Research Expenditures in Higher Education Institutions and University Technology Transfer Licensing

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Abstract

I relate the numbers of university licenses and options to both university characteristics and research expenditures from federal government, the industry, state/local governments and institutional sources. I use the polynomial distributed lag model for unbalanced panel data to estimate the effect of research expenditures from different sources on licensing activity. I find evidence suggesting both federal and business funded research expenditures take 2-3 years from lab to licenses. Breaking down licenses by different types of licensees, I found that federal R&D expenditures have highest effect with small companies while business-funded expenditures have higher effect in licenses with large companies and are more likely to produce licenses yielding more than 1 million dollars. Institution and state/local funding have smaller effect relative to business funding.

Keywords Science Policy; Technology Transfer; innovation; research expenditures; Universities

JEL Classification O31; O32; O38; I23; L31

I. Introduction

To justify public funding for research in higher education institutions, the knowledge generated from the scientific research projects plays an important role. Because most of the results of university research are published in peer-reviewed academic journals without explicit economic values, the output of academic research must be measured by other quantities. The intellectual properties produced by these research have become an important measure for both assessing academic research output and understand the societal benefit generated by especially when university research often provides the basic scientific knowledge that drives other applications (Muscio, 2012).

There have been substantial changes in the management of intellectual property originating from research in higher education institutions since 1980 in the United States. Following the enactment of Bayh-Dole Act of 1980, the inventors of the inventions arising from federally-funded research were permitted to retain the patent rights provided that inventors are affiliated with universities, non-profit research institutions or small businesses. Bayh-Dole act allowed the money from patents of university innovations to be retained by academic inventors and facilitated the prog the institutions and academic partnerships with industry became commonplace. The Bayh-Dole act also facilitated the creation of Technology Transfer Offices (TTOs) in the research universities. TTOs specialize in representing the institution and inventors to negotiate the transfer of intellectual property between academic institutions and the industry. Therefore, the performance of TTOs has been hypothesized to directly correlate with its ability to successfully license the technology.

Two theories predict different societal welfare for the increased intellectual property protection of knowledge generated by academia. One theory suggests that in the absence of appropriate property rights protections of useful inventions (patents), both the private industry and academic inventors would be discouraged from investing in commercialization of inventions, even if the overall societal welfare is positive. The increase of licensing and patents would therefore lead to a net welfare increase as the society benefits from the domestic commercialization of these inventions (Heisey, 2011). However, past studies have found it empirically difficult to support this theory that positively associates welfare with intellectual property protection arising from academia. On the other hand, other studies had suggested that the increase in transaction cost and access costs as a result of intellectual property may results in a welfare loss for the public. Patents also generate significant static inefficiencies due to the imperfect abiliy for patent holders to price discriminate. Patents also introduce the dead weight loss due to the inherent monopoly granted to patent holders. In addition, assuming universities administrators have the utility function to maximize the revenue of the institution, the licensing income may introduce bias in the decision making and direct administrators to encourage more research subjects in more patentable areas and to put less attention in areas less patentable and instruction (Just, 2006). In the long run, therefore, an increase in licensing activity reduces the societal welfare and the production of public good research. To evaluate the theories relating to the university technology transfer and commercialization, I test various hypotheses about the university research expenditure, number of licenses and TTO characteristics. First, the source of research expenditure may have different effect on the number of licenses executed by TTOs. Governmental funding agencies, such as the National Institute of Health (NIH) and National Science Foundation (NSF) of the United States, employ a two-stage peer-reviewing processes where the experts in both stages considers the scientific merits of the project and authors' qualification without explicitly considering the commercialization potential of research projects. Business funded research, on the other hand, may have a stronger emphasis on commercialization and patentability of the research subjects and therefore lead to a larger number of licenses executed. In addition, I also investigated the temporal lag between the research expenditures from various sources to the number of licenses that were executed. Second, I consider the effect of different characteristics of university and their influences on the university's intellectual property output, in the form of technology transfer licenses executed. For example, an institute with a school of medicine may have more medical-related research projects, which contribute to the large majority of technology licenses from academia whereas the land grant designation was given with an emphasis on public service (Heisey, 2011). Consistent with previous literatures that suggested strong association between licensing activities and TTO characteristics, I also examined the effect of the experiences and the size of TTOs and their effect on licenses.

Lastly, I analyzed the number of licenses and the different types of licensees classified by sizes.. A significant amount of technology transfers are licensed to "research-based academic spin-off companies" (RASOCs) which were startups established by faculty members. Past studies have found that these companies tend to focus on single project and facilitate the commercialization of the license faster than large companies (Vincett, 2010).

The rest of the paper is organized as follows. I first reviewed the empirical literature on the university technology transfer, performance of TTOs and the academic research expenditure in the United States. Following that I briefly described the data source and different variables in Part III along with the empirical specification for the econometrics model I used in Part IV. The results are presented with several alternative estimation techniques in Part V. Lastly, the final section VI discusses the potential implications of our findings and concludes the paper.

II. Literature Review

A. Academic research expenditures and funding

The majority of the research funding in the United States for higher education institution research and development (R&D) in science and engineering fields comes from the federal government with its various agencies as shown in Figure 1. The second largest

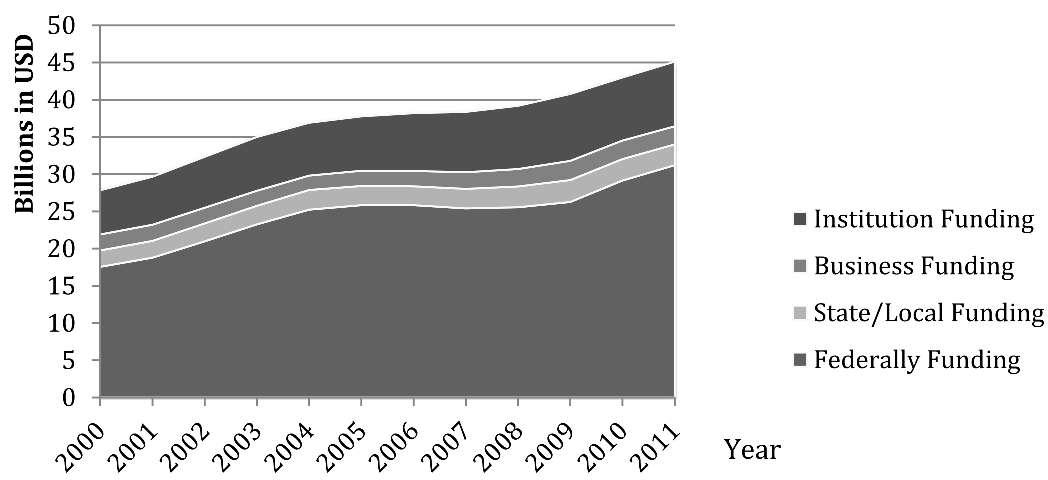

Figure 1. Research Funding in US in Science and Engineering Fields in constant

source of research expenditures is from institutional sources. Private sector funded research expenditures ("Business") have been consistently between 7-12% of that from the federal government varying from year to year. Federal government funding between 2000 and 2011 largely drove the increases in research expenditures. Federal government generally supports research through awards, contracts or grants to researchers while industry support research through sponsored research projects or corporate-sponsored research centers (CRS, 2012). Business funding for research have been found to have mixed effects the output of publications by researchers in different studies but positive association with patent application (Hottenrott, 2011).

