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IPR infringement in the United States: impacts on the input and output of R&D

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Abstract

This paper examines the impact of intellectual property rights (IPR) infringement on the input (R&D spending) and output (patents) of the research process. The extant literature proxies IPR enforcement via composite indices or indicators of institutional quality, whereas this paper employs a direct (hard) measure of IPR crimes. Using data across U.S. states, results show that IPR crimes reduce research spending but do not impact patenting. Upon comparison with a broader measure of weak institutional quality (corruption), we find that greater corruption has a robust negative effect on patenting, but not on R&D spending. Quantitatively, the elasticities of R&D spending with respect to IPR crimes are greater than those of patents with respect to corruption, suggesting that studies that proxy IPR crimes via other measures are likely underestimating their impacts on technological change.

Keywords Intellectual property rights (IPR) · R&D · Patents · Corruption · Institutions · United States

JEL Classification O34 · K42

1 Introduction

The presence of research spillovers has been recognized by inventors, firms, policymakers, and academics for some time (Besen and Raskind 1991; Lerner 2002). Some spillovers are authorized by inventors when they license their technologies, while others, such as from reverse engineering and from trade, are somewhat unavoidable and taken to be costs of doing business or of being innovative. Yet a third type is unauthorized spillovers, where competitors or counterfeiters use inventions without permission/authorization while trying to enter markets or to strengthen their competitive positions. However, little is formally known about the impact of the unauthorized spillovers and the present research attempts to make headway in this regard.

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Research spillovers are indicative of lax intellectual property rights (IPR) protection and more generally of weak institutions. Firms investing in R&D face uncertainty about payoffs and this uncertainty is enhanced when spillovers are widespread. Some of this weak IPR protection might be structural, as in a lack of attention to plugging loopholes or covering both hard and soft technologies by the government, while other types of weaknesses in IPR protection might be engineered or structural—via corruption for instance. A better understanding of the effects of the impact of weak IPR protections is potentially informative to policymakers trying to design policies to bolster technological change.

An earlier informative review of the literature on the economics of research spillovers is due to Griliches (1992) and Feldman (1999) provides a nice compilation of related empirical studies. The presence of research spillovers has been documented by various scholars, both within nations and internationally (Coe and Helpman 1995; Coe et al. 2009; Goel et al. 2016).

This paper examines the impact of IPR infringement crimes on the input (R&D spending) and output (patents) of the research process. R&D and patents are sequential stages of the process of technological change, with the former being the input and the latter being the output. The extant literature proxies IPR enforcement via composite indices or measures of institutional quality, whereas this paper employs a direct (hard) measure of IPR crimes. Equally important, we are able to compare the effects of the IPR crimes with those of weakening (endogeneity) of institutions via corruption (Goel 2003).

Using data across U.S. states, results show that IPR crimes reduce research spending but do not impact patenting. Upon comparison with a broader measure of weak institutional quality (proxied by corruption), we find that greater corruption has a robust negative effect on patenting. In terms of magnitudes, the elasticities of R&D spending with respect to IPR crimes are greater than those of patents with respect to corruption. Policy implications of these results are discussed.

The organization of the rest of the paper includes theoretical background and the model in the next section, followed by data and estimation, results and conclusions.

2 Theoretical background and model

The extant literature on research spillovers is largely theoretical, in part due to the difficulties with quantifying research spillovers (see Griliches 1992). Even the theoretical studies on the research spillovers are often vague, taking spillovers to be some fraction of research rewards, without allowing for spillovers to be different across recipients or that spillovers may be uncertain (d'Aspremont and Jacquemin 1988).

Some spillovers of research knowledge are unavoidable when they occur through trade, FDI and reverse engineering (Krammer 2014, 2015). When firms trade with others or license technologies, there is some learning involved, which unravels some of the mysteries of the underlying innovation. Such spillovers are almost impossible to guard against.

Weak intellectual property rights adversely affect the incentives to innovate (see Denicolò and Franzoni 2012 for some related theoretical arguments; Cohen et al. 2002 provide a comparison of Japan and the United States; also see Goel 1999; Mohnen 2009). Weak intellectual property rights might take the form of cumbersome or vague patent filing procedures, lax or delayed enforcement, or a narrow scope of such rights—e.g., when soft technologies are not covered.

