Exploring the impact of R&D on patenting activity in small women-owned and minority-owned entrepreneurial firms

By: Albert N. Link and Martijn van Hasselt

Link, A. N. & Van Hasselt, M. (2019). Exploring the Impact of R&D on Patenting Activity in Small Women-Owned and Minority-Owned Entrepreneurial Firms. Small Business Economics. DOI: 10.1007/s11187-018-00130-9

Abstract:

The relevant economics literature on the impact of R&D on patenting activity falls within two methodological areas of inquiry. The first area might be classified as a test of the Schumpeterian hypothesis. The second and lesser research area might be classified as an estimation of the knowledge production function relationship between R&D and patenting. This paper focuses on estimates of the R&D-to-patenting relationship for a random sample of small, entrepreneurial firms whose research projects were supported through the US Small Business Innovation Research (SBIR) program. Our paper contributes to the R&D-to-patenting literature in two ways. It examines empirically a unique set of small, entrepreneurial firms funded by the public sector, and it explores the effect of the gender and ethnicity of firm owners on the propensity of their firms to patent from funded research projects.

Keywords: Patenting | R&D | Entrepreneurship | Gender | Minorities

Article:

Introduction

The relevant economics literature on the impact of R&D on patenting activity falls within two methodological areas of inquiry. The first area might be classified as a test of the Schumpeterian hypothesis. Research in this area seeks to identify the relationship between firm size and R&D outputs (e.g., patents). The related literature traces to the early scholarship of Scherer (1965, 1983), as recently summarized by Audretsch et al. (2018) and Link and Scott (2018) and as previously reviewed, in part, by Hall and Harhoff (2012). Only a few studies (e.g., Link and Scott 2018) have tested the Schumpeterian hypothesis using data on small, entrepreneurial firms.

The second and lesser researched area might be classified as an estimation of the knowledge production function relationship between R&D and patenting. Recent empirical contributions to this literature are by Hall and Ziedonis (2001), Czarnitzki et al. (2009), and Link et al. (2018).

Knowledge production functions have yet to be estimated using data on small, entrepreneurial firms. This paper focuses on estimates of the R&D-to-patenting relationship for a random sample of such firms whose research projects were supported through the US Small

Business Innovation Research (SBIR) program. In addition to contributing to the R&D-to-patenting relationship using data on a publicly supported project level, we also contribute to the literature by exploring the effect of the gender and ethnicity of firm owners on the propensity of their firm to patent from their SBIR-funded research.

In Section 2, we briefly overview a knowledge production function specification of patenting as a function of R&D and human capital, and we posit an empirical model using a structural relationship previously developed in the literature. In Section 3, we describe the SBIR data set that we use to estimate our model. Our empirical findings are presented and discussed in Section 4. Section 5 concludes the paper with brief summary remarks and suggestions for future research.

Knowledge production functions

The term knowledge production function refers, in general, to a transformation from innovative inputs into innovative outputs (Griliches 1979). For example, if *I* represents an innovative output, and *Kn* represents an innovative input such as knowledge, then[1]:

$$I = f\,(Kn) \tag{1}$$

Knowledge can be endogenously created through both investments in research and development (R&D) and endowments of human capital (HC).[2] Thus,

$$Kn = F\ (R\&D, HC) \tag{2}$$

where the functional form of f(·) in Eq. (1) may be distinct from the functional form of F(·) in Eq. (2).

Thus, it follows from Eqs. (1) and (2) that:

$$I = G\ (R\&D, HC) \tag{3}$$

where the statistical form of G(·) may be distinct from either f(·) or F(·) from above.

In this paper, we follow convention and innovative output (I) is measured as patent applications, R&D is measured as investments in R&D, and HC is measured in terms of number of employees in the economic unit conducting the R&D—the firm in our case. Thus:

$$Patient\ Applications = G(R\&D, Employees) \tag{4}$$

Suppose that the knowledge production function G(·) takes a Cobb-Douglas form:

$$Patent\ Applications = A\ R\&D^{\alpha}\ Employees^{\beta} \tag{5}$$

where A is a constant or disembodied shift parameter. Equation (5) can be rewritten as:

$$\begin{aligned} Patent\ Applications = \exp\ & (\log\ (A) \\ & + (\alpha + \beta)\ \log\ (Employees) \\ & + \alpha\ \log\ (RD/Employees)) \end{aligned} \tag{6}$$

where $\exp(x) = e^x$ is the exponential function. Equation (6) suggests a nonlinear regression model for examining cross-project differences in the number of patent applications. We use the Poisson and negative binomial regression models to estimate α and β in Section 4. These models have a conditional mean function that satisfies Eq. (6) and account for the fact that the number of patent applications is a count variable.

