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How Private Property Protection Influences the Impact of Intellectual Property Rights on Economic Growth

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1. Introduction

A continual effort to strengthen intellectual property rights (IPRs) has been underway globally, through the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) in 1995, the Patent Law Treaty in 2000, and the current Trans-Pacific Partnership (TPP) talks, among others. However, as Andersen and Konzelmann (2008) point out, "IPR policy encouraging increased enforcement has been largely based on the vision of policy-makers rather than on the findings of solid empirical research; and within the IPR research community, the social and economic effects of tightening the IPR system are not considered obvious." (p. 13)

In this paper, we develop the perspective that the weak empirical evidence in previous IPR-growth studies may be due to a neglect of the role of financial markets and private property rights in the exploitation and utilization of intellectual property protection. Our conjecture is motivated by both theory and empirical evidence. In theory, one key linkage between IPRs and growth is the investment or commercialization of innovations, in which "the investor needs to go to the capital markets in order to obtain development financing" (Mazzoleni and Nelson, 1998, p.277). Empirically, the law and finance literature has established that capital markets are well developed in countries with strong private property rights (La Porta, Lopez-de-Silanes, Shleifer, and Vishny, 1998; Beck, Demirgüç-Kunt, and Levine, 2003), and that well-developed capital markets help firms obtain financing for their investment needs (Demirgüç-Kunt and Maksimovic, 1999; Rajan and Zingales, 1998; Alfaro, Chanda, Kalemli-Ozcan and Sayek, 2004; Antras, Desai, and Foley, 2009). Taken together, they suggest that IPRs and private property rights are complements and work together to promote innovation and economic growth; consequently, IPRs alone may merely have a weak impact on economic growth, as documented in previous studies.

To empirically test our conjecture, we focus on a cross-section of 98 countries, and conduct two sets of tests. The first set is motivated by the recent literature (see, e.g. Falvey et al., 2006; Kim et al., 2012) which examines the IPR-growth relationship by the level of economic development. Our findings can be concisely summarized. If private property rights are not taken into account, the impact of IPRs on economic growth is statistically insignificant across all levels of economic development. However, once private property rights are taken into consideration, the impact of IPRs on growth is statistically significant for low and lower middle income countries.

Our findings help explain some otherwise puzzling phenomena. For instance, Sakakibara and Branstetter (2001), Schneider (2005), Qian (2007) and Lerner (2009) find that strengthening IPRs alone does not affect innovation, particularly in developing countries. Lerner (2009) concludes: "The impact of

strengthened patent protection may simply be far less on innovative activities than much of the economics and policy literature assumes." (p. 348) This puzzle can be explained within our framework. Specifically, enhancing IPRs without strengthening private property rights may not significantly increase the incentive to invent, particularly in developing countries, because poorly-developed capital markets due to weak private property rights may fail to provide firms with the necessary financing for their commercialization needs. We provide empirical evidence to support our conjecture.

Our second set of tests extends the analysis based on OLS by utilizing the *quantile regression* (QR) developed by Koenker and Bassett (1978). Our use of QR is motivated by growing evidence that the IPR-growth relationship may depend on many other factors, besides the level of economic development (see e.g. Gould and Gruben, 1996; Furukawa, 2007; Dinopoulos and Segerstrom, 2010; and Branstetter and Saggi, 2011). The implication is that, conditional on a particular level of IPR protection, the IPR-growth relationship could be different across countries depending on their growth experience. A natural approach to capture such heterogeneity is to estimate the IPR-growth relationship by grouping countries with similar growth experiences, which is precisely what quantile regression is designed to do. Our QR tests reinforce our OLS results, and suggest that IPRs alone have weak effects on growth, but that IPRs and private property rights together have significant impact on growth for most countries.

Our findings are different from some previous studies. For instance, Kim et al. (2012) and Hu and Png (2013) find that the IPR-growth relationship is instead weaker in developing countries. The difference may be due to two reasons. First, we use the cross-sectional regression and, therefore, focus on the variation in growth across countries. In contrast, previous studies typically use the fixed-effects panel regression and, as a result, look at the variation in growth within countries. Barro (2012) insightfully points out that, in growth regressions, "with country fixed effects, it is challenging to estimate statistically significant coefficients on X variables that do not have a lot of independent variation over time within countries." (p. 6) This may be especially true in the case of the IPR-growth relationship, since institutions such as IPRs and private property rights change slowly over time in developing countries. Therefore, focusing on the cross-sectional differences may lead to more significant results, since "the typically substantial cross-sectional variation in the X variables makes it easier to isolate statistically significant effects." (Barro, 2012, p. 6) Second, we use long-horizon data (e.g. 10-year or 20-year data), while previous studies typically use relatively short-horizon data (e.g. 5-year data). As Barro (2003) points out, using short-horizon data may contaminate statistical inferences for growth studies that investigate the long run relationship, "because five-year growth rates tend to be sensitive to temporary factors associated with 'business cycles'." (Barro. 2003, p. 235) Thus, using long-horizon data may produce cleaner results.