As mentioned, some of the lax IPR protection might be structural—where government's overall institutional setup is weak. In such cases, even when IP-protecting statutes look good on paper, a lack of effective complementary institutions renders overall IPR protection ineffective.

Yet another impact on institutions might be more deliberate where through corruption and bribery, market participants can undermine institutions.[1] In the case of technological change, this undermining might take several forms, including bribing to have lower punishment or escape detection for IPR infringement, firms might be offering bribes/campaign contributions to have the scope of their inventions widely defined, or offering bribes to have international trade barriers erected, etc. Goel (2003) formally models some of these aspects in a game-theoretical setup. His results show that greater rent-seeking by rival firms lowers a firm's profit-maximizing research and rent-seeking activity.[2]

Whereas, there is recognition that research spillovers exist (both formal and informal), evidence and formal research on their effects is scarce and it is in this respect that the present study attempts to make a contribution.

Based on the above discussion, we formulate the following hypotheses that we shall test empirically:

H1 Greater IPR crimes would, ceteris paribus, reduce R&D spending.

H2 Greater IPR crimes would, ceteris paribus, reduce patenting.

H3 Greater corruption would, ceteris paribus, reduce R&D spending.

H4 Greater corruption would, ceteris paribus, reduce patenting.

To test the above hypotheses, we formulate a set of equations that we will estimate with data from U.S. states.

With the dependent variables, PATENT and R&D spending, capturing sequential stages of the process of technological change, our estimated equations take the following general form (with subscript i denoting a state).

$$\text{R\&D output}\left(\text{PATENT}_{\text{i}}\right) = f\left(\text{IPRcrime}_{\text{i}},\ \text{CORRUPT}_{\text{i}}, \text{Institutions}_{\text{k}},\ \text{Z}_{\text{im}}\right) \tag{1}$$

and

$$\text{R\&D input}\left(\text{IndustryR\&D}_{\text{i}};\text{TotalR\&D}_{\text{i}}\right) = g\left(\text{IPRcrime}_{\text{i}},\ \text{CORRUPT}_{\text{i}},\ \text{Institutions}_{\text{ik}}, \text{Z}_{\text{im}}\right) \tag{2}$$

$$\text{i} = 1, 2, \ldots, 51$$

$$\text{k} = \text{EconFREE},\ \text{Regulation}$$

$$\text{m} = \text{RGDP, POP, URBAN},\ \text{EDU, UNEMP}$$

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[1] Examples of related institutions are those dealing with governance, economic freedom and IPR protection (see Krammer 2015).

[2] Along another related dimension, corruption and rent-seeking might impact the scope of patents (Goel 2002).

In our sample, the average number of patents granted per capita across U.S. states was 0.0003 (average of 2014–2015), the average industry R&D per 1000 dollars of state GDP $13.92, and the average total R&D (industry plus academic R&D) per 1000 dollars of state GDP was $17.67. There was, however, considerable variation in research spending across individual states with TotalR&D being the highest in Massachusetts ($51.61 per $1000 of state GDP) and the lowest in Wyoming ($2.85 per $1000 of state GDP). The variation in patents granted was even more pronounced, with a high of 40,661 (California in 2014) to a low of 40 (Alaska in 2015).

The main control variable of interest, and one that is unique to this study, is related to IPR/copyright and counterfeit crimes in a state. This is a direct measure that is pertinent to research investments and patenting (as opposed to composite indices of patent protection (Park 2008) that have been used in the literature). In our sample, IPR crimes ranged from 1 to 277.

As a broader measure of weak institutional quality and potential spillover leakages, we include corruption prosecutions in a state (CORRUPT). Other things being the same, states with greater corruption would signify greater uncertainty about appropriability of research benefits—both in the research input and research output stages (Goel 2003).[3] In a broader context, the consideration of corruption can be seen as adding to the literature on the effects of corruption (see Dimant and Tosato 2018 for a recent literature review), or corruption can be indicative of weak governance institutions (Krammer 2015).

