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Using Patent Citations to Measure International Knowledge Spillovers in the U.S. Pharmaceutical Industry

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Abstract : Production in the pharmaceutical industry is gradually shifting to low income countries. Product cycle models of international trade view businesses in high income "North" countries as innovators and those in lower income "South" countries as imitators. One indicator of how entrepreneurs view competitors is the extent to which they learn from one another. We measure such knowledge spillovers using patents held by U.S. pharmaceutical manufacturers that cite foreign patents or have a foreign inventor. Controlling for R&D spending and domestic and international competition, we find evidence of South-North knowledge spillovers, contradicting standard views of North innovation and South imitation.

Keywords: Innovation, Patents, Spillovers, International Trade, Pharmaceutical
JEL classification: O3, F6

1. Introduction

The IQVIA Institute for Human Data Science (2019) estimates that the worldwide market for pharmaceutical products was approximately $1.2 trillion in 2018, with spending of $485 billion in the U.S., the world's largest consumer of pharmaceutical products. China is the world's second largest consumer of pharmaceutical goods and the anticipated growth in the market is expected to come predominantly from what IQVIA calls "Pharmerging" countries – China, Brazil, Russia, India, Algeria, Argentina, Colombia, Bangladesh, Indonesia, Mexico, Nigeria, Pakistan, Poland, Saudi Arabia, South Africa, Philippines, Turkey, Romania, Chile, Kazakhastan and Vietnam – emerging economies where the use of pharmaceuticals is growing rapidly (IQVIA, 2019).

On the production side, though, the industry is dominated by manufacturers from high income economies. Only two of the 50 largest pharmaceutical companies in the world are not from high income economies (PharmExec, 2019). However, an analysis of trade in pharmaceuticals does show a changing pattern over time. Data from the U.S. International Trade Commission (USITC) show that U.S. pharmaceutical imports from low and middle income economies grew by approximately 300% from 2008-2018, while imports form high income economies increased by 61% over the same time period. About 12 % of U.S. pharmaceutical imports came from low/middle income countries in 2018 compared to only 5% in 2008.

As competition in the U.S. from firms in low and middle income countries intensifies over time, the ability for manufacturers in the high income countries to learn from their counterparts in lower income economies increases. Such learning from others is contrary to the standard view of innovation which views manufacturers from high income economies as innovators and manufacturers from lower income economies purely as imitators.

In this paper we look at the extent to which firms in high income economies take advantage of "knowledge spillovers" from their competitors from lower income economies. Specifically, we analyze patent spillovers from pharmaceutical manufacturers in low and middle income countries to their counterparts in the U.S.A.

2. Literature Review

Starting with Vernon (1966) and Krugman (1979), and with notable extensions from Romer (1990), Grossman and Helpman (1991a, 1991b, 1991c), and Aghion and Howitt (1992), the research on innovation in a North-South setting describes a world of innovative firms from the high income "North" competing with one another and also with firms from the lower income "South". A defining aspect of these models is that South firms are imitative of the North firms, and are not innovative in their own right. North firms create new products, and enjoy a monopoly for some finite period of time. During this they face competition, however, from other innovative North firms and from South firms, which eventually copy the new product. The dual nature of the competition pushes North firms to continuously invest in innovative efforts in their quest for greater profits.

However, as companies in low and middle income economies move from imitation to innovation, their counterparts in the North might start to learn from them – the knowledge of the innovator "spilling over" and being utilized by third parties. One way to measure such knowledge spillovers is by using the information contained within patents. Patent documentation includes two pieces of information which capture the idea of international spillovers: (i) the location of the inventor/co-inventor of the patent, and (ii) citations of previously granted patents by country of origin that are considered to be instrumental to the development of the new patent. Patent citations have been frequently used in the literature to measure international knowledge spillovers, (see for example, Jaffe, Trajtenberg, and Henderson 1993, and Jaffe, Trajtenberg, and Fogarty, 2000). Patent citations are used by Branstetter (2006) for spillovers from Japanese multinationals undertaking direct investment in the U.S., and by Hu and Jaffe (2003) for spillovers from the U.S. and Japan to South Korea and Taiwan.