We perform extensive robustness checks to ensure that our results are not due to chance. More specifically, we show that our results are robust to alternative ways to take into account private property

protection, alternative sample periods, alternative sample countries, alternative ways to classify countries, and alternative regression methods (i.e. OLS versus quantile regression). We further strengthen our results by examining how IPRs and private property rights affect R&D and investment. Consistent with the growth regression results, innovation and investment depend on not only IPRs but also private property protection.

Our results have important theoretical as well as policy implications. In terms of theoretical implications, the extant IPR-growth literature has not yet taken into account the role of financial markets and private property rights in enabling intellectual property protection to influence innovation and ultimately productivity growth. In this regard, we suggest a fresh dimension for future research. In terms of policy implications, our results suggest that, to promote innovation and growth, developing countries should not only strengthen their IPRs but also provide a supportive system of private property rights, which is not emphasized enough in the current policy discussion.

The remainder of the paper is organized as follows: section 2 discusses our motivation in detail; section 3 describes our empirical methodology and data; section 4 reports our empirical results based on OLS; section 5 presents the results based on quantile regression; and section 6 concludes.

2. Motivation

IPRs are hypothesized to have a positive impact on economic growth, which is based on two related notions. The first is that innovation, whether measured by R&D or patents, leads to growth (e.g. Romer, 1990; Rivera-Batiz and Romer, 1991; Lederman and Saenz, 2005; Hasan and Tucci, 2010), while the second is that stronger IPRs result in more innovation activities (e.g. Gilbert and Shapiro, 1990).

Given the importance of the IPR-growth relationship to policy decision-making, previous work has tested the IPR-growth relationship empirically. However, the existing evidence is far from conclusive. Gould and Gruben (1996) and Falvey, et al. (2006) find that IPR protection has a positive impact on economic growth for open or low- and high-income economies, while Park and Ginarte (1997) do not find the same evidence. Although Thompson and Rushing (1996, 1999), Park and Ginarte (1997), Varsakelis (2001), Kanwar and Evenson (2003), Chen (2008), and Kim et al. (2012) find that IPR protection positively affects growth through its impact on R&D as well as capital accumulation, Sakakibara and Branstetter (2001), Qian (2007), and Lerner (2009) find that IPRs alone do not affect R&D or innovation activities. Lerner (2009) considers the weak evidence puzzling: "the failure of domestic patenting to respond to enhancements of patent protection, and the particularly weak effects seen in developing nations … were quite striking" (p. 348).

In this paper, we conjecture that the weak IPR-growth evidence in previous studies may be due to a neglect of the role of financial markets and private property rights. Our conjecture is motivated by the

recent law and finance literature. Its intuition is as follows. Consider two African countries, Egypt and Niger. Their IPR protection is similar. Measured by the IPR index developed by Ginarte and Park (1997) and Park (2008), the average IPR protection from 1995 to 2005 is 2.12 in Egypt and 2.27 in Niger, respectively. However, private property rights are stronger in Egypt than in Niger. Measured by the legal system and property rights index from the Fraser Institute (a common measure used in the law and finance literature), the protection of private property rights is 5.37 in Egypt but only 3.83 in Niger. Stronger private property rights help explain the better-developed financial market in Egypt (La Porta, Lopez-de-Silanes, Shleifer, and Vishny, 1998; Beck, Demirgüç-Kunt, and Levine, 2003). For instance, according to the data in Ndikumana (2001), during 1990-1998 period, the credit by banks as a percentage of GDP (a common measure of financial development) is 88.7% in Egypt but only 11.9% in Niger. If better-developed financial markets make it easier for firms to obtain financing for their investment needs (Demirgüç-Kunt and Maksimovic, 1999; Rajan and Zingales, 1998; Alfaro, Chanda, Kalemli-Ozcan and Sayek, 2004), we should expect more innovation and growth in Egypt. Consistent with this law-and-finance perspective, the GDP growth rate in Egypt is considerably higher than that in Niger. From 1995 to 2005, the GDP growth rates are 23% in Egypt and 10% in Niger.

This law-and-finance perspective suggests that financial markets and private property rights are important for the IPR-growth relationship, particularly for developing countries. Without strong private property rights and well-developed financial markets, IPRs may not lead to innovation and growth in developing countries, because firms may not be able to obtain the necessary financing for their investments needs and take their innovations to the marketplace. Hence, IPRs and private property rights are complements and work together to promote innovation and economic growth; consesquently, IPRs alone may not have a strong impact on growth.