Fewer regulations and tax complexities are likely to make research and patenting more desirable by lowering the transactions costs, although some regulations might be tied to IPR safeguards. We include a broader measure of economic freedom (EconFREE) and a narrower measure of regulation (Regulation) to see their effects on research spending and patenting.

The set of control variables that we employ are denoted by the vector Z and these include economic prosperity (RGDP), state size (POP), urbanization (URBAN), literacy (EDU) and unemployment (UNEMP). Greater economic prosperity can be tied to greater opportunity and better institutions in wealthier states, whereas larger states would have larger potential markets for invented products (although at the same time, there would be greater challenges to guard proprietary information in larger states). The degree of urbanization is related to networking opportunities and information flows, and greater literacy would empower both research spending and patenting. Finally, greater unemployment provides a ready availability of labor input, although the purchasing power of the unemployed is limited.

Within this overall setup, the satisfaction of Hypotheses 1–4, would imply negative and statistically significant coefficients on IPRcrime and CORRUPT in Eqs. (1) and (2), respectively.

We turn next to a discussion of the data employed and the estimation procedure used to test the above equations.

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[3] In light of the well-known multidimensional nature of corruption, one could argue that R&D and patents could have reverse feedbacks on corruption. This seems less likely with the state-dependent nature of most R&D. Further, the cross-sectional nature of our data mitigates these concerns (which could be examined with appropriate data in due course). Also see Sect. 4.5.

3 Data and estimation

3.1 Data

The main and unique variable in this study is the number of IPR and copyright violations per state in the United States. However, the availability of this variable is limited to a single year (2015—see www.ic3.gov) and this limits our analysis to a cross-section. This limitation also constrains our ability to consider relevant aspects like lags in research and patenting (Goel and Saunoris 2016). Yet, as a first formal attempt to discern the impacts of IPR crimes, the present exercise seems worthwhile.

Given that there could be lumpiness in patent grants and in corruption prosecutions (i.e., some years with unusually high or low occurrences), we take the average of 2 years (2014 and 2015) to smooth out such effects. Total R&D is the sum of academic and industrial R&D at the state level.

The data are from reliable sources that are routinely used in other contexts. Details about the variables used, including definitions, summary statistics and data sources are provided in Table 1. Table 2 reports pairwise correlations among the key variables. As expected, both R&D spending measures, IndustryR&D and TotalR&D, have a high correlation with PATENT. Interestingly, the correlation between IPRcrime and CORRUPT is a modest 0.34 which suggests that while the two measures are positively related, they are picking up somewhat different aspects and that our use of a direct measure in the form of IPRcrime will yield some new insights. Finally, all the correlations of IPRcrime are statistically insignificant and the formal econometric analysis will reveal if some of these relations turn out to be statistically significant when other relevant factors are accounted for.

3.2 Estimation

Given the cross-sectional nature of the data, we are somewhat limited in the estimation techniques that can be employed. Tables 3 and 4 report OLS estimation results, with t-statistics based on robust standard errors. To address issues with possible outliers and to as a robustness check, Table 5 reports results of a robust regression. All estimations were conducted using the STATA software.

4 Results

4.1 Baseline models

Our baseline results are reported in Table 3. The R^2 is at least 0.36 and the RESET test shows an absence of significant specification issues in all cases.

With regard to the impact of IPR crimes, we find that greater IPR crimes reduce research spending, but do not have a significant effect on patenting. The effect on research spending holds for both industrial R&D and total R&D (which also includes academic research spending). The insignificant effect on patents can be seen in light of the fact that firms at the patenting stage are farther along the research process (with many fixed and sunk costs) and therefore greater appropriation uncertainty, as signified by greater IPR crimes, has relatively less impact on patents (compared to R&D spending when firms may have greater flexibility in changing research course or abandoning projects altogether).