Different funding sources of R&D expenditures also choose projects to fund through different decision-making processes with different utility functions. While the private sector evaluate the commercialization potential and application values of research outcomes, Federal government utilizes a dual peer review process to evaluate research proposals. For example, the grant applications are first evaluated by a panel of non-government scientists in relevant areas, who gave a priority score for each new grants application in the National Institute of Health. The applications with priority scores above certain pre-determined threshold are then forwarded to the one of the twenty-seven NIH institutes where a national advisory committee in that institute makes recommendations to the director of the institute to make final funding decisions. In both stages, the committees consider an application's significance, technical merit, innovativeness and investigators' qualifications. Although NIH implemented the science-driven funding mechanisms, past studies have found that the funding from NIH are influenced by other factors such as the state's congressmen membership of the Subcommittee of Labor, Health, and Human Services (LHHS) of the Committee on Appropriations in the House of Representatives (Hegde, 2009). In addition, the institutional characteristics of the grant applicant have been found to associate with funding decision. The sizes of the institution, which indicate the size of the peer groups for the scientists, have been found to positive associated with the funding outcomes within Germany (Grimpe, 2012).

B. Complementarity Public Research Funding

In classical economic theory, public research funding for biomedical R&D can be complement or substitute to the private R&D funding. Public research often serve as the financial support for the initial phase of research in basic biomedical or pharmaceutical sciences before the technologies that have commercialization potential attract private investments. The empirical model of pharmaceutical R&D postulated that the level of private investment are affected by the interaction between marginal cost of capital (MCC) and marginal rate of return (MRR). Factors changing the MCC include the availability of funds, interest rates. MRR is determined by demands, which are associated with factors such as health status, FDA regulatory standards and public scientific knowledge (Toole, 2007). The basic assumption of this model is the interaction between public research funding for basic research and the private investment in clinical or later-stage developments. The lag between the two can be measured by OLS, although the multicollinearity between different time lag dependent variables may produce imprecise estimates and require correction. Therefore, a finite-distributed lags model for two stages may be required to resolve the multicollinearity among lagged variables in the regression, which are called Almon lags (Toole 2007). The lags coefficient can be positive or negative, which can be viewed as an indicator for the complementarity or substitutability between public and private R&D spending. Previous studies have found that there exist a strong complementary relationship between private and public R&D funding in difference science disciplines, including pharmaceutical research, in both US and other European countries (Muscio 2013; Toole 2007; Blume-Kohout 2012). Some studies have used the lags between the basic research funding and late-stage developments as the end points for the lag model, such as clinical trials or new molecule entity approval dates. The complementarity of public research funding and private investments suggests that public research funding have an effect in the initial commercialization of technology from university whereas business funding are more critical in later-stage.

In some cases, the complementarity is very critical. For example, developing new technology or novel pharmaceuticals for neglected diseases (NDs) requires public research funding to seed most of the initial researches due to the inability of NDs to attract private investments. NDs are typically defined as the diseases that create disproportional impact, in the form of mortality and morbidity, on low- and middle-income countries relative to high-income countries. While there is little consensus on the exact list of NDs, the majority of NDs is unable to attract private investments due to the affected population's low ability to pay (Moran, 2009). The World Health Organization describes NDs as being strongly associated with poverty, and flourish in impoverished and tropical environments (Cloyd, 2012). Thus, if the pharmaceutical development process is parallel to solving jigsaw puzzles for different diseases, private investments would provide to resources to solve existing puzzles while public research funding is required for the genesis of new puzzles to solve (Toole 2007). Therefore, NDs are a class of diseases, which its treatments, in lieu of any other secondary uses in other indications, are, by definition, strong complements to private investments. In addition, the scarcity of ND research funding may influence the NIH funding decisions, as more application-based proposals may be more effective than basic science based applications. The focus on application-based research can introduce a shorter time lag for NDs relative to other disease funding.

C. University Technology Transfer

As the US economy became increasingly dependent on the knowledge production as the primary driver for growth, universities played an important role in the genesis of new technical knowledge in the economy and can be viewed as a university technology commercialization (UTC) industry (Cardoza, 2010). The outputs of the industry are primarily intellectual properties, especially patents, to firms in other industries. Bayh-Dole act was specifically designed encourage the commercialization of university developed technology, and to facilitate the market entry of the product. The typical value chain in UTC is the transformation of research into invention disclosures, invention disclosures into patents, patents into licenses and finally licenses into income. It typically takes between $1.5 million dollars to $3 million dollars in basic research expenditure to generate one invention disclosure (Thomas, 2007). There exist large fallout along the value chain. A potential useful invention will need to first be “disclosed” by the researchers to their TTO. TTO would evaluate the invention and submit patent application if it finds the invention has commercial potential that . After patent is granted, the TTO the seek private sector investors who are willing to license the technology, which in turns generate revenues. 15% of the invention disclosures (with patents) will be licensed for further development and commercialization. Only a small fraction (2% of licenses; 0.1-0.2 % of invention disclosures) of research projects eventually achieves commercial success and generates more than $100,000 dollars in royalties to the university and the inventor. About 10% of the licenses go to start-ups, which many RASOCs are classified as and are fully dependent on the license transferred (Thomas, 2007).

Regarding the subject area of the UTC licenses, most of the licenses are pharmaceuticals (e.g. drug Taxol with license from Florida State University) or broadly adopted biotechnology tools (e.g. recombinant DNA patent with license from Stanford University). It has . estimated that 60 to 75 percent of the university licenses are related to life sciences while another 10 to 20 percent are from electronics/software/IT fields (Roessner, 2013). It is worth noting that although this paper do not differentiate patents of different natures, the development process of individual licenses vary widely due to different nature of license,

The temporal lags between license execution and eventual commercialization vary widely because of the nature of the licenses as well as the regulatory process in later-stage development processes. Therefore, only less than half of the startup companies would obtain enough funding to bring the technology to the market. Because of the faster transfer process in RASOCs, some studies suggested that RASOCs actually generate more financial returns than licenses to large or small companies (Siegel, 2007).