To identify the role of private property rights, we focus on the comparison between two IPR measures. The first is the patent rights protection index developed by Park and Ginarte (1997) and Park (2008) (IPR), which is commonly used by previous studies and does not take into account private property rights. "The (IPR) index takes on values between zero and five, higher numbers reflecting stronger levels of protection. The index consists of five categories: (i) coverage, (ii) membership in international patent agreements, (iii) provisions for loss of protection, (iv) enforcement mechanisms, and (v) duration. Each category takes on a value between zero and one.The sum of these five values gives the overall value of the IPR index for a particular country." (Park and Ginarte, 1997, p.52).

The second measure takes into consideration private property rights by combining the IPR index with the legal system and property rights index from the Fraser Institute (Fraser).[1] The Fraser index

[1] Hu and Png (2013) also combine the patent rights index with the Fraser index but from an enforcement perspective. They argue that "The [patent rights] index focused only on patent laws, as published, with no attention

ranges from 0 to 10, and its key components are judicial independence, impartial courts, protection of property rights, and rule of law (see Gwartney, Lawson, and Hall, 2011). More specifically, since we conjecture that IPRs and private property rights are complements for economic growth, we construct our *modified* IPR index as MIPR = IPR × Fraser. For robustness, we also construct the MIPR indexes as simple or weighted averages of the underlying indexes (to be discussed further below).

If IPRs and private property rights are complements for growth, we should expect MIPR to perform better in explaining the cross-sectional differences in growth than IPR. To empirically test this prediction, we focus on a cross-section of 98 countries and conduct two sets of tests. The first set, motivated by Falvey, et al. (2006) and Kim et al. (2012), is to examine the IPR-growth relationship by level of economic development. Such tests can shed light on the IPR-innovation puzzle documented in Lerner (2009) among others. The second set of tests extends our analysis based on OLS by using quantile regression, which captures the heterogeneity of the IPR-growth relationship across countries in a parsimonious way.[2]

3. Empirical methodology and data

3.1 A simple model of IPR protection and growth

In the tradition of empirical growth models (e.g. Mankiw, Romer, and Weil, l992; Hall and Jones, 1999), we use the following conceptual framework:

$$GROWTH = G(INITIAL, INVEST, SCHOOL, R\,\&\,D, NGD, IPR, MF) \quad (1a)$$

$$INVEST = G(INITIAL, IPR, MF, GOV, EDU) \quad (1b)$$

$$SCHOOL = G(INITIAL, IPR, MF, GOV, EDU) \quad (1c)$$

$$R\,\&\,D = G(INITIAL, IPR, MF, GOV, EDU) \quad (1d)$$

where *GROWTH* denotes the long-run growth rate of GDP per capita, *INITIAL* initial GDP per capita, *IPR* the IPR index, *MF* the market freedom index, *GOV* the ratio of government consumption to GDP, *EDU* initial secondary school attainment, *NGD* the population growth rate plus 5%[3], and *INVEST*,

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to actual enforcement." (p. 4). We do not agree with Hu and Png (2010) for two reasons. First, patent laws are generally civil, not criminal laws, and consequently patent rights should be enforced by the patent owner not the government. Second, the patent rights index does contain an enforcement category. The patent rights index is based on both statutory laws and case laws. Case laws are based on court cases and court rulings, which can reveal if and how laws are implemented. As a result, the patent rights index does take into account patent laws in practice.

[2] For empirical evidence on the heterogeneity of the IPR-growth relationship across countries, see Gould and Gruben (1996), Falvey, Foster, and Greenaway (2006), Furukawa (2007), Dinopoulos and Segerstrom (2010), Branstetter and Saggi (2011), and Kim et al. (2012).

[3] 5% is suggested by Mankiw, Romer, and Weil, l992 and Lichtenberg (1992).

SCHOOL and *R&D* stand for the rate of investments in physical capital, human capital, and R&D capital, respectively.

Eq. (1a) allows IPR protection to directly affect growth, while Eqs. (1b) to (1d) models the indirect effects of IPR protection on growth through investment and R&D. For macro policy decision making, the total (including the direct and the indirect) impact of IPRs on growth is more relevant. Therefore, we focus on the total impact of IPR on growth by substituting Eqs. (1b – 1d) into (1a).

$$GROWTH = G(INITIAL, IPR, MF, GOV, EDU, NGD) \quad (2)$$

Consequently, in Eq. (2), the coefficient on *IPR* measures the total impact of IPR protection on growth.

3.2 Data

PPP Converted GDP per Capita (Chain Series at 2005 constant prices), *GOV* (Government Consumption Share of PPP Converted GDP Per Capita), and population from 1950 to 2009 are from Heston, Summers and Aten (2011). The IPR index data at five-year intervals from 1960 to 2005 are from Park (2008). The Fraser index and the market freedom index (MF) from 1970 to 2005 are from Gwartney, Lawson, and Hall (2011).[4] The *EDU* data from 1950 to 2010 are from Barro and Lee (2010).