Table 1 Variable definition, summary statistics and data sources

Variable	Definition (mean; standard deviation)	Source
PATENT	Number of patents granted as distributed by year of patent grant, per capita, average of 2014–2015 (0.0003; 0.0002)	[1]
IndustryR&D	Industry R&D per 1000 dollars of state GDP, 2014 (13.92; 11.47)	[2]
TotalR&D	Industry plus academic R&D per 1000 dollars of state GDP, 2014 (17.673; 11.91)	[2]
IPRcrime	IPR/copyright and counterfeit crimes per capita, victims by state, 2015 (4.04e−06; 2.32e−06)	[3]
CORRUPT	Number of federal public corruption convictions per capita, average of 2014–2015 (3.17e−06; 3.32e−06)	[4]
Regulation	Index of regulatory policy, higher values, less regulation, 2014 (− 0.077; 0.14)	[5]
EconFREE	Index of economic freedom, higher values, greater freedom, 2014 (− 0.045; 0.26)	[5]
UNEMP	Unemployment rate, population aged 16 and over, 2015 (5.92; 1.34)	[6]
EDU	Educational Attainment, percent of population aged 25 and over with high school graduate or higher, 2015 (88.745; 2.92)	[2]
RGDP	Real GDP (in millions of constant 2009 dollars), 2015 (315,491.8; 400,104.6)	[7]
POP	State population, 2015 (6,302,330; 7,201,100)	[6]
URBAN	Urbanization rate, percent of state population residing in urban areas, 2000 (72.247; 15.28)	[2]

All data are by state, including, where available, the District of Columbia

[1] U.S. Patent and Trademark Office, Patent Technology Monitoring Team (PTMT)

[2] Statistical Abstract of the United States

[3] U.S. Department of Justice, 2015 Internet Crime Report

[4] U.S. Department of Justice, Public Integrity Section

[5] Cato Institute, Freedom in the 50 States

[6] U.S. Census Bureau, American Community Survey

[7] U.S. Department of Commerce/Bureau of Economic Analysis/Regional Product Division

Table 2 Correlation matrix of key variables

	PATENT	IndustryR&D	TotalR&D	IPRcrime	CORRUPT
PATENT	1.00				
IndustryR&D	0.82**	1.00			
TotalR&D	0.82**	0.99**	1.00		
IPRcrime	0.15	0.01	0.03	1.00	
CORRUPT	− 0.36**	− 0.36**	− 0.34**	0.34**	1.00

See Table 1 for variable details

N = 51

**Denotes statistical significance at the 5% (or better) level

Table 3 Effects of IPR infringement: baseline models

Dep. var.	3.1 PATENT	3.2 IndustryR&D	3.3 TotalR&D	3.4 PATENT	3.5 IndustryR&D	3.6 TotalR&D
IPRcrime	**− 19.35** **(20.0)**	**− 2,091,407**** **(869,558.7)**	**− 2,162,762**** **(871,239.2)**			
CORRUPT				**− 28.44**** **(9.7)**	**− 1,055,256**** **(432,709.7)**	**− 974,702**** **(420,641.2)**
RGDP	8.33e−10 (5.5e−10)	0.00002 (0.00)	0.00002 (0.00)	7.96e−10 (5.4e−10)	0.00002 (0.00)	0.00002 (0.00)
POP	− 2.99e−11 (2.9e−11)	− 4.35e−07 (1.6e−06)	− 3.87e−07 (1.8e−06)	− 2.91e−11 (2.9e−11)	− 6.67e−07 (1.8e−06)	− 6.46e−07 (2.0e−06)
URBAN	4.50e−06 (3.7e−06)	0.40** (0.12)	0.42** (0.13)	2.06e−06 (3.0e−06)	0.22** (0.1)	0.25** (0.1)
EconFREE	− 0.0001 (0.00)	− 2.23 (7.6)	− 3.77 (7.8)	− 0.0001 (0.00)	0.03 (7.4)	− 1.27 (7.8)
EDU	0.00003** (0.00)	1.34** (0.5)	1.41** (0.5)	0.00003** (8.9e−06)	1.01** (0.5)	1.08** (0.5)
N	50	50	50	50	50	50
R^2	0.42	0.38	0.39	0.50	0.36	0.36
RESET test (F-value)	0.52	0.86	0.62	1.04	1.31	0.88

See Table 1 for variable details. Constant included but not reported in these OLS regressions. The numbers in parentheses are robust standard error

Bold values indicate variables/estimates of main interest

* and **, respectively, denote statistical significance at the 10% and 5% (or better) levels

