University Research Productivity and its Impact on the Regional Agricultural Economy: The Case of Colorado State University and the Colorado Economy

Yoo Hwan Lee

Department of Agricultural and Resource Economics
Colorado State University, Fort Collins CO 80523
yoo.lee@colostate.edu

Gregory D. Graff

Department of Agricultural and Resource Economics
Colorado State University, Fort Collins CO 80523
gregory.graff@colostate.edu

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Yoo Hwan Lee[1], *Gregory D. Graff*[1]

1. Department of Agricultural and Resource Economics at Colorado State University, Fort Collins CO 80523

Introduction

The economic impacts of university research and technology transfer on industrial R&D and commercial innovation are important to policy makers and industry leaders, and have been the subject of economic analysis. University research is a major engine of innovation in both traditional and high-tech industries. Interaction between university and industry generates positive social returns as well as economic growth and development. .

History of University and U.S. Policy Changes

- **Educational Mission**: Teaching, preservation, and dissemination of knowledge; 19th century: **Morrill Land-Grant Act of 1862**.
- **Research Mission**: By late 19th century, transformed to research university, kept original educational mission: **Hatch Act of 1887**.
- **Outreach Mission**: In early 20th century, a third mission emerged for economic and social development, still keeping other two missions: **Smith-Lever Act of 1914** & **Bayh-Dole Act of 1980**.

Literature Review

- **Knowledge Production Function (KPF)**: **Griliches (1979)**, and **Pakes & Griliches (1984)** analyzed patents as a useful indicator of unobservable knowledge capital created by U.S. industry, developing an empirical model of the relationship between research expenditures as input and patents as output.
- **Knowledge Production Function in agriculture**: **Pardey (1989)** analyzed the research input-output relationship within U.S. state agricultural experiment stations (SAES).
- **Academic Knowledge Production**: **Jaffe (1989)** modeled the knowledge spillovers from university R&D. **Mansfield (1991, 1995)** analyzed the extent to which industry's new products and processes were based on recent academic research. **Adams & Griliches (1998)** analyzed the research productivity of U.S. research universities by academic field. **Crespi & Geuna (2008)** applied a polynomial distributed lags model to the research inputs and outputs of research universities.
- **Academic Intellectual Property**: **Mowery et al (2001)** show how patenting and licensing activities by universities increased due to public policy. According to **Shane (2002)**, to the extent that universities foster faculty entrepreneurship, they help to overcome a range of market failures.

Research Questions

- What are the historical trends of CSU's knowledge production and transfer activities, across all of the different colleges, departments, and research units of the university?
- How do changes in research inputs affect research outputs, across the different units of the university?
- How can we model the dynamics of university knowledge production inputs and outputs?
- What is the importance of a state university's research on innovation and economic development within the state economy?

Data Description

- A comprehensive dataset of Colorado State University's research inputs and outputs from 1989 to 2012.
- **Research Inputs**: Total Research Expenditures, Grant Awards, FTEs, Lab Space, & Value of Equipment.
- **Table 1**: Summary Statistics: Various research inputs

	Total Expenditures (1989-2012)	Total Grant Award (1989-2012)	FTEs (2003-2013)	Research Space (2013)	Value of Equipment (1981-2013)
	Mean (million $)	Mean (million $)	Mean	Total (sq ft)	Sum (million $)
CSU Total	195.01	164.64	3965.03	1,899,843	180.96
Veterinary Medicine	46.87	38.09	955.96	546,402	59.67
Engineering	45.38	40.27	653.95	383,434	54.55
CSFS	35.70	6.39	—	—	—
CEMML	25.33	11.87	260.93	13,581	—
Natural Sciences	21.38	21.68	595.96	323,524	38.43
Natura Resources	16.15	21.29	339.21	108,749	6.62
Others	15.94	7.54	—	—	2.84
Agricultural Sciences	13.06	8.74	243.56	258,315	10.26
Health & Human Sciences	7.46	6.57	319.38	155,977	5.29
Business	1.42	0.89	155.65	33,634	1.71
Liberal Arts	1.31	1.32	440.45	76,227	1.59

Note: CEMML (Center for Environmental Management of Military Lands) founded in 2001 and CSFS (Colorado State Forest Service) was moved into CSU in 2004

- **Research Outputs by channels of impact**:
  1. Public Domain: Journal Articles & Degree Awards.
  2. Collaboration: Private Sponsorship Grant Awards, Extension-Budgets, & Industry Co-Authorship Articles.
  3. Patenting/Licensing: Invention disclosures & Patent applications.
  4. Venture Creation: Startup companies.