III. Theoretical Development

Many studies of university production function treat R&D expenditures as a production input while using different output measures. Patent statistics have been used as indicators of research output from private firms in previous studies. However, some research of university production functions used the number of publications from the research as the output. However, using the publications present some empirical difficulties, including the availability of the comprehensive data, how to account for the fluctuating number of academic journals and how to measure spillover effect from other science fields.

Coupe (2003) estimated the university patent production function as a function of R&D expenditures and, in some specifications, number of Public/R&D staff. Coupe used Poisson and negative binomial models to estimate the patent production and found decreasing returns to scale after controlling for institutional fixed effects. In addition, he found that Bayh-Dole Act did not have a significant effect on patenting activity but the establishment of TTOs does, perhaps as a direct result of the Bayh-Dole Act.

Foltz (2007) described university's production output to be a combination of doctorate degree granted, patents and publications. Between these outputs, the study found evidence for an economy of scope between patents and publications but a negative association between doctorate granted and patent or publication production. Examining the link between publication and patent in a global context, Wong (2009) found that between 1977-2000, universities patents grew faster outside of US than in the US. In addition, Wong found that internationalization of faculty members reduced the number of patents in North American universities.

While licenses of technology does not equate to patents, they share similar traits as measureable metrics for university output as a result of the research as both are necessary procedure in UTC value chain. Furthermore, because of its position further down the value chain of UTC, number of licenses more precisely reflects the projects that have the high potential to become commercialized. While all patent filing is required to be "useful", not all patents can be commercialized because of various factors such as market conditions or practical constraints. Therefore, licenses more closely associate with the societal welfare the university generated than patents do. This study does not aim to measure doctorate as a measurable output as it has been found that there exist a tradeoff between patent and doctorate production; research expenditures may have high effect on patents than doctorate productions.

However, using the licensing income as university output can also be biased. In the majority of institutions in US, most of the licensing income comes from one or two high-earning licenses while the rest do not contribute significantly (Thomas, 2007). Therefore, it is not a perfect measure for university's licensing activity. To more precisely reflect the university output in transfer the technology developed, I hypothesized the following model

- The license activities, measured by number of licenses and patents granted, are determined by
    - Total stock of knowledge the university possess, as measured by the past research expenditures funded from different sources
    - The ability of the university TTO, as measured by the experiences of TTO and the number of TTO full-time licensing employees (excluding non-licensing supporting staff)

- The university characteristics that directly influence the type of research conducted in the university such as land grant status, having a medical school and the control of the university (public or private).

For factors that have been found to be associated with both research expenditures and licensing activities, I also estimated a 2-stage-least-square model in which the research expenditures are first estimated by the absolute size categories of the university, the level of research activities in the institution, religious affiliation and the size of the university endowments.

Some studies have outlined the production function of the university and the intellectual property generated. Particularly, studies have focused on licensing income or licensing income's proportion in total university expenditures as the measure for the licensing activity (Heisey, 2009). While licensing income is continuous and can be more informative about the relative contribution to total license income of different licenses, licensing income may not accurately reflect the licensing activity for year t as some licenses provide running royalties across multiple years. In addition, most of the institutions have only one or two licenses that dominate the majority of its licensing income every year (Thomas, 2007). Using licensing income can be misleading considering only a very limited number of licenses eventually lead to successful commercialization. Therefore, it is inadequate to use only licensing income as the university output as most of the licenses do not directly contribute to the licensing income immediately unless the licenses are executed under a lump sum royalty scheme. In this study, I first attempt to use the number of licenses executed every year as dependent variable. While using the number of total licenses executed provides no information about the differences among licenses executed, the total number of licenses executed can still be a significant measure as university output as the commercialization values of license does not have definite associations with the research expenditures spent. Since Federal funding process for research expenditures do not involve future commercialization values, number of license executed can better reflect the majority of licenses that contribute only a small portion to the total licensing income.

IV. Data

A. Licensing activity

I used the data from both the annual Licensing survey from the Association of University Technology Managers (AUTM) and the Higher Education Research and Development survey (HERD) conducted by National Science Foundation. AUTM survey had been self-reported by its TTO members and normally received replies from over 80% of its members and about 150 institutions annually, which covers the majority of American research-oriented universities. AUTM respondents' research expenditures represent more than half of the total federal supported research expenditures every year.

The survey asked the institution's annual total royalties income from licenses and options that generate more than $1000 USD income and the number of US patents filed between 2000 and 2011. In addition, the AUTM survey asks institutions to self-report total, federal and business research expenditures as well as other TTO information like disclosure data. TTO related metrics are also incorporated into the survey such as the

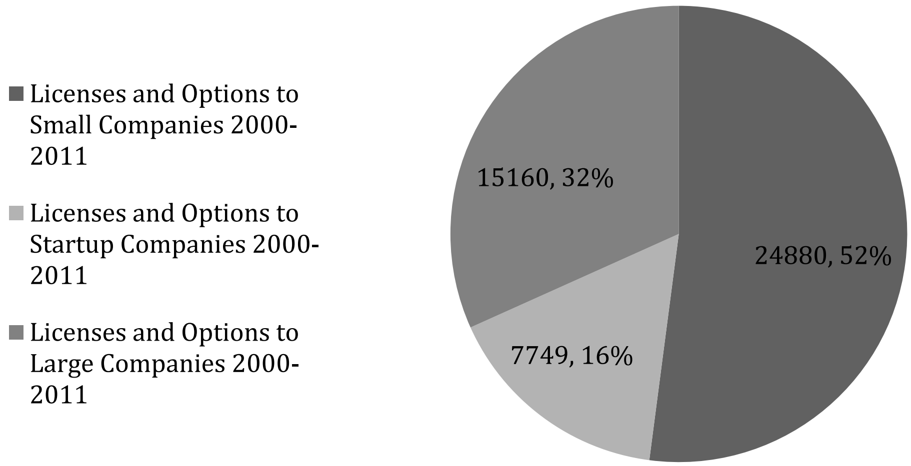

Figure 2. Licenses and Options to Type of Companies 2010-2011
Source: AUTM survey

year of establishment for TTO office when the offices have at least 0.5 full-time employees (FTEs). The experiences of TTO are estimated by the total year TTO has been in operation (current year less the year TTO established). The numbers of full-time-equivalent licensing TTO employees are also reported while excluding supporting staff that is not related to licensing activity. In AUTM survey, the universities self-reported name sometimes changed overtime. For instance, Ohio State University and The Ohio State Research Foundation were both used. The different names were consolidated according to the institutional code recorded by Federal Interagency Committee on Education (FICE). If the data were reported in AUTM survey as a university system but individual universities in other datasets, the data are combined to match to the AUTM observations by aggregating individual campus observations to one university system observation in order to match the university-system reported in AUTM survey(e.g University of California System).

According to AUTM survey, 52 % the licenses in the survey partner with small companies with fewer than 500 full-time employees. 16% of the licenses and options partner with a new startup that are established on the base of license/options negotiated (Figure 2).