Patent citations are an imperfect measure of knowledge spillovers, however, and there appear to be significant geographic aspects at work. Jaffe and Trajtenberg (1999) find that a patent's citations are more likely to come from the inventor's country than from foreign countries, and Jaffe, Trajtenberg, and Henderson (1993) find that patents with U.S. inventors are more likely to cite innovations that arose in the same geographic area than those from further away. Thompson (2006) finds that the citations provided by the inventor of a patent are more likely to be from local patents than the citations provided by the patent examiner.

There are other problems with using patent citations to measure knowledge spillovers. Sampat (2010) finds that a relatively low number of citations for a patent are provided by the actual inventors, and that many citations are added "after the fact" by the patent examiner. Lampe (2012) finds patent applicants under-cite others as a deliberate strategy.

Nevertheless, patent citations continue to be a regarded as a valid, though flawed, approach to measuring knowledge spillovers. Branstetter (2000) reviews various models of knowledge spillovers, including using patent citations, and notes that "Ultimately, though, the significance of these theories will be, and rightly should be, determined by empirical evidence" (p. 517). With this study, we hope to contribute to this evidence.

Several researchers have looked at patenting in the pharmaceutical industry. Furman et al. (2006) find a strong correlation between the patenting output of pharmaceutical firms and locally generated academic or government research. Kim, Lee, and Marschke (2009) find that U.S. pharmaceutical and semiconductor manufacturers have increased the extent to which they work with or employ workers with foreign experience. Tseng and Pai (2014) use U.S. patenting data to examine knowledge flows in the Indian pharmaceutical industry, and find no significant effect of knowledge spillovers between pharmaceutical manufacturers on knowledge creation.

Of particular relevance to our study is the work of Simons and Linde (2019). They examine how competition from pharmaceutical firms affects the level of patenting in U.S. pharmaceutical manufacturers, and find that increased competition from manufacturers in low/middle income countries increases the number of patents obtained by U.S. firms, while increased competition from rivals in high income countries decreases the number of patents obtained by pharmaceutical manufacturers in the U.S. In this study, we instead look at how such competition affects the transfer of knowledge from pharmaceutical firms in low/middle income economies to their counterparts in the U.S.

3. Methodology

To be able to make a direct comparison of these two different aspects to U.S. pharmaceutical patenting, we use a similar approach to Simons and Linde (2019). Our model specification is that the amount of patent-based knowledge spillovers utilized by a particular U.S. pharmaceutical firm in a given year is a function of the level of competition it faces, the size of the firm, its research and development (R&D) spending, and the number of patents that it obtains in that year. To further clarify different effects, we distinguish between competition coming from other U.S. firms, firms in other high income countries, and firms in low and middle income countries. The details of our specification are laid out in equation (1) and its accompanying definitions:

$$SPILLOVERS_{kt} = f[PATENTS_{kt}, REVENUE_{kt}, R\&D_{kt}, REVENUE_{USt} - REVENUE_{kt}, IMPORTS_{G1t}, IMPORTS_{G2t}] \quad (1)$$

Where

- $SPILLOVERS_{kt}$ is the number of granted pharmaceutical patents that were applied for in the U.S. in year t, which cite a patent from a Group 2 country or which have an inventor from a Group 2 country, where firm k is the assignee
- $PATENTS_{kt}$ is the number of granted pharmaceutical patents that were applied for in the U.S. in year t, where firm k is the assignee.
- $REVENUE_{kt}$ is firm k's revenue in year t.
- $R\&D_{kt}$ is firm k's spending on research and development in year t.
- $REVENUE_{USt}$ is overall pharmaceutical production in the U.S.A. in year t.
- $IMPORTS_{G1t}$ is pharmaceutical imports into the U.S.A. from Group 1 in year t.

- $IMPORTS_{G2t}$ is pharmaceutical imports into the U.S.A. from Group 2 in year t.
- Group 1 – high income economies
- Group 2 – low/middle income economies
- Subscript k designates individual U.S. pharmaceutical firms, and t is years. All monetary amounts are in millions of real 2009 U.S. dollars.