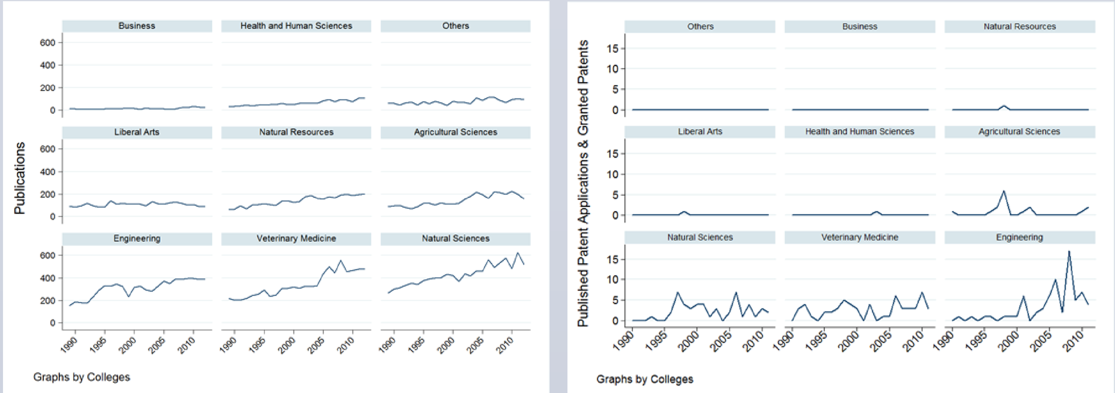
- **Figure 1**: Four types of knowledge dissemination channels.

	Non-Rivalrous ("Slippery" information, lower transaction costs, lower capacity requirements)	Rivalrous ("Sticky" information, higher transaction costs, higher capacity requirements)
Non-excludable	Release via Public Domain	Collaboration
Invoked exclusion	Patenting/ Licensing	Venture Creation

- **Table 2**: Summary Statistics: Selected research outputs (1989-2012)

	Publications		Doctoral Degree		Industry Co-authorship Articles		Patent Applications		Invention Disclosures		Startups		
	Mean	Sum	Mean	Sum	Mean	Sum	Mean	Sum	Mean	Sum	Mean	Sum	Obs.
CSU Total	1621.5	38,916	166.63	3,999	123.33	2,960	8.13	195	62.56	1,564	1.71	41	24
Agricultural Sciences	143.83	3,452	16.88	405	9.46	227	0.67	16	7.44	186	0.17	4	24
Business	14.83	356	0	0	1.125	27	0	0	0.08	2	0	0	24
Engineering	308.75	7,410	40	960	33.75	810	2.88	69	19.52	488	0.46	11	24
Human & Health Sciences	62.92	1,510	3.17	76	2.83	68	0.04	1	1.16	29	0.13	3	24
Liberal Arts	106.38	2,553	9.13	219	1.79	43	0.04	1	0.40	10	0.04	1	24
Natural Resources	140.33	3,368	14.21	341	8.54	205	0.04	1	0.72	18	0.00	0	24
Natural Sciences	428.13	10,275	53.04	1273	18.54	445	2.04	49	12.40	310	0.50	12	24
Veterinary Medicine	340.71	8177	22.13	531	44.13	1059	2.42	58	18.20	455	0.42	10	24
Others	75.63	1815	8.08	194	3.17	76	0	0	2.64	66	0	0	24

- **Figure 2**: Selected research outputs by college level (1989-2012)



Model Framework

- The quantitative relationship between research inputs and outputs is called the "Knowledge Production Function (KPF)" by **Pakes & Griliches (1984)** and can be modelled by a number of production functional form, including Cobb-Douglas.
- We adapt a panel count data model, using a negative binomial MLE with polynomial distributed lags, for determining the systematic relationship between inputs and outputs.
- **Equation 1**: Given the panel data model with the count dependent variable is negative binomial. If beta is transformed as polynomial distributed lag (PDL), equation 1,

$$\ln Y_{i,t} = \alpha + \sum_{j=0}^{k} \beta_j \ln X_{i,t-j} + \delta T + \varepsilon_{i,t}$$

$$\text{where,} \quad \beta_j = \omega_0 + \omega_1 \cdot j + \omega_2 \cdot j^2 + \omega_2 \cdot j^3 + \cdots + \omega_m \cdot j^m, \ \forall \ m < k$$