B. Research and Development Expenditures Statistics

The R&D expenditures of different institutions from are collected by the source of funding. The monetary figures from both sources are deflated by the fiscal year GDP based on 2000 as of May 2009).

The academic R&D expenditures survey by NSF includes R&D expenditures variables from different source of funds (federal, state and local, industry, institutional and other), recipient structures (passed from recipient or subrecipient), expenditures in Science and Engineering (S&E) fields (Table 1). From 2003, the academic R&D expenditure survey also collected the number of Principal Investigators and Postdoctoral in each institution.

Table 1. Summary Statistics for R&D Expenditures reported to NSF Survey of Research and Development expenditures at Universities and Colleges (academic R&D expenditures survey) 2000-2011

	Federal funded Higher Education R&D Expenditures (thousands USD$)				Business funded Higher Education R&D Expenditures (thousands USD$)			
Year	Mean	Standard Deviation	Max	Min	Mean	Standard Deviation	Max	Min
2000	105257	152825	1415227	378	13086	21470	177664	0
2001	109675	162972	1494839	371	12544	20739	171903	18
2002	118743	176196	1635932	456	11721	19142	165357	0
2003	125383	190392	1823191	474	11128	19474	162712	0
2004	135385	207291	1990940	592	10439	18089	155527	0
2005	138242	210096	2030009	455	11201	19797	157444	0
2006	137640	207847	2001502	289	11226	20110	162879	0
2007	138177	203472	1962625	205	12326	23614	185035	0
2008	138999	204048	1935404	332	13030	24451	213493	0
2009	141287	215622	1970091	474	13474	28485	262043	0
2010	160437	238046	2161111	389	13500	29419	264659	0
2011	153595	181952	1472874	484	11114	18504	169033	0

In addition, the AUTM data provide self-reported research expenditure figures. The NSF survey data is merged to AUTM data set and all schools that did not respond to AUTM surveys are skipped without the information on licensing activities. Analysis has been done to both sets of expenditures with similar results.

Most results presented in this paper used the NSF figures because of the comprehensive nature of NSF survey. The AUTM survey includes expenditures from two sources (Federal and Business), while NSF survey included two other sources of expenditure (Institutional and Other). Since the majority of research expenditures in higher education came from the sum of federal and industrial expenditures, I examined the Federal and Industrial funding from both data sets and obtained similar results.

C. University Characteristics

Data about particular institutions are gathered from a variety of sources as stated on *Table 2*. These characteristics provide us with a picture about each institution. 60-75 % of the university licenses are based in life sciences while other 10-20% of the licenses are related to software/IT/electronics (Roessner, 2013). Since institutions with medical school are more capable in medical research, the presence of medical school can have positive effect on the number of licenses executed. Similarly, land grant institutions were designated with the mission to conduct practical agricultural studies and engineering research while have a larger economies of scale and scope in research, which can also determine the type of research and number of licenses executed (Foltz, 2007).

The characteristics and performances of TTOs have been studied extensively and most studies found positive associations between the size and experience of TTOs

Table 2. Summary of Institutional characteristics used in the study and the data sources		
Characteristics	**Description**	**Source**
SOM	If the school has a school of medicine	Association of University Technology Managers (AUTM) Licensing Survey
Special Focus	If the school only focus on one single discipline (e.g. independent schools of medicines)	Carnegie Foundation for the Advancement of Teaching
Religion	If the university is affiliated with Association of Catholic Colleges and Universities, Council of Christian Colleges & Universities, Church of Latter-day Saints or General Board of Higher Education & Ministry (United Methodist Church)	Various associations of colleges or churches
LandGrant	If the school is a land grant school	Association of Public and Land-Grant Universities
Public	=1 if the institution is mostly public	National Science Foundation Academic R&D Expenditures Survey
Large, Medium, Small	=1 if the school is 1very small (<1000 undergraduate and graduate enrollment), small (1000-2999), or Large (3000-9999)	Carnegie Foundation for the Advancement of Teaching
TTO FTEs	The number of full-time employees for the institution	AUTM Licensing Survey
TTO experience	Experience of TTOs, proxy by the length of the existence of the TTO	AUTM Licensing Survey
Res_rating_h/vh	=1 if the schools is of 1 very high research activity 2 high research activity 3 doctoral research universities	Carnegie Foundation for the Advancement of Teaching
Log (endowment)	Ten Log of the size of university endowment in constant USD	Center for Measuring University Performance

and both licensing revenue and numbers, but not the licensing efficiency, which is normally calculated by dividing licensing income by total research expenditures (Heisey, 2009). From qualitative analysis from interviews, Siegal (2003) found positive correlation between number of TTO staff and number of licenses executed but not licensing income. Siegal also found other environmental variables, such as external legal fee and number of disclosures conducted to be positively associated with licensing income, but not the number of licenses. However, because of the high correlation between most TTO characteristics, I used both the size to TTO's licensing staff and the years in existence of TTO as control variables for measuring TTO. Other environmental variables, such as religious affiliations and size of endowments, do not directly determine the licensing activities but may be correlated with research expenditures are also included in the dataset.

IV. Empirical Specifications

I incorporated the polynomial distributed lag models (PDL) in order to accurately measure coefficients of the lagged variables.

To determine appropriate instrumental variable for research expenditures, I first estimated the research expenditures using year-fixed effect OLS. I estimated the research expenditure as the function of time-variant and time-invariant university characteristics as follows:

$$(Log(ReschExps.)) = \sum_{v=0}^{n} \beta_v X_{it} + \sum_{k=0}^{n} \sigma_k Z_{it} + \delta_t + \mu_{it} \quad (1)$$

in which the research expenditures of institution *i* in year t is determined by a set of time-variants university co-variates *X* and time invariant dummy variables *Z* with a year-fixed effects for year t δ and a normally distributed error term μ.

I also estimated the effect of finite distributed lags and covariates on the log of the total number licenses. Just like a standard OLS model, the basic model of PDL is described as

$$(Log(licensesexec_{it})) = \sum_{v=0}^{n} \alpha_{1j} (LogResearchExps.)_{it-j} + \sum_{k=0}^{n} \gamma_k P_{it} + \varepsilon_{it} \quad (2)$$

in which the log of number of licenses executed is regressed on lags of the predicted research expenditures from equation (1) with lag length n and other TTO- and School-related covariates vector *P* with an error term ε.

However, simple OLS will not produce unbiased α as there exist significant multicollinearity between different lags as they are all highly correlated with each other. The standard error from OLS estimation, as a result, would be large and produce statistically insignificant results and imprecise estimated α.