Discussion of data

Our data relate to Phase II SBIR-funded research projects conducted in small, entrepreneurial firms between 1992 and 2001 (inclusive). The SBIR program is a set-aside program created through the Small Business Innovation Development Act of 1982 (Public Law 97-219).[3] The creation of this program by Congress singled out small firms as vehicles for innovation and economic growth. The Act of 1982 states that:

> [W]hile small business is the principal source of significant innovation in the Nation, the clear majority of federally funded research and development is conducted by large businesses, universities, and Government laboratories; and small businesses are among the most cost-effective performers of research and development and are particularly capable of developing research and development results into new products.

The specific purposes of the Act were and generally still are:

1. to stimulate technological innovation;
2. to use small business to meet Federal research and development needs;
3. to foster and encourage participation by minority and disadvantaged persons in technological innovation; and
4. to increase private sector commercialization innovations derived from Federal research and development.

When the Act was reauthorized in 1992 through the Small Business Research and Development Enactment Act (Public Law 102-564), the language of purpose (3) above was modified and broadened to focus on women as well as disadvantaged persons: "to provide for enhanced outreach efforts to increase the participation of socially and economically disadvantaged small business concerns, and the participation of small businesses that are 51 percent owned and controlled by women." It is this amended purpose (3) of the SBIR program that motivates the gender and ethnicity emphasis in this paper.

Government agencies are required to set aside a portion of their extramural funding for small firms (less than 500 employees).[4] The current set-aside rate is 3.2%. SBIR research awards fall within two categories. Phase I awards generally last for 6 months and are currently funded at not more than $150,000. The purpose of Phase I research is to establish the technical merits of the project as well as its commercial potential. Phase II awards generally last for 2 years and are

currently funded at not more than $1,000,000.[5] The purpose of Phase II research is to continue the research from Phase I with the commercialization of the developed technology being a primary objective. The data in this paper relate to Phase II awards.

Table 1 Variables used in the estimation of Eq. (6)

Variable	Definition
Patent Applications	Number of patent applications by the firm related to the technology developed in the current Phase II project
Employees	Number of employees in the firm at the time the Phase II proposal was submitted
R&D	Phase II award amount (thousands $2005)
Previous awards	= 1 if the firm previously received one or more Phase II awards that are related to the current Phase II project/technology supported by the current Phase II award, 0 otherwise
University	= 1 if the firm conducting the Phase II project involved university resources (personnel and/or equipment) in the research, 0 otherwise
Women-owned	= 1 if the firm conducting the Phase II project is owned by a woman, 0 otherwise
Minority-owned	= 1 if the firm conducting the Phase II project is owned by a minority, 0 otherwise
DOD	= 1 if the Phase II project was funded by DOD, 0 otherwise
NIH	= 1 if the Phase II project was funded by NIH, 0 otherwise
NASA	= 1 if the Phase II project was funded by NASA, 0 otherwise
DOE	= 1 if the Phase II project was funded by DOE, 0 otherwise
NSF	= 1 if the Phase II project was funded by NSF, 0 otherwise

The SBIR program has been periodically reauthorized by Congress. As part of the year 2000 reauthorization, Congress mandated that the National Research Council (NRC) of the National Academies of Science, Engineering, and Medicine conduct an evaluation of the economic benefits associated with the program. To accomplish this charge to evaluate the economic benefits, the NRC conducted a survey of a random sample of Phase II projects funded between the years 1992 and 2001 (inclusive). The NRC-surveyed projects in the data set were funded by the five largest agency SBIR programs: Department of Defense (DoD), the National Institutes of Health (NIH), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the National Science Foundation (NSF).Footnote6 While much of the 2005 survey focused on the success of the funded firms' projects in commercializing its developed technology, the NRC also collected data on the intellectual contributions or knowledge spillovers produced by the research, as well as the gender and ethnicity of the owners of the firms conducting the research. In particular, data were collected on patent applications that resulted from the funded Phase II project.

Table 1 defines the variables in the NRC SBIR data set that we used in our estimation of Eq. (6). Descriptive statistics for these variables are in Table 2.