"i" is a college, department, or research unit, and "t" is a time period

- **Equation 2**: becomes the intermediate equation of PDL:

$$\ln Y_{i,t} = \alpha + \omega_0 z_{0i,t} + \omega_1 z_{1i,t} + \omega_2 z_{2i,t} + \omega_3 z_{3i,t} + \omega_4 z_{4i,t} + \varepsilon_{i,t}$$

$$\text{where,} \quad z_{0,i,t} = \sum_{\eta=0}^{k} \eta^0 X_{i,t-\eta} = X_{i,t} + X_{i,t-1} + X_{i,t-2} + X_{i,t-3} + \cdots + X_{i,t-k}$$

$$\vdots$$

$$z_{m,i,t} = \sum_{\eta=0}^{k} \eta^m X_{i,t-\eta} = X_{i,t-1} + 2^m X_{i,t-2} + 3^m X_{i,t-3} + \cdots + k^m X_{i,t-k}$$

- **Equation 3**: Unrestricted PDL model after recovering betas.

$$\ln Y_{i,t}^{UR} = \alpha + \sum_{j=0}^{6} \tilde{\beta}_j^{UR} \ln X_{i,t-j} + \tilde{\delta} T + \varepsilon_{i,t}$$

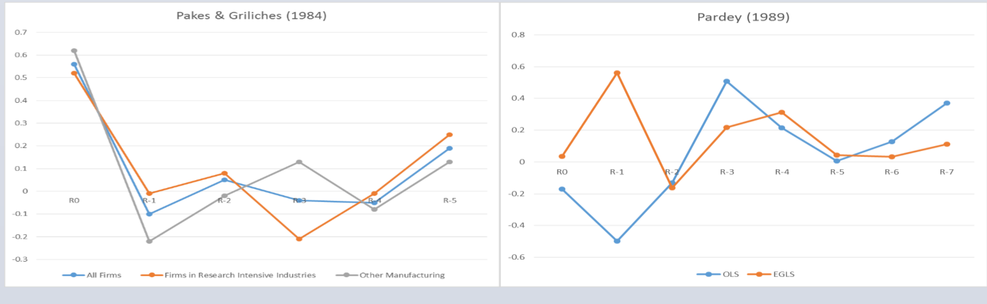
- **Equation 4**: Imposing end-point restriction: Restricted PDL model.

$$\ln Y_{i,t}^{R} = \alpha + \sum_{j=0}^{6} \tilde{\beta}_j^{R} \ln X_{i,t-j} + \tilde{\delta} T + \varepsilon_{i,t}$$

where, end point restriction:

$$\beta_{k+1} = \omega_0 + (k+1)\omega_1 + (k+1)^2 \omega_2 + \cdots + (k+1)^m \omega_m = 0$$

- **Figure 2**: Pattern of slope coefficients of previous studies.



- **Equation 5**: We create a Collaboration Index (million $) as a proxy variable measuring traditional university collaboration activities. It consists of grant awards from industry sponsors ("private"), published academic articles with industry co-authors ("co-author") transformed by the average dollars per article, and departmental level expenditures on extension ("extension"):

$$CI_{i,t} = private_{i,t} + co-author_{i,t} + extension_{i,t}$$

- **Equation 6**: Tech transfer metrics consists of invention disclosures ("invention"), patent applications ("patent"), and startup companies ("startup").