Past literatures have employed a structured low-degree PDL (Almon Lags) to deal with the multicollinearity in which I assume there exist a polynomial distributed relationship between different lag weights α. For this study, I used second-degree polynomial models as follows:

$$\alpha_{1j} = \lambda_0 + \lambda_1 j + \lambda_2 j^2, j = 0, 1, 2, ...n \quad (3)$$

$$(Log(licensesexec_{it})) = \sum_{v=0}^{n}(\lambda_0 + \lambda_1 j + \lambda_2 j^2)(LogResearchExps.)_{it-j} + \sum_{k=0}^{n} \gamma_k P_{it} + \varepsilon_{it} \quad (4)$$

Substituting equation 3 into equation 2, I obtained the reduced form equation 4:

The model allows reasonable flexibility of coefficients while assuming a secondary polynomial structure of α coefficients in equation 3. I also set lag constraint to zero in the far end (high lags) as the effect of research expenditures are predicted to decline in the long lags.

There is currently no standard way to choose the exact finite lag length *n* to use. Some studies have used high R square as the standard (Alene, 2009) while Akaike Information Criterion (AIC) has also been used to measure the fit of PDL models. In the study, I tested different lag lengths and found that lag length between 4 and 5 generally maximizes adjusted R square. Another additional consideration when picking lag length is as the lag length increased in an unbalanced panel data, the available number of observations decreased. Therefore, I also avoid using any long lag length that reduces the number of observations to lower than 500, even if they have a higher R square. The sum of all lag coefficients also represent the long-term dynamic effect of research expenditures on number of licenses executed. The polynomial coefficients λ do not inherently have economic interpretations and must be interpreted within the context of the α coefficients estimated. The estimation procedure for PDL is parallel to an OLD regression with polynomial constraints that minimized standard errors. In the 2SLS model, I used the instrumental variable to try to eliminate the endogeneity of research expenditures in PDL.

The PDL models are estimated using least squares and robust Huber-White standard errors & covariance in EViews 7.2. Year-fixed effect OLS regressions are estimated in Stata 12. The results from both softwares are cross-referenced with SAS system to detect any errors.

V. Results

A. Identification of appropriate instrument for research expenditures

To identify appropriate instrument variable and detect discrepancies between AUTM and NSF data for research expenditures, I analyzed the variables related to university characteristics to the federal and industrial expenditures (Table 3). The discrepancy in estimated coefficients between the AUTM Licensing survey and NSF academic R&D

expenditures survey is due to the different set of schools included in two surveys. There exist substantial similarity in the significances of the variables and signs of coefficients. Interestingly, the coefficient estimate for the interaction term between research university with very high research activity are not only positive but also larger in business funding than federal funding, which may indicates the industry's preference in funding for large, research intensive university relative to smaller ones or those without extensive research activities. The result also supports that larger universities have the economies of scale and scope to attract more funding from both the federal government and the industry. In addition, the religion coefficient is negative in both data sets for federal research expenditures, which may reflect the teaching-oriented nature of some religiously affiliated colleges and the tradeoff between religion and research in a university's output decision.

The size of university's endowment (logendow) appear to be an ideal instrument as it is not only significantly correlate with research expenditures but also not directly related to the licensing activities in an institution. Endowment also explains at least 25% of the variation (R^2=0.2631, NSF data; 0.2527, AUTM data) in business funded research expenditures and at least 40% of the variation in federal funded expenditures (R^2=0.4097, NSF data; 0.4335, AUTM data). Therefore, I chose endowment to be used as the instrument in 2SLS regressions in the PDL models.

Table 3 Research Expenditure as a function of university characteristics for federal and				
	AUTM Self-Reported expenditures Data		NSF academic R&D expenditures survey	
	(1) Federal Research Expenditure	(2) Business funded Research Expenditure	(3) Federal Research Expenditure	(4) Business funded Research Expenditure
Research University – Very High (RUVH) Activity	0.270*	-0.0898	0.136	-0.588
	(2.50)	(-0.53)	(0.47)	(-1.56)
Research University-High Activity (RUH)	0.0113	-0.202***	0.350***	-0.289*
	(0.30)	(-3.51)	(3.55)	(-2.15)
RUVH_Large	0.261*	0.525**	1.358***	1.499***
	(2.30)	(2.98)	(4.51)	(3.78)
RUVH_Medium	-0.213	-0.156	0.181	0.0128
	(-1.79)	(-0.85)	(0.57)	(0.03)
religion	-0.182***	0.0900	-0.593***	-0.130
	(-3.31)	(1.09)	(-4.17)	(-0.70)
accu	-0.200**	-0.423***	-0.387*	-0.929***
	(-2.87)	(-4.04)	(-2.17)	(-3.98)
logendow	0.404***	0.323***	1.013***	0.880***
	(22.74)	(12.03)	(21.52)	(14.18)
Large	-0.405***	-0.337**	-1.397***	-1.151***
	(-4.90)	(-2.71)	(-6.35)	(-3.96)
medium	-0.294***	-0.0834	-0.940***	-0.601*
	(-3.49)	(-0.66)	(-4.20)	(-2.04)
small	0.0820	0.0323	0.107	-0.388
	(0.98)	(0.26)	(0.48)	(-1.34)
Constant	5.814***	5.246***	5.905***	4.388***
	(49.16)	(29.47)	(18.77)	(10.61)
N	1509	1482	1557	1537

B. Interaction between R&D Expenditures and Number of Licenses

To examine the interaction between research expenditures and number of licenses and options ("licenses"), I used both standard PDL procedures and PDL with 2SLS (regression 8 and 12) as shown in Table 4. Table 4 showed the effects of the research expenditures on the total licenses executed by institutions per year. Several institutional characteristics such as land grant status, public status and TTO experiences were included in the analysis as time-invariant covariates. I applied the model with definite lag lengths (n) from 4 to 8 and found similar results; results from n=5 and 7 are shown in Table 4. Comparing the p-values with different degrees of polynomials, I found in all regression the coefficients for polynomials equation become insignificant around cubic polynomial coefficients. Therefore, I used second-degree polynomial distributed lag model for the following regressions in Table 4 and 5.

Among the time-invariant variables that play a statistically role in determining the number of licenses executed, I found that the variables directly related to TTOs have been consistently positive. I found that both TTO experiences and the licensing staff size have been associated with licensing activity. Specifically, the addition of 1 more full-time licensing staff are correlated with about 3 % increase in the number of licenses while 1 year of additional experiences of TTO are associated with 1-2% increase in number of licenses executed. Our findings in TTO variables are largely consistent with previous literatures that increasing staff size in TTO are associated with increasing numbers of licenses and licensing revenues (Heisey, 2007). However, to detect the endogeneity of TTO-related variables, I estimated regression 5 and 9 without TTO related variables. I observed identical signs and similar significance in coefficients in regression 5 and 9 compare to regression 6 and 10 with TTO-related variables.

TTO-related characteristics are consistently positive correlated with licenses executed in all models in a significant fashion. However, the direction of causality can be both ways for number of TTO licensing employees as higher number of licenses generally leads to more hire for licensing personnel. Public schools also have significantly more licenses executed every year than private schools in all four models.