Based on the relevant literature on R&D and patenting, whether within the Schumpeterian tradition or the knowledge production function tradition, we hypothesize that R&D per employees will be positively related to patent applications, other project and firm characteristics held constant.

Regarding other project and firm characteristics, we hypothesize that firms that have had prior Phase II research experience with the technology related to the current Phase II project will be more successful in their current Phase II project than firms with no such prior experience. Thus, holding the project's R&D budget and the firm's number of employees constant, we

hypothesize that previous related research success will be positively related to the number of patent applications associated with the current research project.

Table 2 Descriptive statistics on the variables (n=1554)

Variable	Mean	Standard deviation	Range
Patent applications	0.818	3.000	0–100
Employees	31.508	57.344	1–451
R&D	763.328	349.317	19.260–8039.64
R&D/employees	138.247	263.277	1.380–8039.64
Previous awards	0.400	0.490	0/1
University	0.362	0.481	0/1
Women-owned	0.100	0.300	0/1
Minority-owned	0.080	0.272	0/1
DOD	0.480	0.500	0/1
NIH	0.248	0.432	0/1
NASA	0.098	0.298	0/1
DOE	0.087	0.282	0/1
NSF	0.087	0.282	0/1

Only projects that were not discontinued prior to completing their Phase II research are included in the sample

All of the firms that are eligible for SBIR awards are small, and in fact in the NRC's random sample the mean number of employees in the firm at the time of submission of the Phase II proposal is just over 31 (see Table 2). Small firms might not always have sufficient internal resources to conduct a specific research project even when the research is funded by the public sector (or any third party for that matter). One possibly relevant external resource is to include a university in the conduct of the research project (Link 2015). Thus, we hypothesize that those firms that relied on university resources to assist with their Phase II projects will be more successful in their current research and will thus engage more in patenting applications, holding constant R&D and employment size, than those firms that did not rely on university resources.

With reference to the 1992 amended purpose (3) of the SBIR program, there is a robust literature on firm behavior in women-owned firms (Link and Strong 2016), but the study of minority-owned firm behavior is in its infancy. And, when the firm behavior is patenting, both bodies of literature become smaller. The NRC data are robust in the sense that they have information on the gender and minority status of owners of the firms that received a Phase II SBIR award. Drawing on the research of Ding et al. (2006), Rosser (2009, 2012), Cook and Kongcharoen (2010), Hunt et al. (2012), and Milli et al. (2016), all of whom find that women (although not women-owned firms per se) patent less than men, we hypothesize that the number of patent applications from Phase II research in women-owned firms will be fewer than that in men-owned firms. There is insufficient prior literature about the relative patenting activity of minority entrepreneurs or minority-owned firms for us to offer a hypothesis about the relationship between minority ownership and patent applications.[7]

Empirical findings

We estimated Eq. (6) as a Poisson model and as a negative binominal model. The coefficient estimates are given in columns (1) and (2) of Table 3. [8]

Table 3. Poisson and negative binomial coefficient estimates (n=1554)

	(1) Poisson	(2) Negative Binomial
log(employees)	0.2606	0.2080
	(0.1490)	(0.1620)
log(R&D/employees)	0.4220**	0.3731*
	(0.1518)	(0.1576)
Previous awards	0.4008*	0.3887***
	(0.1655)	(0.1106)
University	0.4431*	0.3437**
	(0.2208)	(0.1264)
Women-owned	−0.5084**	−0.4282*
	(0.1961)	(0.1960)
Minority-owned	0.6899	0.5044
	(0.5185)	(0.3749)
Constant	−2.7186**	−2.2674*
	(1.0114)	(0.9784)
Funding agency controls	Yes	Yes
LR statistic	78.9249	82.3056
p value	< 0.000	< 0.000
Log-likelihood	−2435.4295	−1805.7758
alpha	–	2.0929

*p < 0.05; **p < 0.01; ***p < 0.001
Robust standard errors in parentheses

Two DoD project records in the NRC SBIR data set warrant discussion. The two projects were funded to the same firms only a few months apart in 1998. The projects had reported award amounts in the database that differed by about $4000, but the other survey responses are similar. We assume that one of these project records in the NRC SBIR data set is a double counting error. In the absence of information about which project record is correct, we estimated our models using one project record and then the other project record. The results presented in Tables 2 and 3 are based on only including the project with the larger coded award amount. The other set of results is available from the authors on request