Because SPILLOVERS is a non-negative integer, we use a Poisson regression. As different firms innovate differently, we use a firm fixed effects regression model.

While equation (1) is our initial specification of the model, we also consider variations using natural logarithms as a robustness check.

For robustness, we use natural logarithms for two additional specifications of the model, based on the function shown in equation (1):

$$\ln(SPILLOVERS_{kt}) = f[\ln(PATENTS_{kt}), \ln(REVENUE_{kt}), \ln(R\&D_{kt}), \ln(REVENUE_{USt} - REVENUE_{kt}), \ln(IMPORTS_{G1t}), \ln(IMPORTS_{G2t})] \quad (2)$$

$$SPILLOVERS_{kt} = f[PATENTS_{kt}, \ln(REVENUE_{kt}), \ln(R\&D_{kt}), \ln(REVENUE_{USt} - REVENUE_{kt}), \ln(IMPORTS_{G1t}), \ln(IMPORTS_{G2t})] \quad (3)$$

In the discussion below, we refer to the specifications represented by equations (1)-(3) as Models 1-3, respectively.

4. Data

We use date for the time period 1997-2015. The start date is due to the limitations of the import database listed below. The end date is due to the time lags in the patenting processing system.

For the IMPORTS variables, we use the U.S. International Trade Commission's DataWeb database (dataweb.usitc.gov), giving pharmaceutical imports for NAICS code 3254 (Pharmaceutical and Medicine Manufacturing). This allows us to measure the degree of competition faced by U.S. firms from pharmaceutical manufacturers in other countries.

To ensure that our selection of U.S. firms is unbiased while remaining relevant for this study, we limit our analysis to pharmaceutical firms that: (1) have their corporate headquarters within the U.S.A.; (2) are considered to be in the top 50 largest pharmaceutical producers; and (3) reported spending on R&D for each year 1997-2015.

We use firms' financial reports for data on their R&D spending and revenues, and Pharmaceutical Executive (PharmExec, 2015) for a ranking of global pharmaceutical manufacturers by size, giving us the following 13 U.S. firms to use in our analysis: Abbott Laboratories, Alexion Pharmaceuticals Inc., Amgen Inc., Baxter International Inc., Biogen Inc., Bristol-Myers Squibb Co., Celgene Corp., Eli Lilly and Co., Gilead Sciences Inc., Johnson & Johnson, Merck & Co., Inc., Mylan N.V., and Pfizer Inc.

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We use the U.S. Patent and Trademark Office's online patent database (http://www.uspto.gov) for all of our patent and spillover data, and we obtain data on domestic U.S. pharmaceutical and medicine production (NAICS code 3254) from the online database of the U.S. Bureau of Economic Analysis' (BEA).

For the purpose of evaluating the level of overseas competition faced by U.S. pharmaceutical manufacturers, we split countries and their trade data into two groups. Group 1 comprises countries that the World Bank classifies as high income in its 2020 classification (available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519). This is our proxy for "North" countries. Group 2 comprises countries that the World Bank classifies as low, lower-middle, or upper-middle-income economies. This is our proxy for "South" countries.

Finally, we convert all monetary amounts in our data set into real 2009 dollars using the BEA's U.S. GDP Deflator.

5. Results

Tables 1 and 2 give the summary statistics and regression results.

The positive and significant coefficient on $PATENTS_{kt}$ indicates that U.S. firms that patent more learn more from innovators in low and middle income economies – comparing firms with the same level of revenue and R&D spending, those that patent more intensively learn more from their South counterparts. The positive and significant coefficient on $REVENUE_{kt}$ indicates that larger U.S. firms learn more from innovators in low and middle income economies – comparing firms with the same level of R&D spending and patenting intensity, firms with greater revenue learn more from their South counterparts. These two results seem reasonable – more aggressive innovators and larger pharmaceutical firms learn more from others.