Comparing the temporal length of significant lag variables, I found significant effect of 2^{nd} and 3^{rd} lags of research expenditures in most regressions indicating the lag length to be between 2-3 years. This corresponds to the typical modal lag for 2 years for university research expenditure in other similar studies (Heisey, 2009). Oehmke and Schimmelpfennig (2004) also found that aggregate research expenditures have significant 1 or 2 years short-term effects on US agricultural multifactor productivity. Our results indicate that it is likely that research expenditures directly impact licensing activity in short-run within two to three years. Furthermore, business-funded research expenditures also have significant coefficients on 1^{st} lags variables, indicating that time it take from expenditures to commercialization may spread wider for business than federal funded research expenditures.

In addition, the sum of the coefficients of lagged variables produced the long-term dynamic effect of research expenditure on percentage of licenses executed every year. Even though there exist high correlation between lagged variables (R square=0.99 for 1^{st} and 2^{nd} lagged NSF federal research expenditure) and PDL may not resolve the multicollinearity entirely, the linear combinations of these estimators (sum) are still generally well estimated (Blume-Kohout, 2012). Comparing equations 6 and 10, I found the aggregate effect of research expenditures are quite similar despite that business-funded research expenditures are only a fraction of the federal government funded government expenditures. The result shows that a 1% increase in business funded research, even though smaller in absolute scale relative to federal funded research expenditures, high amount of licenses. A 1% increase in federal funded research expenditures leads to higher percentage increase of number of licenses than industrial funding.

To further distinguish the effects of different sources of research expenditures, I investigated the differences in license with different type of licensees, defined by their size and if the partner is a startup with two additional types of the source of research expenditures (state/local and institutional funding) , as shown in Table 5.

The differences in effects from research expenditures on licenses that are executed with 1) start-up 2) small 3) large companies and 4) licenses that yielded more than 1 million in licenses in the fiscal year are also estimated in figure 3 and table 5. The sums of lagged federal funded research expenditures coefficients showed that Federal funding have larger effect in startup/small companies while industrial funded R&D spending have larger effect in large companies. In addition, only federal-funded and business-funded research expenditures have significant effects on licenses generated more than 1 million yields. Business funded research expenditures have significantly higher effect on licenses generate large revenues, which supports theories that private sector funded research are strongly associated with high commercial potential licenses. There exist

Table 4 Effect of Federal and Business Research Expenditures on Number of Licenses Executed

	Federal Government Funded Research Exp.				Business Funded Research Expenditure			
	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Method	OLS			2SLS	OLS			2SLS
Research Expenditure	-0.08	0.0869	-0.057	0.143	0.155*	0.090	0.106	0.143
	(-0.343)	(0.649)	(0.229)	(0.647)	(1.87)	(1.27)	(1.52)	(0.64)
1st Lag	0.065	0.098*	0.0137	0.171	0.131***	0.086***	0.090*	0.171
	(0.79)	(2.19)	(0.116)	(1.52)	(4.25)	(3.19)	(2.40)	(1.52)
2nd Lag	0.157***	0.0989***	0.0667*	0.179***	0.106***	0.078***	0.073***	0.178***
	(5.429)	(4.972)	(2.05)	(5.20)	(10.09)	(7.67)	(5.60)	(5.19)
3rd Lag	0.200*	0.0896	0.100**	0.165***	0.081*	0.065*	0.058***	0.165***
	(2.23)	(1.637)	(2.709)	(6.85)	(2.75)	(2.55)	(5.12)	(6.85)
4th Lag	0.184	0.0700	0.116	0.130**	0.054	0.048	0.0445*	0.131**
	(1.76)	(1.104)	(1.53)	(2.990)	(1.56)	(1.59)	(2.04)	(2.99)
5th Lag	0.118	0.0401	0.114	0.076*	0.027	0.026	0.032	0.076*
	(1.58)	(0.888)	(1.24)	(2.089)	(1.10)	(1.20)	(1.20)	(2.08)
6th Lag			0.094				0.02	
			(1.107)				(0.815)	
7th Lag			0.056				0.009	
			(1.03)				(0.60)	
School of Medicine	-0.135	-0.181*	-0.299*	-0.000264	-0.007	-0.08	-0.21*	-2.65E-05
	(-1.17)	(-2.237)	(-2.47)	(-0.000137)	(-0.08)	(-1.07)	(-2.19)	(-0.00032)
Land Grant	0.098	-0.0466	-0.081	0.129	0.118	-0.053	-0.068	0129
	(1.21)	(-0.5848)	(-0.84)	(1.546)	(1.34)	(-0.62)	(-0.637)	(1.54)
Public	0.063	0.085	0.085**	0.474***	-0.138	-0.058	-0.087	0.475***
	(0.849)	(1.06)	(0.94)	(5.15)	(-1.80)	(-0.77)	(-0.93)	(5.15)
Special Focus	-0.238*	-0.121	-0.21	0.453***	-0.293*	-0.154	-0.239	0.453***
	(-2.15)	(-1.06)	(-1.50)	(3.58)	(-2.56)	(-1.45)	(-1.66)	(3.59)
TTO Experience		0.0133***	0.009*	0.0169***		0.0156***	0.0106**	0.016***
		(4.73)	(2.21)	(4.63)		(5.07)	(3.06)	(4.63)
TTO FTEs		0.038***	0.04***	0.0349***		0.041***	0.040***	0.034***
		(7.91)	(4.04)	(4.97)		(4.84)	(4.35)	(4.97)
Constant	-4.54	-3.26***	-3.28***	-4.28***	-2.11***	-1.23***	-1.36**	-4.28
	(-1.17)	(8.69)	(-3.34)	(-8.80)	(-5.76)	(-3.40)	(-2.94)	(-8.80)
Akaike Info Criterion	2.77	2.64	2.70		2.84	2.70	2.74	
R Square	0.386	0.4546	0.421	0.4552	0.334	0.417	0.403	0.455
Sum of lagged Coefficients	0.640***	0.484***	0.505***	0.864***	0.556***	0.393***	0.434***	0.864***
N	856	849	572	689	846	841	566	689
Number of School	150	149	137	139	148	147	137	139

t statistics in parenthese * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