To examine the relationship between IPR protection and growth by level of economic development, we use the World Bank's country classification system, which classifies countries into four groups based on gross national income per capita. The groups are low income (L), lower middle income (LM), upper middle income (UM), and high income (H). The historical data on country classifications go back to 1987 and are available from the World Bank.[5]

Although our merged data cover the period from 1985 to 2005 at five-year intervals (assuming that country classifications do not change from 1985 to 1987), we focus on the sample period from 1995 to 2005 (at five-year intervals) for two reasons. One is the availability of the IPR index and the Fraser index. The other is that a new global IPR regime started in 1995 when the WTO came into being and instituted TRIPS.[6] As a result, using a longer sample period may lead to incorrect inferences due to possible structural breaks. Nevertheless, in our robustness checks, we show that the results based on the whole sample period from 1985 to 2005 are qualitatively similar.

Table 1 presents summary statistics for all countries as well as for four income groups for the period from 1995 to 2005. Again, MIPR = IPR × Fraser. The total number of countries that have the required data is 98. Countries are grouped based on their World Bank classification in 2000.

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[4] The Fraser index is the second component of the Economic Freedom of the World index (EFW) (i.e., Legal System and Property Rights), while the MF index is the fourth component of the EFW (i.e., Freedom to Trade Internationally).

[5] http://data.worldbank.org/about/country-classifications/a-short-history.

[6] Developing economies were given five-year extensions to implement TRIPS.

Table 1. Summary statistics: 1995-2005

Variable	Panel A: All countries (98) Mean	SE	Min	Max
GDP per capita growth	0.21	0.21	-0.75	0.82
GDP per capita in 1995 ($)	11170	11169	353	49741
Market freedom index	6.84	1.11	3.43	9.67
Government consumption to GDP (%)	9.40	3.59	3.21	22.39
Secondary schooling in 1995	2.35	1.25	0.18	5.36
Population growth	0.07	0.05	-0.04	0.18
IPR	3.20	0.89	1.00	4.88
MIPR	20.23	10.85	4.14	42.41
Fraser	5.97	1.78	2.23	9.27

Variable	Panel B1: Low income (23) Mean	SE	Min	Max	Panel B3: Upper middle income (20) Mean	SE	Min	Max
GDP per capita growth	0.09	0.30	-0.75	0.49	0.28	0.19	-0.09	0.82
GDP per capita in 1995 ($)	1214	919	353	4003	8732	2861	5383	15798
Market freedom index	5.72	0.95	3.43	7.17	7.00	0.74	5.70	8.40
Government consumption to GDP (%)	10.78	4.03	3.57	22.39	7.97	3.54	3.21	15.37
Secondary schooling in 1995	1.15	0.98	0.18	4.51	2.28	0.73	1.21	4.34
Population growth	0.11	0.05	-0.04	0.18	0.06	0.04	-0.01	0.13
IPR	2.39	0.45	1.77	3.68	3.26	0.62	2.14	4.19
MIPR	10.35	3.25	4.14	17.66	19.08	5.44	11.10	29.71
Fraser	4.32	0.97	2.23	6.10	5.81	0.89	3.53	7.10

Variable	Panel B2: Lower middle income (25) Mean	SE	Min	Max	Panel B4: High income (30) Mean	SE	Min	Max
GDP per capita growth	0.23	0.18	-0.04	0.80	0.25	0.11	0.09	0.58
GDP per capita in 1995 ($)	4453	1845	2074	8245	26026	7650	10547	49741
Market freedom index	6.58	0.73	5.13	7.67	7.80	0.80	6.10	9.67
Government consumption to GDP (%)	9.48	4.02	4.29	17.78	9.24	2.52	3.42	15.27
Secondary schooling in 1995	2.07	0.94	0.59	4.33	3.56	0.84	1.82	5.36
Population growth	0.07	0.04	-0.02	0.13	0.04	0.03	0.00	0.12
IPR	2.76	0.67	1.00	3.80	4.14	0.53	2.75	4.88
MIPR	13.80	3.91	4.29	21.44	33.91	6.79	20.62	42.41
Fraser	5.02	0.86	3.57	6.50	8.15	0.94	6.33	9.27

Table 1 presents summary statistics for all countries as well as for four income groups for the period from 1995 to 2005. MIPR = IPR × Fraser. We use the World Bank's country classification system, which classifies countries into four groups based on gross national income per capita. The groups are low income (L), lower middle income (LM), upper middle income (UM), and high income (H).

