examine different loci of innovation inside an organization
  - Project level (not firm-level) [cf. EU studies, NSF BRDIS]
- Overall, the rate of "significant" non-R&D innovation is ~10%
- Industry variation in the rates of non-R&D innovation

Findings: Drivers of R&D v. non-R&D

- Industry knowledge environments significant affect rates of non-R&D innovation
  - General knowledge environments associated with increase in invention productivity by R&D (H1)
  - Knowledge visibility associated with increase in invention productivity by non-R&D (H2)
- Results robust to different operationalizations of R&D v. non-R&D (although sig. levels sometimes change)

Discussion and Conclusions

- Shows how modeling the variations in the learning process and incorporating project level data can provide tests of the empirical implications of these different literatures
  - Limitation of R&D focused models
- Observe non-R&D inventions beyond the stereotypical image of process improvements or marginal shop-floor inventions
- Less general and more visible knowledge environments (relatively) increase non-R&D learning for innovation.
  - Need to develop more sophisticated measures of visibility and other knowledge characteristics

Managerial and Policy Implications

- A need for more work on how to build **a learning organization** to cultivate non-R&D workers' creativity
  - Reorganizing structure (Thomas, 1994; Vallas, 2003) e.g., lean manufacturing, re-engineering programs
  - Choices in technology design (Noble, 1984, Zuboff, 1988)
- Encourage workers to disclose their invention regardless of their work role (**Culture of innovation**)
- Importance of non-R&D work (manufacturing, sales, etc.) as **another source for innovation**
  - Outsourcing of manufacturing = outsourcing of innovation

Questions? Comments? Suggestions?

jpwalsh@gatech.edu

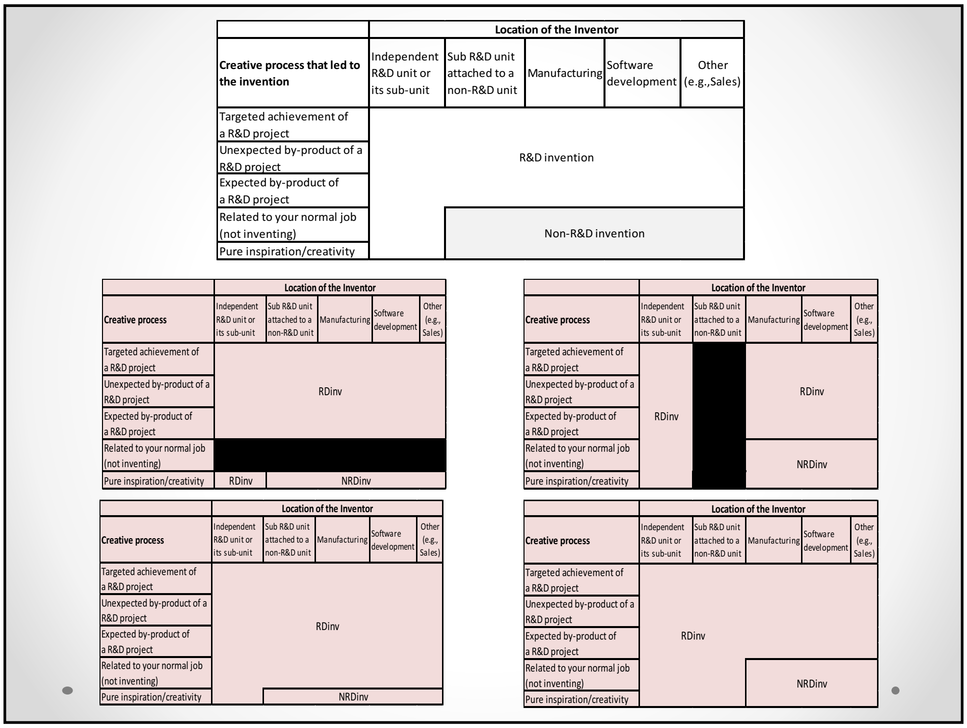
High vs. Low visible industries

Visibility of knowledge	High	food, beverage, textile, apparel, wood product, paper, printing, fabricated metal, machinery, computer and electronic product (except semiconductor), furniture and miscellaneous manufacturing (including medical equipment and supplies)	NAICS 311-316, 321-323, 332-334 (except 3344), 336-339
	Low	chemical, pharmaceutical, petroleum and coal, plastics and rubber, non-metallic mineral, metal, semiconductor, and electrical equipment	NAICS 324-327, 331, 3344, 335

		Organizational forms	
		Prefactory/early	Railroad/modern
Mechinical	High	Furniture,Miscellaneous (including medical equipment)	Fabricated metal, Machinery, Computer and electronic (except semiconductor), Transportation
	Low	Food, Beverage, Textitle, Wood, Paper, Printing	Chemical, Pharmaceutical, Plastics, Rubber, Nonmetallic mineral, Primary metal, Semiconductor, Electrical