The positive and significant coefficient on ($REVENUE_{USt}$ – $REVENUE_{kt}$) indicates that U.S. firms learn more from low and middle income economies as competition in the U.S. increases. Again, this result is reasonable – greater domestic competition gives an incentive for U.S. pharmaceutical firms to learn from the innovative efforts of others regardless of their location.

The negative and significant coefficient on $IMPORTS_{G1t}$ (imports from Group 1), means that U.S. firms learn *less* from firms in low and middle income economies when they faces greater competition from high income economies. This result seems counter intuitive – a heightened threat from competitors in high income countries would seem like it would push U.S. firms to try and learn from others no matter their country of origin. We postulate that this seemingly perverse result might be due to a substitution effect – greater competition from pharmaceutical companies in the North encourages a firm to learn more from their northern competitors and, in so doing, focus less and learn less from their competitors in the South.

The positive and significant coefficient on $IMPORTS_{G2t}$ (imports from Group 2) indicates that as the U.S. imports more from low and middle income economies, U.S. firms are learning more from innovators in those economies. This is the clearest indication that U.S. pharmaceutical firms see the firms in these countries as innovative competitors, rather than just imitative competitors.

6. Summary and Conclusions

The above results indicate that South-North spillovers increase as pharmaceutical manufacturers in the U.S.A. face more competition from manufacturers in low and middle income economies. Traditional North-South models of innovation assume that South manufacturers are merely imitative, leaving no rationale for the transfer of knowledge from the South to the North. In contrast, our analysis indicates that North manufacturers view South manufacturers as, in part, innovative in their own right. This result connects with the findings of Simons and Linde (2019) who find that U.S. pharmaceutical manufacturers increase the amount of patents that they hold as competition from the South increases. So, taken together, these two pieces of research indicate that increased competition from low/middle income economies leads these U.S. manufacturers to both learn more from their Southern counterparts and to increase their own innovation output.

There are, of course, limitations to our work. First, in our analysis we count how many patents have an inventor or cite a patent from Group 2 countries. We do not count *how many* inventors or citations from Group 2 are contained in each patent. This implies that we are underestimating the amount of knowledge spillovers, as a cited patent with five inventors from Group 2 is counted the same as a patent with a sole inventor from Group 2.

Second, and more problematically, some of the U.S. imports of pharmaceutical products are likely from overseas subsidiaries/production facilities of U.S. companies. Our analysis treats these imports from subsidiaries as “foreign competition”, though there would be no reason for a U.S. firm to view these imports as coming from competitors. Unfortunately, data limitations prevent us from identifying these imports separately from those coming from companies with no U.S. ownership.

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Table 1. Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N.
SPILLOVERS	6.401	11.291	0	93	247
PATENTS	79.065	85.616	0	377	247
REVENUE	17371.939	17464.688	1.015	68298.844	247
R&D	2537.908	2512.96	11.639	10976.971	247
$REVENUE_{US}$	190497.569	29509.603	124865.405	234782.569	247
$IMPORTS_{G1}$	59714.226	21822.885	17453.077	90906.803	247
$IMPORTS_{G2}$	3580.519	2739.127	633.657	8977.816	247

All monetary amounts are in 2009 $millions

Table 2. Regression Results

Variable	Model 1	Model 2	Model 3
PATENTS	0.00601**	0.516***	0.00599**
	(0.00249)	(0.138)	(0.00250)
$REVENUE_k$	1.71e-05	0.259**	0.376**
	(2.41e-05)	(0.131)	(0.186)
$R\&D_k$	5.50e-06	-0.243*	-0.0900
	(3.00e-05)	(0.141)	(0.226)
$REVENUE_{US}$ - $REVENUE_k$	1.26e-05*	0.902	2.1246**
	(7.60e-06)	(0.625)	(0.875)
$IMPORTS_{G1}$	-8.62e-06	0.135	-1.148***
	(1.42e-05)	(0.396)	(0.405)
$IMPORTS_{G2}$	0.000262***	0.462***	1.239***
	(5.10e-05)	(0.0996)	(0.270)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1