Although some countries' classifications change between 1995 and 2005 (24 countries), in the robustness check section, we show that our results still hold when these countries are excluded. As we can see, high income countries have substantially higher levels of property rights protection (both IPR and Fraser). As a result, we may expect that stronger IPR protection may not lead to higher growth in high income countries due to diminishing returns. On the other hand, diminishing returns may suggest that low and lower middle income countries with significantly lower IPR and Fraser may benefit significantly from stronger IPR protection. The diminishing returns to IPR protection are plausible because excessive IPR protection may reduce subsequent innovation by substantially increasing the cost of conducting new innovation (see e.g. Gilbert, 2011).

3.3 Empirical models

Empirically, to identify the role of private property rights, we focus on the comparison between the following two regression models. They are

$$GROWTH_i = a_0 + a_1 \log(INITIAL_i) + a_2 \log(MF_i) + a_3 \log(GOV_i) + a_4 \log(EDU_i) + a_5 NGD_i + a_6 \log(IPR_i) + e_i \quad (3)$$

and

$$GROWTH_i = a_0 + a_1 \log(INITIAL_i) + a_2 \log(MF_i) + a_3 \log(GOV_i) + a_4 \log(EDU_i) + a_5 NGD_i + a_6 \log(MIPR_i) + e_i \quad (4)$$

GROWTH is the difference between the log of 2005 GDP per capita and the log of 1995 GDP per capita, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – *MF*, *GOV*, and IPR (*MIPR*) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR (MIPR) averaged over the sample period from 1995 to 2005, respectively.

If private property rights and intellectual property protection work together to promote innovation and growth, we should expect that Eq. (4) will perform better than Eq. (3) in terms of explaining the cross section of economic growth. That is, MIPR should be more (positively) significant compared to IPR, and the adjusted R^2 of Eq. (4) should also be higher than that of Eq. (3). This model comparison approach is dominant in the finance literature (e.g., Fama and French, 2012).

To allow IPRs to have differential effects on growth conditional on the level of economic development, Kim et al. (2012) include interaction terms of IPR and an income dummy. However, such a specification has some limitations. Specifically, this specification assumes that the impact of other growth determinants does not depend on income or the level of economic

Table 2. IPRs, private property rights and growth: 1995-2005

	Constant	INITIAL	MF	GOV	EDU	NGD	IPR	R^2	N
				Panel A: IPR alone					
All	-0.87*	0.02	0.31*	0.02	-0.06	-0.11***	0.03	0.15	98
	(-1.85)	(0.51)	(1.84)	(0.37)	(-0.89)	(-2.68)	(0.29)		
L & LM	-1.51*	0.13	0.13	0.06	-0.10	-0.06	0.25	0.17	48
	(-1.93)	(1.52)	(0.57)	(0.66)	(-1.36)	(-1.47)	(1.64)		
UM & H	0.10	-0.10*	0.40**	0.03	0.02	-0.11	0.01	0.10	50
	(0.24)	(-1.88)	(2.14)	(0.54)	(0.24)	(-1.39)	(0.06)		
				Panel B: IPR and private property rights					
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
All	-0.77	-0.00	0.26	0.01	-0.05	-0.09**	0.11	0.17	98
	(-1.47)	(-0.04)	(1.40)	(0.30)	(-0.81)	(-2.40)	(1.30)		
L & LM	-1.69**	0.10	0.02	0.06	-0.09	-0.01	0.37***	0.32	48
	(-2.10)	(1.33)	(0.09)	(0.76)	(-1.20)	(-0.27)	(4.15)		
UM & H	0.31	-0.14**	0.33*	0.02	-0.00	-0.10	0.10	0.12	50
	(0.72)	(-2.36)	(1.77)	(0.54)	(0.05)	(-1.16)	(0.92)		

The dependent variable is GROWTH, the difference between the log of 2005 GDP per capita and the log of 1995 GDP per capita, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1995 to 2005, respectively. MIPR = IPR × Fraser. White's (1980) procedure is used to calculate standard errors to take possible heteroskedasticity into account. We use the World Bank's country classification system, which classifies countries into four groups based on gross national income per capita. The groups are low income (L), lower middle income (LM), upper middle income (UM), and high income (H). *, ** and *** denote 10% level of significance, 5% level of significance and 1% level of significance, respectively.

development, which may not be plausible. Empirical evidence exists suggesting that the role of other determinants of growth may also be conditional on income, for instance, economic convergence or initial income (e.g. Dowrick and Nguyen, 1989). Hence, it might be more appropriate if we estimate Eqs. (3) and (4) within each income group. However, this approach results in small sample sizes. Therefore, as a compromise, we divide our sample countries into two groups: the first group consists of the low income countries (denoted by L) and lower middle income countries (denoted by LM), while the second group consists of the upper middle income countries (denoted by UM) and high income countries (denoted by H). By doing so, we have a roughly equal and relatively large number of countries in each group (48 in Group 1 and 50 in Group 2).