$$TTM_{i,t} = invention_{i,t} + patent_{i,t} + startup_{i,t}$$

Selected Empirical Result

- **Table 3**: Select regression results, at department level, 1989-2012

	Publications ($k^b = 6$, $m^c = 2$)			Collaboration Index ($k^b = 9$, $m^c = 4$)		Tech Transfer Metrics ($k^b = 9$, $m^c = 2$)		
	ODL[a]	Unrestricted PDL[d]	Restricted PDL[d]	ODL[a]	Unrestricted PDL[d]	ODL[a]	Unrestricted PDL[d]	Restricted PDL[d]
Negative binomial	YES	YES	YES	NO	NO	YES	YES	YES
Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES
Expend	0.0363***	0.0235***	0.0126*	0.0018	0.0079	0.0807**	0.0432**	0.0492***
	(0.0138)	(0.0078)	(0.0074)	(0.0250)	(0.0219)	(0.0383)	(0.0178)	(0.0168)
_t-1	-0.0271	0.0020	0.0089***	0.0289	0.0255*	0.0033	0.0390***	0.0323***
	(0.0178)	(0.0041)	(0.0033)	(0.0305)	(0.0152)	(0.0532)	(0.0109)	(0.0098)
_t-2	0.0074	-0.0101	0.0059***	0.0905***	0.0679***	0.0452	0.0328***	0.0180***
	(0.0180)	(0.0056)	(0.0011)	(0.0321)	(0.0145)	(0.0568)	(0.0105)	(0.0043)
_t-3	-0.0102	-0.0127	0.0035	0.0438	0.0943***	-0.0604	0.0249**	0.0064**
	(0.0187)	(0.0059)	(0.0024)	(0.0341)	(0.0103)	(0.0585)	(0.0123)	(0.0025)
_t-4	-0.0055	-0.0057	0.0017	0.1086***	0.0839***	0.0813	0.0151	-0.0025
	(0.0199)	(0.0040)	(0.0033)	(0.0344)	(0.0131)	(0.0529)	(0.0126)	(0.0051)
_t-5	-0.0168	0.0108**	0.0005	0.0355	0.0354**	-0.0009	0.0034	-0.0087
	(0.0207)	(0.0047)	(0.0033)	(0.0393)	(0.0141)	(0.0539)	(0.0108)	(0.0072)
_t-6	0.0637***	0.0368***	-0.0001	0.0161	-0.0324**	0.0663	-0.0101	-0.0123
	(0.0222)	(0.0126)	(0.0021)	(0.0513)	(0.0155)	(0.0902)	(0.0084)	(0.0081)
_t-7	—	—	—	-0.1502***	-0.0812***	-0.0019	-0.0255**	-0.0132*
	—	—	—	(0.0523)	(0.0206)	(0.0880)	(0.0113)	(0.0079)
_t-8	—	—	—	-0.0121	-0.0528***	0.0096	-0.0427**	-0.0115*
	—	—	—	(0.0523)	(0.0171)	(0.0904)	(0.0213)	(0.0065)
_t-9	—	—	—	0.1175***	0.1309***	-0.1987**	-0.0617*	0.0688***
	—	—	—	(0.0426)	(0.0348)	(0.0838)	(0.0359)	(0.0252)
Sum of lag coeffs	0.0477***	0.0446***	0.0330***	0.2803***	0.2795***	0.0245	0.0185	0.1264***
	(0.0079)	(0.0072)	(0.0097)	(0.0199)	(0.0198)	(0.0306)	(0.0286)	(0.0260)
Time Trend	0.0227***	0.0228***	0.0236***	-0.0076*	-0.0075*	0.0250**	0.0254**	0.0264**
	(0.0028)	(0.0028)	(0.0027)	(0.0041)	(0.0040)	(0.0124)	(0.0122)	(0.0123)
Constant	2.1544***	2.1536***	2.1486***	-0.0631	-0.0629	0.2365	0.2882	0.1651
	(0.0958)	(0.0956)	(0.0955)	(0.0632)	(0.0631)	(0.2549)	(0.2461)	(0.2332)
SBIC	5967.942	5944.8	5946.8	1200.7	1171.2	1523.1	1483.0	1478.8
Obs	1044	1044	1044	930	930	675	675	675
Group	58	58	58	62	62	45	45	45

Note: a is ordinary distributed lag model such as Koyck model, b is number of lag length (k), c is number of degree (m), d is polynomial distributed lag model or Almon model, SBIC is Schwarz Bayesian Information Criterion: the smallest value is the best fitness of model, Standard errors in parentheses, and *** at 1%, ** at 5%, and * at 10% significant.

- Given results, (**See Table 3**), PDL models have better statistically significant and more intuitive outcomes than ordinary distributed models. Comparing across models, the PDL's SBIC are much smaller than the ODL model's, but have similar constant terms.
- In particular, ODL models have discontinuous patterns of their slope coefficients, but the restricted PDL model tells us that the current stock of knowledge is a multiplicative function of past expenditures.
- All of the models have decreasing returns to scale, and the long run effects of research expenditures positively and significantly affect current knowledge output measures, except for the tech transfer metrics in the ODL and unrestricted PDL models.

Evidence of Impact on Ag Sector of the Economy

- Knowledge is not only an important issue of economic growth from spillovers, but also from direct impact on commercial invention and innovation. Basic university knowledge had public good attributes. But, in recent decades, it has became more complex.
- Interactions between university and industry are important for dissemination of university knowledge, and the geographic location of impact is arguably influenced by characteristics of the knowledge being disseminated (**See Figure 1**).
- The state economy of Colorado has long depended on agriculture and innovation as an drivers of economic growth. In 2011, the supply of agricultural inputs by Colorado agribusinesses contributed $2 billion, crop and livestock sales contributed more than $8 billion, and food/beverage manufacturing contributed $15 billion to the state economy (**Graff et al 2014**).
- In 2011, in the Ag. and food sciences, CSU researchers co-authored 214 articles with industry, received $18.3 million in private sponsored grants, $13.2 million in extension budgets, and had 23 invention disclosures, 11 patent applications, and 5 startups.