With respect to the effect of corruption—that captures weak institutions (both research-related and others like tax and licensing), greater corruption lowers both research spending and patenting. This is consistent with corruption having short-term as well as long-term effects. Viewed differently, IPR crimes capture specific issues with appropriability, and corruption address more general related issues. In the following

Table 4 Effects of IPR infringement: additional considerations

	4.1	4.2	4.3	4.4
Dep. var.	PATENT	TotalR&D	PATENT	TotalR&D
IPRcrime	**− 6.02** **(21.1)**	**− 1,928,501*** **(1,034,634)**		
CORRUPT			**− 34.82**** **(16.5)**	**− 1,353,560*** **(742,647)**
RGDP	9.09e−10* (5.4e−10)	0.00002 (0.00)	6.49e−10 (5.5e−10)	8.08e−06 (0.00)
POP	− 4.12e−11 (2.8e−11)	− 9.38e−07 (1.6e−06)	− 2.78e−11 (2.9e−11)	− 3.37e−07 (1.9e−06)
URBAN	4.74e−06 (3.7e−06)	0.42** (0.1)	2.26e−06 (3.0e−06)	0.22* (0.12)
Regulation	− 0.0002 (0.00)	− 13.38 (11.8)	− 0.0004 (0.00)	− 19.83 (12.0)
UNEMP	− 0.00004 (0.00)	− 0.28 (1.1)	− 0.00003 (0.00)	− 0.49 (1.2)
N	50	50	50	50
R^2	0.33	0.32	0.45	0.34
RESET test (F-value)	0.64	0.74	2.8*	2.1

See Table 3

Table 5 Effects of IPR infringement: robust regression

	5.1	5.2	5.3	5.4
Dep. var.	PATENT	TotalR&D	PATENT	TotalR&D
IPRcrime	**− 28.57** **(17.7)**	**− 1,779,454**** **(848,844.5)**		
CORRUPT			**− 19.84**** **(9.6)**	**− 897,206.6** **(604,963.1)**
RGDP	7.36e−10 (4.9e−10)	0.00002 (0.00)	6.29e−10 (4.7e−10)	0.00001 (0.00)
POP	− 2.70e−11 (2.7e−11)	− 4.41e−07 (1.3e−06)	− 2.29e−11 (2.6e−11)	− 1.36e−07 (1.6e−06)
URBAN	7.74e−06** (2.3e−06)	0.30** (0.1)	4.35e−06** (2.0e−06)	0.20 (0.12)
EconFREE	− 0.00003 (0.00)	− 13.41** (6.7)	− 0.00003 (0.00)	− 4.05 (8.3)
EDU	0.00002** (0.00)	0.78 (0.5)	0.00002* (1.0e−05)	1.03 (0.6)
N	50	50	50	50
F-value	6.7**	6.4**	6.7**	3.0**

See Table 1 for variable details. Constant included but not reported in these robust regressions

Bold values indicate variables/estimates of main interest

The numbers in parentheses are standard errors

* and **, respectively, denote statistical significance at the 10% and 5% (or better) levels

sections, we test the validity of these findings by using an alternate set of determinants and an alternate estimation technique.

As expected, greater literacy (EDU) boosts both patenting and R&D—the resulting coefficient is statistically significant in all instances. Greater literacy thus mitigates the negative effects of IPR infringement and weakness in institutions (as captured by corruption). Greater urbanization, on the other hand, positively affects research spending but not patenting. This finding can be seen as being consistent with urbanization being associated with informal networking and information flows that might assist research spending decisions; whereas, with patenting, inventors are seeking exclusivity and then the insignificant influence of urbanization seems plausible.

The effects of economic prosperity, state size (as denoted by population),[4] and economic freedom are statistically insignificant in all the models in Table 3.

4.2 Robustness check 1: additional considerations

In Table 4, we consider a set of additional control variables to see whether they affect patenting and R&D spending. Specifically, the additional variables we consider are the unemployment rate (UNEMP) and Regulation, which is a more specific index of the economic freedom index (EconFREE) employed earlier.

Since the findings for IndustryR&D and TotalR&D were quite similar in Table 3, we drop IndustryR&D as a dependent variable here (and also in Table 5). Furthermore, since education and unemployment would be related, EDU is dropped as a regressor.