4. Empirical results based on OLS

4.1 Main results

The OLS results for Eq. (3) are reported in Panel A of Table 2, while those for Eq. (4) are presented in Panel B of Table 2. White's (1980) procedure is used to calculate standard errors to take potential heteroskedasticity into account.

Panel A shows that IPR is not statistically significant at conventional levels across all income groups. The coefficient on log (IPR) is 0.25 (t = 1.64) for L and LM, while that for UM and H is 0.01 (t = 0.06). Panel B shows that MIPR instead has a statistically significantly effect on growth for L and LM. The coefficients on the log of MIPR is 0.37 (t = 4.15) for L and LM, while that for UM and H is 0.10 (t = 0.92). Correspondingly, for L and LM, the adjusted R^2 increases to 0.32 for Eq. (4) from 0.17 for Eq. (3). Thus, consistent with our conjecture, our results suggest: IPR protection itself does not have a significant effect on growth, which is consistent with the evidence in Lerner (2009), among others; but IPR protection and private property rights together do promote growth, controlling for other factors. Again, the diminishing returns to IPR protection may be plausible because excessive IPR protection may reduce subsequent innovation by substantially increasing the cost of new innovation (e.g. Gilbert, 2011).[1]

4.2 Robustness checks

In this section, we conduct a series of robustness checks. First, we consider two alternative versions of the modified IPR protection measures. The first version is the simple average of the underlying indexes; that is, MIPR = 0.5 (IPR × 2 + Fraser). We multiply IPR by 2 to give equal weights to IPR and Fraser, since the IPR index ranges from 0 to 5 while the Fraser index ranges from 0 to 10. The second version is the weighted average of the underlying indexes. That is, MIPR = $\alpha \times$ IPR + (1 - α) × Fraser, where $\alpha = \dfrac{\dfrac{1}{\text{var}(IPR)}}{\dfrac{1}{\text{var}(IPR)} + \dfrac{1}{\text{var}(Fraser)}}$. With these alternative

[1] Table 2 shows that the coefficients of other growth determinants (besides IPR protection) also vary with income. For instance, INITIAL is significantly negative for relatively wealthy economies (UM and H) but insignificant for the less wealthy (L and LM), which suggests that economic convergence depends on income; market freedom (MF) is significantly positive for UM and H but is insignificant for L and LM, which implies that market freedom has differential effects on economic growth depending on the level of economic development. The variation in regression coefficient estimates of these other growth determinants across different income groups supports our research design of studying these groups separately.

Table 3. Alternative measures of modified IPR protection: 1995-2005

	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
			Panel A: Simple average						
All	-0.86*	-0.00	0.26	0.01	-0.05	-0.09**	0.21	0.16	98
	(-1.76)	(-0.01)	(1.41)	(0.30)	(-0.82)	(-2.40)	(1.18)		
L & LM	-1.98**	0.10	0.00	0.06	-0.09	-0.01	0.78***	0.32	48
	(-2.36)	(1.32)	(0.02)	(0.70)	(-1.26)	(-0.22)	(4.06)		
UM & H	0.22	-0.13**	0.34*	0.02	-0.00	-0.10	0.20	0.12	50
	(0.55)	(-2.30)	(1.79)	(0.57)	(-0.02)	(-1.15)	(0.83)		
			Panel B: Weighted average						
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
All	-0.81	0.01	0.28	0.02	-0.06	-0.10**	0.14	0.16	98
	(-1.61)	(0.19)	(1.55)	(0.38)	(-0.88)	(-2.47)	(0.95)		
L & LM	-1.62**	0.12	0.03	0.07	-0.10	-0.02	0.62***	0.26	48
	(-2.00)	(1.51)	(0.15)	(0.73)	(-1.44)	(-0.48)	(3.05)		
UM & H	0.21	-0.12**	0.37*	0.03	0.01	-0.10	0.11	0.11	50
	(0.52)	(-2.09)	(1.98)	(0.61)	(0.12)	(-1.20)	(0.56)		

The dependent variable is GROWTH, the difference between the log of 2005 GDP per capita and the log of 1995 GDP per capita, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1995 to 2005, respectively. In Panel A: MIPR = 0.5 (IPR × 2 + Fraser). In Panel B, MIPR = α × IPR + (1- α) × Fraser, where α = (1/var(IPR)/(1/var(IPR) + 1/var(Fraser)). White's (1980) procedure is used to calculate standard errors to take possible heteroskedasticity into account. We use the World Bank's country classification system, which classifies countries into four groups based on gross national income per capita. The groups are low income (L), lower middle income (LM), upper middle income (UM), and high income (H). *, ** and *** denote 10% level of significance, 5% level of significance and 1% level of significance, respectively.