Across both models, the coefficients of log(R&D/Employees), Previous Award, University and Women-owned are statistically significant. As hypothesized, the amount of R&D per employees, a prior technology-related Phase II award, and university involvement in the funded research are all positively related to the number of patent applications. Women-owned firms are associated with fewer patent applications, as hypothesized. Finally, our results suggest that minority-owned firms are associated with a higher number of patent applications, but the estimates are not statistically significant. As is clear from Table 3, all coefficient estimates are robust across the two estimated models.[9]

A specific emphasis in this paper is on the relationship between women-owned and minority-owned firms and patent applications. Using the negative binominal results in column

(2) of Table 3, the calculated marginal effect of Women-Owned is − 0.29. Thus, women-owned firms are associated with 0.29 fewer patent applications than men-owned firms. Similarly, the calculated marginal effect of Minority-Owned is 0.51. Thus, minority-owned firms are associated with 0.51 more patent applications than non-minority-owned firms. The latter estimate, however, is not statistically significant at a traditional level and thus should only be interpreted as suggestive evidence.

Conclusion

The findings presented in our paper contribute to the R&D-to-patenting literature in two ways. Using a set of research project data related to SBIR-funded small, entrepreneurial firms, we confirmed the robustness of the knowledge production function model. Our results show that research projects with a higher R&D intensity are associated with a higher number of patent applications. Our results also show that SBIR-funded research projects in women-owned firms are associated with slightly fewer patent applications, compared to SBIR-funded research projects in men-owned firms.

As unique as our findings are, especially our empirical results about the gender and ethnicity impact of firm ownership on patent applications from SBIR-funded research projects, care must be exercised in generalizing from our findings. First, our findings relate to publicly funded SBIR research projects in small, entrepreneurial firms and not to R&D projects in general or to firms of all sizes. Second, our analysis did not control for the role of the firm owner in the research project. Future research perhaps could focus on the R&D-to-patenting relationship on small, entrepreneurial firms in general and not only those with projects supported with public funds.

An important question from our specific analysis is “Why are women-owned firms less patent-application active based on their SBIR-funded research?” We believe that the answer to this question does not rest on whether the research project was or was not publicly funded. Rather, we hypothesize that the answer to this question rests on a better understanding of the endowments of human capital within the researching firm, where human capital refers to more than the gender and ethnicity characteristics of the owner.

Certainly, reflecting on the 1992 amended purpose (3) of the SBIR program—“to provide for enhanced outreach efforts to increase the participation of socially and economically disadvantaged small business concerns, and the participation of small businesses that are 51 percent owned and controlled by women”—future research perhaps could focus on the role of firm owners, not only in terms of their gender but also in terms of their specific ethnicity. Future research could go beyond this charge and examine the research expertise and perhaps the research experience not only of the firm owner but also the principal investigator involved in a research project. In addition, different owners might have different levels of experience within their firm to adopt intellectual property protection mechanisms that go beyond patenting (Veugelers and Schneider 2018). Perhaps our findings will motivate future research in these directions.

Notes

(1) This specification comes from Audretsch as discussed in Audretsch and Link (2019).

(2) Audretsch and Link (2018) make a case that knowledge that spills over from the public sector is also a relevant input into Kn. Our SBIR data set, as discussed in Section 3, does not include a measure of knowledge spillovers from the public sector to the private sector.
(3) Early emphasis on small firms traces at least to the Small Business Act of 1953 (Public Law 85-536) which created the Small Business Administration (SBA). Over two decades later, President Jimmy Carter's 1979 Domestic Policy Review foretold of what was to become the current SBIR program (although a prototype program started in 1977 at the National Science Foundation). See President Carter's Industrial Innovation Initiatives Message to the Congress on Administration Actions and Proposals (October 31, 1979): http://www.presidency.ucsb.edu/ws/index.php?pid=31628. President Carter's message to Congress was in response to the productivity slowdown throughout the US economy that began in the early 1970s and worsened in the late-1970s.
(4) Institutional background on the SBIR program is in Link and Scott (2012), Leyden and Link (2015), and Hayter et al. (2018) and in the public domain references therein. See also, Hayter and Link (2018) on patenting and publishing in entrepreneurial firms.
(5) Current funding guidelines allow, under certain conditions, an agency to increase Phase I and Phase II awards by up to 50%.
(6) About 50% of all SBIR Phase II awards are funded by DoD. See Link and Scott (2012).
(7) The NRC survey asks if the owner of the firm is a minority or not; the survey does not ask about the ethnicity of the minority owner. Thus, our ownership categories are de facto White-owned and non-White-owned firms.
(8) One could take the logarithm of both sides of Eq. (5) to derive a linear knowledge production function model. However, to estimate it by least squares, firms with zero patent applications would have to be deleted. The Poisson model and negative binominal model allow for the dependent variable to be zero.
(9) Based on the statistical significance of the overdispersion parameter (alpha) in the negative binominal model, overdispersion (i.e., the variance being greater than the mean) is an issue and thus the negative binominal model provides a better fit to the data, compared to the Poisson model.