The R^2 is at least 0.32 in all the models estimated and the RESET test, with the exception of Model 4.3, signifies an absence of major specification issues.

The coefficients on both Regulation and UNEMP are all negative but statistically insignificant. More importantly, however, the pattern for the main variables of interest—IPRcrime and CORRUPT—is similar to Table 3. In other words, greater IPR crimes only negatively impact total R&D spending, while greater corruption negatively affects both patenting and R&D spending. We turn next to an alternate estimation technique that addresses robustness issues related to estimation.

4.3 Robustness check 2: alternate estimation

Table 5 replicates Table 3 with robust regression estimation. This technique allows us to account for disproportionate influences of possible outliers. The F-value is statistically significant in all the models.

We find a sharper distinction with robust regression regarding the effects of IPR crimes and corruption—the former has a negative effect on research spending, while the latter negatively affects patenting. IPR crimes can be seen as increasing ex-ante uncertainty about the research, while greater corruption can be seen as adding to ex-post uncertainty.

The pattern of other findings is largely similar qualitatively to what was reported in Table 3. In particular, the effects of population and economic prosperity (RGDP) are again statistically insignificant.

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[4] The insignificance of state size can partly be understood in the context of information leakages or spillovers via the internet, since such spillovers are less constrained by physical borders or state size.

Table 6 Summary of elasticities

Model	3.2	3.3	3.4	5.2	5.3
	OLS regression			Robust regression	
$\varepsilon_{\text{IndustryR\&D,IPRcrime}}$	− 0.48**				
$\varepsilon_{\text{TotalR\&D,IPRcrime}}$		− 0.49**		− 0.41**	
$\varepsilon_{\text{PATENT,CORRUPT}}$			− 0.30**		− 0.21**

All elasticities are evaluated at the sample means reported in Table 1

The model numbers correspond to the respective models from Tables 3 and 5

** denotes statistical significance at least at the 5% level

Greater literacy positively impacts patenting, but has no effect on research spending. This can be seen as literacy aiding the transaction or filing costs associated with patenting. Urbanization, contrary to Table 3, has greater statistical support for patenting than for R&D spending. This suggests that perhaps outliers were affecting the findings with respect to the impact of urbanization in Table 3. Interestingly, greater economic freedom has a negative and significant impact on research spending in Model 5.2—perhaps signifying that greater economic freedom involves less government vigilance against IPR abuse.

4.4 Relative magnitudes of effects

In Table 6 we summarize the magnitude of effects by reporting elasticities evaluated at respective sample means.

From Table 3 (with OLS regression), the elasticity of research spending with respect to IPR crimes is significantly greater than that of patents with respect to corruption (− 0.5 versus − 0.3, respectively). IPR crimes have a more pronounced (negative) effect on research spending than greater corruption does on patenting. This pattern holds true in Table 5 (with robust regression) where the elasticities are − 0.4 and − 0.2, respectively. Thus, a ten percent increase in IPR crimes would lower research spending by four percent, while a similar increase in corruption would lower patenting by 2% (Table 6). Given that research spending and patenting are sequential stages, a lowering of research spending via greater IPR crimes would in due course lower patenting also.

4.5 Additional consideration: accounting for the sequential nature of R&D and patents using mediation analysis

Since R&D and patents are sequential in nature, with R&D preceding patents, it would be instructive to study the extent of the influence of IPRcrime and CORRUPT on patents that passes through R&D. For this purpose, we employ mediation analysis and the results are reported in Table 7.[5]

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[5] There is more than one way to conduct mediation analysis. Our analysis was conducted using the "sem" command in STATA (for details, see https://stats.idre.ucla.edu/stata/faq/how-can-i-do-mediation-analysis-with-the-sem-command/).