- **Table 4**: Geographic distance of industry co-authors with CSU's publications by research categories (1989-2012).

Web of knowledge categories	Geographic Distance: In Colorado*** (# of Articles / Citation* / Team Size**)	Geographic Distance: Outside Colorado**** (# of Articles / Citation* / Team Size**)	Sum of Articles	Share of Total (%)
Agriculture-related directly	59 / 6.6 / 4.5 (30.9%)	132 / 10.6 / 6.0 (69.1%)	191	6.5
Food-related	26 / 38.3 / 7.2 (16.0%)	136 / 47.5 / 9.7 (84.0%)	162	5.5
Natural resource-related	59 / 13.2 / 4.3 (31.4%)	129 / 19.9 / 5.5 (68.6%)	188	6.4
Engineering-related	128 / 11.9 / 4.3 (32.4%)	267 / 14.1 / 5.2 (67.6%)	395	13.3
Biology/Chemistry-related	118 / 18.4 / 5.5 (28.0%)	303 / 34.9 / 6.4 (72.0%)	421	14.2
Veterinary-related	154 / 13.1 / 5.7 (18.6%)	676 / 19.7 / 6.7 (81.4%)	830	28.0
Others	202 / 14.4 / 5.3 (26.1%)	571 / 20.5 / 11.5 (73.9%)	773	26.1
Total Categories	746 / 14.5 / 5.2 (25.2%)	2214 / 22.5 / 7.8 (74.8%)	2960	100.0

** Citation is average citations per articles ** Team size represents average number of authors per article. *** In Colorado represents the locations in Colorado, in general, it is within 300mi. **** Outside Colorado means other states in U.S. and foreign locations. Parentheses are ratio between these two.*

- **Table 5**: Geographic location of CSU affiliated startups by research category levels (1989-2012).

Research Categories	Geographic Distance: In Colorado*	Geographic Distance: Outside Colorado**	Sum of Companies	Share of Total (%)
Agriculture-related directl	4 (100%)	0 (0.0%)	4	9.8
Food-related	2 (100%)	0 (0.0%)	2	4.9
Engineering-related	9 (81.8%)	2 (18.2%)	11	26.8
Biology/Chemistry-relatec	8 (100%)	0 (0.0%)	8	19.5
Veterinary-related	9 (90.0%)	1 (10.0%)	10	24.4
Others	5 (83.3%)	1 (16.7%)	6	14.6
Total Categories	37 (90.2%)	4 (9.8%)	41	100.0

** In Colorado represents the locations in Colorado, in general, it is within 300 mi. ** Outside Colorado means other states in U.S. , except foreign locations. (None of foreign locations in our dataset)*

- **Total outside co-inventors on CSU patents** were 185 out of 392 inventors from 1990 to 2011, with 23% in state, 65% out of state, and 12% foreign. (Total CSU's patents was 195 from 1990-2011)
- **Total CSU's invention disclosures** were 1,564 from 1989 to 2012: with 189 (12%) Ag. related, 17 (1%) in natural resources, 20 (1%) in food, 240 (15%) in bio or chemistry, 488 (31%) in engineering, 453 (29%) in veterinary, and 157 (10%) in other fields.

Conclusions

This study investigated CSU's knowledge production and transfer activities, and how they impact commercial innovation, especially in the agriculture-related sectors. Although it is only one institution, we attempt to ascertain the systematic relationship between research inputs and outputs. Preliminary empirical results suggest that CSU's research outputs are heterogeneous, with public domain research outputs (publications) having more systematic relationship with research inputs, compared to others channels. In measures of economic impact, CSU's publication output is significant both locally and globally. Indications of geographic distribution of industry collaboration, from co-authorship on articles, shows out-of-state and foreign contribution of 75%, from patent applications, 77%. However, CSU affiliated startup companies involve "sticky" knowledge transfer, with only 10% located out of state and none in a foreign location.

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Contact

Lee, Yoo Hwan: (email: yoo.lee@colostate.edu)
Graff, Gregory D.: (email: gregory.graff@colostate.edu)