MIPR measures, we re-estimate Eq. (4) and report the results in Table 3. As we can see, the results are qualitatively similar as those in Panel B of Table 2, suggesting that IPR protection and private property rights (i.e. MIPR) jointly determine the economic growth of low income (L) and lower middle income (LM) countries.

Second, we extend our sample period back to 1985 and use the country classifications in 1995 to group countries. As a result, three problems arise. The first one is that our sample size decreases from 98 to 87, which may decrease the power of our tests. The second one is that more countries undergo a change in classifications over this 20-year period, which may make our results harder to interpret. The third one is that, again, a new global IPR regime started in 1995 when the WTO came into being and instituted TRIPS. As a result, using the sample period from 1985 to 2005 may lead to incorrect inferences, due likely to structural breaks. Nevertheless, we re-estimate Eqs. (3) and (4), and report the results in Panel A of Table 4. As we can see, the

results based on this longer sample period are qualitatively similar as those based on the 1995-2005 period, confirming that IPR protection and private property rights jointly explain the economic growth of low income (L) and lower middle income (LM) countries.

Next, we exclude 24 countries in our 1995-2005 sample whose World Bank classifications change between 1995 and 2005. The results are presented in Panel B of Table 4 and are consistent with those based on all 98 countries, which reinforce the importance of private property rights.

Then, we re-estimate Eqs. (3) and (4) for each of the four income groups and report the results in Table 5. The idea is to document a finer relationship between IPR protection and growth. Although there is some variation in the IPR-growth relationship among the developing economies, L and LM, the general pattern is consistent with the previous results. That is, IPR protection alone does not have significantly positive effects on growth across all income levels; however, IPR protection and private property rights together do have a significantly positive association with the growth of the developing countries, namely the L and LM groups.

Finally, we study the IPR-growth relationship by the IPR index or the Fraser index. Developing countries typically have weak IPRs and private property rights. Therefore, we should expect to see the same pattern when the IPR-growth relationship is studied by the IPR index or the Fraser index. Empirically, in each case, we first divide our whole sample of 98 countries into two equal-size groups, the weak IPR/Fraser group and the strong IPR/Fraser group; then, we re-estimate Eqs. (3) and (4) for each group. The results are presented in Table 6. Consistent with our conjecture, the general pattern in Table 6is qualitatively similar to that in Table 2. That is, IPR protection alone (i.e. IPR) has a weak impact on growth; however, IPR protection and private property rights combined (i.e. MIPR) have stronger effects on growth for the developing countries (i.e. the countries with weak IPRs and private property rights).

Table 4. Alternative sample period and sample countries

	Panel A: Sample period of 1985-2005								
	Constant	INITIAL	MF	GOV	EDU	NGD	IPR	R^2	N
All	-0.72	-0.06	0.52**	-0.03	0.07	-0.34**	-0.05	0.14	87
	(-1.09)	(-0.56)	(2.02)	(-0.34)	(0.73)	(-2.13)	(-0.37)		
L & LM	-2.65**	0.03	0.47	0.07	-0.04	-0.83**	0.18	0.13	50
	(-2.19)	(0.22)	(1.45)	(0.47)	(-0.38)	(-2.31)	(1.02)		
UM & H	0.78	-0.28**	1.04***	0.16*	0.21	-0.15	-0.47*	0.32	37
	(0.60)	(-1.97)	(2.86)	(1.77)	(1.60)	(-1.20)	(-1.82)		
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
All	-0.45	-0.10	0.40	-0.04	0.07	-0.22	0.18	0.17	87
	(-0.63)	(-0.87)	(1.42)	(-0.41)	(0.70)	(-1.42)	(1.40)		
L & LM	-2.84**	0.01	0.34	0.08	-0.03	-0.64*	0.45**	0.24	50
	(-2.36)	(0.11)	(0.99)	(0.57)	(-0.29)	(-1.94)	(2.20)		
UM & H	1.03	-0.28*	1.07***	0.16	0.22*	-0.13	-0.26	0.27	37
	(0.89)	(-1.80)	(2.79)	(1.55)	(1.76)	(-1.03)	(-1.08)		
	Panel B: Excluding the countries whose classifications changes								
	Constant	INITIAL	MF	GOV	EDU	NGD	IPR	R^2	N
All	-0.99**	0.09	0.28	-0.02	-0.12*	-0.03	-0.09	0.16	74
	(-2.18)	(1.53)	(1.41)	(-0.32)	(-1.73)	(-0.31)	(-0.64)		
L & LM	-0.66	0.19**	-0.05	0.00	-0.09	0.32*	0.11	0.18	36
	(-1.20)	(2.54)	(-0.17)	(0.01)	(-1.37)	(1.94)	(0.48)		
UM & H	-0.29	-0.05	0.49**	0.04	-0.11	-0.08	-0.06	0.07	38
	(-0.84)	(-0.97)	(2.28)	(0.91)	(-1.32)	(-0.84)	(-0.37)		
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
All	-0.80	0.06	0.18	-0.04	-0.12*	-0.01	0.09	0.17	74
	(-1.56)	(0.90)	(0.80)	(-0.57)	(-1.70)	(-0.05)	(0.72)		
L & LM	-0.56	0.16***	-0.37	-0.03	-0.07	0.50***	0.48***	0.44	36
	(-1.03)	(2.81)	(-1.54)	(-0.31)	(-1.56)	(2.87)	(4.56)		
UM & H	-0.15	-0.07	0.44**	0.04	-0.12	-0.07	0.04	0.07	38
	(-0.44)	(-1.17)	(2.12)	(0.90)	(-1.50)	(-0.69)	(0.28)		