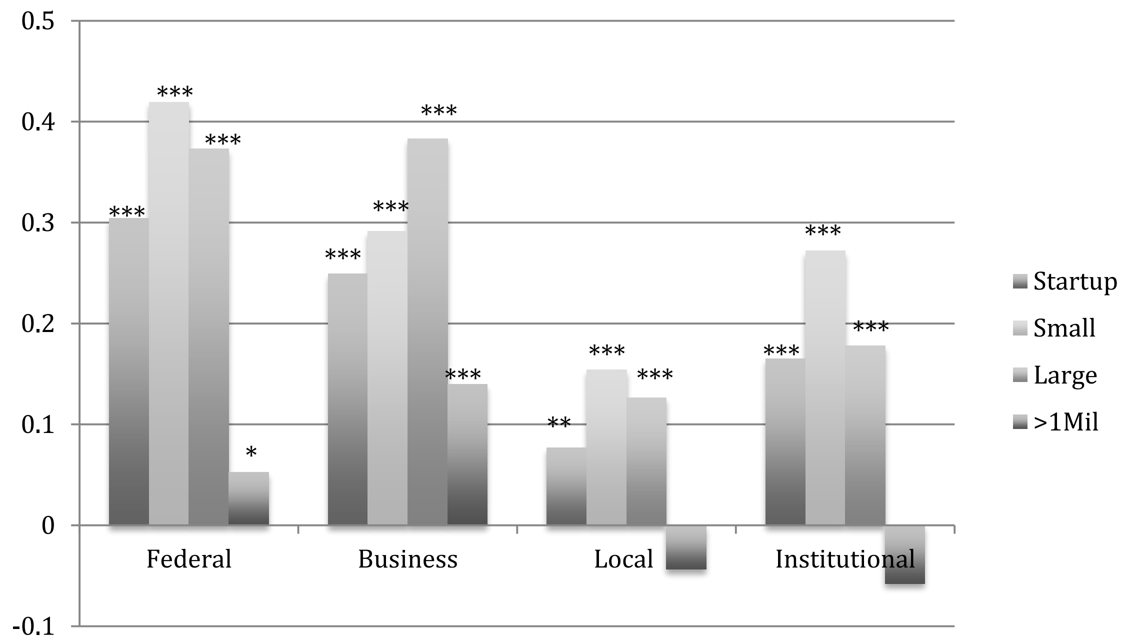

Figure 3 The Sum of Lagged Coeffcients of Research Expenditures by Sources by Size of Licensee. $^{*}\ p < 0.05$, $^{**}\ p < 0.01$, $^{***}\ p < 0.001$

several theories explaining the disproportionate effect of business funded research expenditures on licenses. First, the researchers may gain negotiating advantage during the technology transfer process due to their previous interaction with private sector. Researchers can benefit from the private-sector-know-how as well as the established connections they learned during the grant application process in negotiating higher royalties during technology transfer processes. In addition, private sectors are likely to prioritize the commercialization potential as one of the consideration when deciding which projects to fund. Lastly, large companies are more likely to cooperate with academia and fund research compared to smaller or startup companies. With the exceptions of RASOCs, most small companies and startups do not have extensive ties with academic and are less likely to have the necessary funds to support research projects.

Table 5 Research Expenditure Sources Effects by Different Types of Licenses								
	Federal Government				Business ("Industry")			
Types of Licenses	Startup	Small	Large	>1M	Startup	Small	Large	>1M
	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Research Expenditure	-0.0411	-0.0095	-0.124	0.087	0.108*	0.109	0.048	-0.032
	(-0.30)	(-0.04)	(-0.57)	(0.57)	(2.44)	(1.38)	(0.67)	(-0.91)
1st lag	0.029	0.057	0.011	0.036	0.072***	0.078*	0.070**	0.007
	(0.65)	(0.74)	(0.16)	(0.73)	(4.38)	(2.67)	(2.59)	(0.47)
2nd lag	0.075***	0.097***	0.101***	0.0038	0.042***	0.051***	0.081***	0.037***
	(3.61)	(3.41)	(3.56)	(0.02)	(5.72)	(4.26)	(8.51)	(3.47)
3rd lag	0.095*	0.111	0.145*	-0.02	0.020	0.031	0.079***	0.052*
	(1.70)	(1.33)	(1.75)	(-0.35)	(1.20)	(1.04)	(3.10)	(2.53)
4th lag	0.088	0.100	0.14	-0.028	0.006	0.015	0.065*	0.050*
	(1.38)	(1.01)	(1.469)	(-0.41)	(0.317)	(0.440)	(2.14)	(2.24)
5th lag	0.057	0.063	0.095	-0.021	-0.001	0.005	0.039	0.033*
	(1.25)	(0.89)	(1.35)	(-0.43)	(-0.04)	(0.199)	(1.77)	(2.11)
School of Medicine	-0.114	-0.209	-0.153	0.0064	-0.024	-0.090	-0.089	0.043
	(-1.55)	(-2.04)	(-1.48)	(-0.08)	(-0.365)	(-1.00)	(-1.06)	(0.54)
Land Grant	0.25***	0.087	-0.374***	-0.23**	-0.295***	0.100	-0.436***	-0.277**
	(-3.60)	(0.98)	(-4.36)	(-2.68)	(-4.09)	(1.01)	(-5.04)	(-3.06)
Public	0.188*	0.193*	0.125	-0.060	0.114	0.050	0.047	-0.067
	(2.73)	(2.32)	(1.53)	(-0.77)	(1.66)	(0.565)	(0.569)	(-0.94)
TTO Experiences	0.005	0.0119**	0.0127***	0.010***	0.0066**	0.0146***	0.0144***	0.010***
	(1.89)	(3.02)	(4.48)	(3.99)	(2.54)	(3.89)	(5.53)	(3.93)
TTO FTEs	0.029***	0.032***	0.0466***	0.034***	0.031***	0.0366***	0.045***	0.031***
	(6.05)	(3.35)	(6.01)	(7.66)	(6.56)	(3.79)	(6.20)	(7.32)
Special Focus	-0.609***	-0.12	-0.1048	0.342**	-0.635***	-0.151	-0.135	0.300
	(-6.91)	(-0.90)	(-0.99)	(3.02)	(-7.06)	(-1.06)	(-1.34)	(2.60)
Constant	-2.27***	-3.04***	-2.86***	-0.522	-1.05 ***	-0.896*	-1.996***	-1.16***
	(-4.85)	(-4.28)	(-3.92)	(-1.19)	(-4.46)	(-2.25)	(-5.98)	(-3.41)
Akaike Info Criteron	2.249	2.88	2.67	1.64	2.26	2.95	2.64	1.60
R Square	0.3430	0.326	0.394	0.382	0.334	0.285	0.413	0.408
Sum of Lagged Coefficients	0.3042***	0.419***	0.373***	0.0528*	0.249***	0.291***	0.383***	0.140***
N	711	774	720	349	705	766	713	345
Number of Schools	142	147	142	78	142	145	141	78