References

Audretsch, D. B., & Link, A. N. (2018). Entrepreneurship and knowledge spillovers from the public sector. International Entrepreneurship and Management Journal. https://doi.org/10.1007/s11365-018-0538-z.

Audretsch, D. B., & Link, A. N. (2019). Sources of knowledge and entrepreneurial behavior. Toronto: University of Toronto Press.

Audretsch, D. B., Link, A. N., & Scott, J. T. (2018). Frederic M. Scherer: over a half century—and counting—of seminal scholarly contributions. Review of Industrial Organization, 52, 502–508.

Cook, L. D., & Kongcharoen, C. (2010). The idea gap in pink and black. NBER working paper, 16331.

Czarnitzki, D., Kraft, K., & Thorwarth, S. (2009). The knowledge production of 'R' and 'D'. Economics Letters, 105, 141–143.

Ding, W. W., Murray, F., & Stuart, T. E. (2006). Gender differences in patenting in the academic life sciences. Science, 313, 665–667.
Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. Bell Journal of Economics, 10, 92–116.
Hall, B. H., & Harhoff, D. (2012). Recent research on the economics of patents. Annual Review of Economics, 4, 541–565.
Hall, B. H., & Ziedonis, R. H. (2001). The patent paradox revisited: an empirical study of patenting in the U.S. semiconductor industry, 1979-1995. RAND Journal of Economics, 32, 101–128.
Hayter, C. S., & Link, A. N. (2018). Why do knowledge-intensive entrepreneurial firms publish their innovative ideas? Academy of Management Perspectives, 32, 141–155.
Hayter, C. S., Link, A. N., & Scott, J. T. (2018). Public sector entrepreneurship. Oxford Review of Economic Policy, 34, 676–694.
Hunt, J., J. Garant, H. Herman, and D,J. Munroe (2012). Why don't women patent? NBER working paper 17888.
Leyden, D. P., & Link, A. N. (2015). Public sector entrepreneurship: U.S. technology and innovation policy. New York: Oxford University Press.
Link, A. N. (2015). Capturing knowledge: private gains and public gains from universities research partnerships. Foundations and Trends in Entrepreneurship, 11, 139–206.
Link, A. N., & Scott, J. T. (2012). Employment growth from public support of innovation in small firms. Kalamazoo, MI: W.E. Upjohn Institute for Employment Research.
Link, A. N., & Scott, J. T. (2018). Propensity to patent and firm size for small R&D-intensive firms. Review of Industrial Organization, 52, 561–587.
Link, A. N., & Strong, D. R. (2016). Gender and entrepreneurship: an annotated bibliography. Foundations and Trends in Entrepreneurship, 12, 287–441.
Link, A. N., Morris, C. A., & van Hasselt, M. (2018). The impact of Public R&D Investments on patenting activity: technology transfer at the U.S. Environmental Protection Agency. Economics of Innovation and New Technology. https://doi.org/10.1080/10438599.2018.1542772.
Milli, J., Williams-Baron, E., Berlan, M., Xia, J., & Gault, B. (2016). Equity in innovation: women inventors and patents. Institute for Women's Policy Research Report.
Rosser, S. V. (2009). The gender gap in patenting: is technology transfer a feminist issue? NWSA Journal, 21, 65–84.
Rosser, S. V. (2012). Breaking into the lab: engineering progress for women in science. New York: New York University Press.
Scherer, F. M. (1965). Firm size, market structure, opportunity, and the output of patented inventions. American Economic Review, 55, 1097–1125.
Scherer, F. M. (1983). The propensity to patent. International Journal of Industrial Organization, 1, 107–128.
Veugelers, R., & Schneider, C. (2018). Which IP strategies do young highly innovative firms choose? Small Business Economics, 50, 113–129.