Statistics on non-R&D invention in US manufacturing industries

			NRD Invention	Non-R&D inventors' work units			
				R&D subunit attached to non-R&D unit (e.g., technical service)	Manufacturing	Software development	Others (e.g., sales)
			%	(% of non-R&D inventions)			
NAICS		N	(1)	(2)	(3)	(4)	(5)
311-2	Food, beverage and tobaco product manufacturing	5	0.0	0.0	0.0	0.0	0.0
313-6	Textile, apparel and leather	10	21.4	0.0	100.0	0.0	0.0
321-3	Wood product, paper, printing and related support activities	21	20.8	80.0	20.0	0.0	0.0
325	Chemical manufacturing (except pharmaceutical and medicines)	257	4.1	41.7	41.7	0.0	16.7
3254	Pharmaceutical and medicine manufacturing	56	4.5	33.3	33.3	0.0	33.3
326	Plastics and rubber products manufacturing	78	9.1	25.0	37.5	0.0	37.5
327	Nonmetallic mineral product manufacturing	36	11.9	60.0	20.0	0.0	20.0
331	Primary metal manufacturing	16	10.5	50.0	50.0	0.0	0.0
332	Fabricated metal product manufacturing	74	19.5	31.3	50.0	0.0	18.8
333	Machinery manufacturing	266	18.6	42.1	33.3	1.8	22.8
334	Computer and electronic product manufacturing (except semiconductor)	441	12.9	28.4	28.4	16.4	26.9
3344	Semiconductor and other electronic component manufacturing	177	11.7	53.9	23.1	15.4	7.7
335	Electrical equipment, appliance, and component manufacturing	121	11.5	52.9	23.5	11.8	11.8
336	Transportation equipment manufacturing	63	9.5	50.0	37.5	0.0	12.5
337-9	Furniture and related product, and miscellaneous manufacturing	117	14.8	25.0	30.0	5.0	40.0
	All	1738	12.1	38.6	32.1	7.6	21.7



Robustness tests for alternative measures of R&D vs. non-R&D invention

	Creative process criteria	
	Logit	
	All normal job = RDinv	All normal job = missing
Variables	(1)	(2)
Generality	0.189 **	0.203 **
	(0.088)	(0.090)
Visibility	-0.633 **	-0.666 **
	(0.263)	(0.266)
Inv. patent prop	0.007 *	0.007 *
	(0.004)	(0.004)
Industry growth	0.129 *	0.139 *
	(0.076)	(0.077)
Firm size	0.162	0.156
	(0.128)	(0.130)
Log R&D intensity	0.085	0.069
	(0.142)	(0.143)
Observations	1370	1226

*** at .01, ** at .05, * at .10

Robustness tests for alternative measures of R&D vs. non-R&D invention

	Affiliation criteria			
	Logit		Multinomial probit	
	All R&D sub = RDinv	All R&D sub = missing	Base group = All R&D sub (to non-R&D) inv	
Variables	(1)	(2)	RDinv (3)	NRDinv (4)
Generality	0.068	0.076	0.055 *	0.007
	(0.082)	(0.081)	(0.029)	(0.048)
Visibility	-0.724 ***	-0.731 ***	-0.024	0.430 **
	(0.256)	(0.256)	(0.126)	(0.175)
Inv. patent prop	0.005	0.006	0.005 **	0.000
	(0.004)	(0.004)	(0.002)	(0.003)
Industry growth	0.123 *	0.124 *	0.027	-0.049
	(0.070)	(0.069)	(0.022)	(0.039)
Firm size	0.300 ***	0.247 **	-0.286 ***	-0.434 ***
	(0.106)	(0.108)	(0.078)	(0.093)
Log R&D intensity	0.029	0.035	0.048	0.024
	(0.145)	(0.142)	(0.068)	(0.101)
Observations	1370	1133	1370	

*** at .01, ** at .05, * at .10

Variable	N	Mean	SD	Min	Max
1 R&D (vs. Non-R&D) inv	1738	0.88	0.33	0.00	1.00
2 Generality of knowledge	1738	0.00	2.32	-3.44	8.34
3 Codifiable	1738	0.00	1.00	-3.05	2.46
4 Basic	1738	0.00	1.00	-1.01	4.18
5 University-driven	1738	0.00	1.00	-2.34	1.70
6 Visibility of knowledge	1738	0.57	0.50	0.00	1.00
7 Inventor patent propensity	1384	68.24	32.44	0.00	100
8 Industry annual growth	1738	-2.94	2.80	-6.42	6.90
9 Firm size	1738	6.23	0.89	3.91	6.62
10 Log R&D intensity	1718	-3.03	0.87	-7.42	-0.75

Variable	Correlation								
	1	2	3	4	5	6	7	8	9
1 R&D (vs. Non-R&D) inv	1.00								
2 Generality of knowledge	**0.08**	1.00							
3 Codifiable	0.03	**0.71**	1.00						
4 Basic	**0.10**	**0.82**	**0.35**	1.00					
5 University-driven	**0.05**	**0.80**	**0.29**	**0.56**	1.00				
6 Visibility of knowledge	**-0.10**	**-0.12**	0.02	**-0.35**	0.05	1.00			
7 Inventor patent propensity	0.04	0.03	0.02	0.02	0.04	-0.03	1.00		
8 Industry annual growth	0.04	**0.18**	-0.09	**0.52**	-0.01	**-0.11**	-0.01	1.00	
9 Firm size	0.03	0.00	-0.03	0.02	0.00	**-0.05**	-0.04	-0.05	1.00
10 Log R&D intensity	0.02	**0.31**	**0.34**	**0.11**	**0.28**	0.03	**-0.09**	**0.06**	**-0.14**

Bold at p < .05