Table 5. Continued								
	State/Local				Institutional			
Types of Licenses	Startup	Small	Large	>1M	Startup	Small	Large	>1M
	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
Research Expenditure	-0.0249	0.0875	-0.00885	0.0246	0.054	-0.107	0.070	0.0029
	(-0.89)	(2.41)	(0.24)	(0.78)	(1.04)	(-1.60)	(1.02)	(0.062)
1st lag	0.00271	0.0512	0.021	0.0020	0.041*	0.0031	0.048*	-0.0072
	(0.27)	(3.84)	(1.56)	(0.17)	(2.28)	(0.13)	(2.01)	(-0.44)
2nd lag	0.0209***	0.024**	0.028***	-0.013**	0.030***	0.076***	0.031**	-0.0136
	(3.45)	(3.02)	(3.75)	(-2.32)	(3.54)	(7.253)	(2.91)	(-1.65)
3rd lag	0.030**	0.00462	0.029*	-0.021*	0.0209	0.112***	0.018	-0.016
	(2.47)	(0.30)	(1.90)	(-1.66)	(1.00)	(4.34)	(0.663)	(-0.83)
4th lag	0.029*	-0.0056	0.025	-0.0215	0.012	0.112***	0.0082	-0.015
	(2.15)	(-0.32)	(1.44)	(-1.48)	(0.53)	(3.72)	(0.26)	(-0.66)
5th lag	0.019*	-0.0071	0.0151	-0.145	0.005	0.075***	0.0022	-0.009*
	(2.02)	(-0.58)	(1.24)	(-1.39)	(0.33)	(3.45)	(0.10)	(0.59)
School of Medicine	0.085	0.044	0.095	0.0048	-0.042	-0.143	0.0036	0.055
	(1.25)	(0.495)	(1.11)	(0.059)	(-0.579)	(-1.51)	(0.039)	(0.63)
Land Grant	-0.265***	0.0006	-0.44***	-0.134	-0.280***	-0.0496	-0.380***	-0.166**
	(-3.15)	(0.0060)	(-4.25)	(-1.39)	(-3.62)	(-0.50)	(-3.97)	(-1.79)
Public	-0.303	-0.144	-0.17*	-0.0827	-0.0064	-0.132	-0.147	-0.095
	(-0.413)	(-1.50)	(-1.89)	(-1.25)	(-0.086)	(-1.36)	(-1.59)	(-1.40)
TTO Experiences	0.104***	0.012***	0.019***	0.010***	0.008***	0.015***	0.017***	0.011***
	(3.98)	(5.49)	(4.48)	(4.56)	(3.11)	(4.64)	(5.66)	(4.87)
TTO FTEs	0.040***	0.046**	0.0592***	0.038***	0.036***	0.040***	0.017***	0.038***
	(9.66)	(8.47)	(11.74)	(11.64)	(8.77)	(7.35)	(10.93)	(11.36)
Special Focus	-0.610***	-0.032*	-0.0934	0.366**	-0.556***	-0.072	-0.059	0.312*
	(-5.19)	(-0.217)	(-0.706)	(3.06)	(-4.84)	(-0.50)	(-0.45)	(2.54)
Constant	0.392*	0.293	-0.155	0.430*	-0.49*	-0.847**	-0.493***	0.612*
	(2.104)	(1.21)	(0.672)	(2.22)	(-1.91)	(-2.51)	(-1.55)	(0.024)
Akaike Info Criteron	2.362	2.970	2.773	1.633	2.332	2.923	2.764	1.663
R Square	0.272	0.268	0.337	0.400	0.295	0.301	0.347	0.400
Sum of Lagged Coefficients	0.0769***	0.154***	0.126***	-0.0436*	0.165***	0.272***	0.178***	-0.057***
N	708	772	716	349	677	736	685	333
Number of Schools	142	147	142	78	139	143	138	76

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

State/local funded research expenditures, on the other hand, have the smallest effects on all four types of licensees. State and local government provided 7% ($3.6 billion) of higher education R&D funding in FY 2009. Since the federal Bayh-Dole Act does not apply to state and local funded research, the small effects on licenses may be a result of lack of incentive of researchers to pursue commercialization. There is currently no dominant way of assigning ownership of intellectual property arising from state or locally funded research projects. In some cases, the state retains the intellectual property arising from state-funded research. For instance, the California Stem Cell Research and Cures Initiatives, enacted in 2004 as Proposition 71, gave the state the right to “benefit from royalties, patents, and licensing fees that result from the research” (Silfen, 2005). Further research is needed to compare state policies regarding intellectual properties of state-funded research and its relation to university technology transfer process.

Institution funded R&D are the second largest funding source after federal government but have significantly smaller effect in the number of licenses. Institutional funds encompass institutionally financed research expenditures and uncovered indirect costs and cost sharing, which can contribute to the smaller effect on licenses. In addition, institutional funds are also more likely to be spent on research capacity building compared to funding from other sources.

VI. Conclusion

I found evidence that federal government funded research led to a higher number of technologies being licensed from universities between the year 2000 and 2011. Before the passage of the Bayh-Dole Act, studies found that federal-funded research was not fully commercialized and thus implementation required incentives for academic inventors to commercialize the research (Cardoza, 2010). The results show that the gap in commercialization had decreased in terms of the number of licenses generated by federal- and business-funded research. However, there still exist discrepancies in the numbers of licenses executed relating to different sources of funding. Business-funded research projects are more likely to result in partnering with large companies and generate large income per license while federal funded research projects partners with small and startup companies. state-and-local-funded research expenditures, while have similar size to business-funded research expenditures, have much smaller effects on university technology transfer process. The small effect may be associated with the lack of regulations similar to Bayh-Dole Act in the state level. Further studies are needed to clarify the relationship between having Bayh-Dole Act-like intellectual property policies and the number of licenses executed. It is also possible that state and local funders have different utility functions than the federal funder and therefore supported different projects that generate intellectual property at different rates.

I also found evidence suggesting the temporal lags between research expenditures and licenses being executed are about 2-3 years regardless of the sources of funding or types of the licensee. However, the methodology still suffers from the small number of samples as well as the limitations of Almon lags and more research is needed to produce precise estimate for the temporal lag between research spending and licenses execution. In addition, it is important to examine the temporal lag between other stages of the university technology processes, e.g. patent filing and invention disclosures to establish clear understanding of the timeframe for the university technology transfer process.

Consistent to previous literatures, TTO characteristics, including the number of licensing employees and the experience of TTOs, have consistently shown a positive significant relationship with the number of license executions. However, with the land grant status being an exception, most other university characteristics, such as having school of medicine, have insignificant association with the numbers of licenses executed.

For policy makers, the study indicated that the biggest beneficiary from federal funded research and its technology transfer are small and startup companies while large companies are benefited from both federal and business research expenditure funding. The lower impact of federal-funded research on licenses yielding over 1 million dollars in income requires additional studies to understand the factors contributing to the difference. In addition, states should consider policies similar to Bayh-Dole Act and its impact in incentivizing commercialization of state- or local-funded research. It is worth noting that commercialization does not necessarily guarantee a net gain in welfare due to the inefficiencies introduced by monopolies.

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