Table 7 Mediation analysis of the effects of IPRcrime and CORRUPT on PATENT

	Model 7A (effects of IPRcrime)	Model 7B (effects of CORRUPT)
Direct effect	13.61 (13.0)	− 15.16** (6.9)
Indirect (mediated) effect	− 32.96** (14.6)	− 13.28* (7.4)
Total effect	− 19.35 (18.6)	− 28.44** (9.9)

Models 7A and 7B, respectively, use the setup of Models 5.1 and 5.3 from Table 5, with the addition of TotalR&D as the mediator variable. See Table 1 for variable definitions

The analysis was conducted using the "sem" command in STATA

The numbers in parentheses are OIM standard errors; * and **, respectively, denote statistical significance at the 10% and 5% (or better) levels

The estimation setup of the direct and indirect effects captured through mediation analysis, following the framework and notation of Eqs. (1) and (2), can be outlined as

$$\mathrm{PATENT_i} = \alpha_0 + \alpha 1\left[\mathrm{IPRcrime_i \ or \ CORRUPT_i}\right] + \alpha_2 \mathrm{TotalR\&D_i} + \alpha_3 \mathrm{Institutions_{ik}} + \alpha_4 \mathrm{Z_{im}} + \varepsilon_a \tag{3a}$$

and

$$\mathrm{TotalR\&D_i} = \beta_0 + \beta_1\left[\mathrm{IPRcrime_i \ or \ CORRUPT_i}\right] + \beta_1 \mathrm{Institutions_{ik}} + \beta_2 \mathrm{Z_{im}} + \varepsilon_b \tag{3b}$$

where ε_a and ε_b are error terms.

The total effect of IPRcrime and CORRUPT, respectively, on PATENT is the sum of the direct effect (via influence on PATENT in (3a)) and the indirect effect (via influence on TotalR&D in (3b)).[6]

Results from the mediation analysis, with TotalR&D as the mediator variable, show that both the indirect effects of the mediator variable on patenting are negative and significant—the impacts of IPR crimes and corruption passing through total R&D are negative on patents. However, only the direct effect of corruption on patents is negative and significant (Model 7B). Consequently, the total effect of corruption on patents is negative and significant, while that of IPR crimes, albeit negative, is statistically insignificant.[7,8] These findings support what was reported in Table 5 with robust regression and provide insights into the mechanics of the effects.

Overall, we find support for Hypotheses H1 and H4, but not robust support for H2 and H3. The concluding section follows.

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[6] For example, the direct effect of corruption would be (∂PATENT/∂CORRUPT), and the indirect effect would be (∂PATENT/∂TotalR&D)(∂TotalR&D/∂CORRUPT), and likewise for the case of IPRcrime.

[7] This insignificance of IPRcrime is in line with the lack of significance in related correlations in Table 2.

[8] As a further test of validity of the mediation analysis findings, we reran Eqs. (3a) and (3b), while dropping economic freedom (EconFREE) from Eq. (3b). The results, available upon request, were very similar to what is reported in Table 7.

5 Concluding remarks

Adding formal insights into the effects of IPR infringement (or more broadly unauthorized transfer of technologies), this paper examines the impact of IPR infringement crimes on the input (R&D spending) and output (patents) of the research process. The extant empirical literature trails theoretical contributions and proxies IPR enforcement via composite indices or measures of institutional quality, whereas this paper employs a direct (hard) measure of IPR crimes.

Using data across U.S. states, results show that IPR crimes reduce research spending but do not impact patenting. Upon comparison with a broader measure of weak institutional quality (proxied by corruption), we find that greater corruption has robust negative effect on patenting (but not necessarily on research spending). Quantitatively, the elasticities of R&D spending with respect to IPR crimes are greater than those of patents with respect to corruption. Given that research spending and patenting are sequential stages, a lowering of research spending via greater IPR crimes would in due course lower patenting also. The mediation analysis conducted provides insights into the channels of influence and supports earlier results. Specifically, with TotalR&D as the mediator variable, the total effect of corruption on patents is negative and significant, while that of IPR crimes is statistically insignificant (Table 7).

Insights into the drivers of R&D spending and patenting are of obvious importance for policymakers looking to boost economic growth via research. The results suggest that studies that proxy IPR crimes via other measures are likely underestimating their (negative) impacts on technological change. Underestimation with proxies has implications for R&D subsidies and for IPR protection policies. Another insight is that urbanization and literacy are able to somewhat counter the negative influences of IPR infringement and weak institutions on R&D spending and patenting. With appropriate data in due course, related time series dimensions may be considered.

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