In Panel A, the dependent variable is GROWTH, the difference between the log of 2005 GDP per capita and the log of 1985 GDP per capita, INITIAL GDP per capita in 1985, EDU the average year of secondary schooling in 1985, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1985 to 2005, respectively. MIPR = IPR × Fraser. In Panel B, the dependent variable is GROWTH, the difference between the log of 2005 GDP per capita and the log of 1995 GDP per capita, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1995 to 2005, respectively. MIPR = IPR × Fraser. We exclude 24 countries whose World Bank classifications change between 1995 and 2005. White's (1980) procedure is used to calculate standard errors to take possible heteroskedasticity into account. We use the World Bank's country classification system, which classifies countries into four groups based on gross national income per capita. The groups are low income (L), lower middle income (LM), upper middle income (UM), and high income (H). *, ** and *** denote 10% level of significance, 5% level of significance and 1% level of significance, respectively.

Table 5. IPRs, private property rights and growth: four income groups: 1995-2005

	Constant	INITIAL	MF	GOV	EDU	NGD	IPR	R^2	N
				Panel A; IPR alone					
L	-2.63***	0.32**	0.13	0.03	-0.20**	-0.01	0.19	0.19	23
	(-2.80)	(2.38)	(0.34)	(0.21)	(-2.42)	(-0.14)	(0.45)		
LM	1.51***	-0.20**	-0.26	0.05	0.04	-0.26***	0.14	0.44	25
	(2.68)	(-2.13)	(-1.53)	(0.71)	(0.85)	(-3.49)	(1.14)		
UM	1.80*	-0.28***	0.03	0.04	0.21***	-0.27**	0.07	0.33	20
	(1.80)	(-2.89)	(0.12)	(0.50)	(2.62)	(-2.29)	(0.36)		
H	0.51	-0.04	0.27	0.04	-0.13*	0.06	-0.09	0.06	30
	(0.53)	(-0.41)	(1.54)	(0.59)	(-1.70)	(0.80)	(-0.43)		
				Panel B: IPR and private property rights					
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
L	-2.90***	0.32***	-0.07	-0.03	-0.16**	0.08	0.47***	0.43	23
	(-3.24)	(2.74)	(-0.22)	(-0.18)	(-2.09)	(1.59)	(5.28)		
LM	1.09**	-0.19**	-0.28*	0.08	0.03	-0.21***	0.22**	0.50	25
	(2.11)	(-2.23)	(-1.82)	(1.10)	(0.71)	(-3.32)	(2.55)		
UM	1.71*	-0.27***	0.02	0.03	0.20**	-0.27**	0.05	0.33	20
	(1.70)	(-2.80)	(0.06)	(0.48)	(2.30)	(-2.09)	(0.30)		
H	0.79	-0.08	0.22	0.03	-0.13*	0.08	0.03	0.06	30
	(0.83)	(-0.62)	(1.18)	(0.44)	(-1.66)	(1.03)	(0.20)		

The dependent variable is GROWTH, the difference between the log of 2005 GDP per capita and the log of 1995 GDP per capita, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1995 to 2005, respectively. MIPR = IPR × Fraser. White's (1980) procedure is used to calculate standard errors to take possible heteroskedasticity into account. We use the World Bank's country classification system, which classifies countries into four groups based on gross national income per capita. The groups are low income (L), lower middle income (LM), upper middle income (UM), and high income (H). *, ** and *** denote 10% level of significance, 5% level of significance and 1% level of significance, respectively.

Table 6. IPR-growth relationship by IPR protection and private property rights: 1995-2005

	Constant	INITIAL	MF	GOV	EDU	NGD	IPR	R^2	N
				Panel A: By the Fraser index					
Weak	-1.68**	0.08	0.35	0.08	-0.09	-0.10**	0.20	0.21	49
	(-2.12)	(1.23)	(1.53)	(0.87)	(-1.32)	(-2.20)	(1.34)		
Strong	0.53*	-0.09*	0.15	0.06	0.03	-0.04	0.05	0.06	49
	(1.85)	(-1.74)	(0.84)	(1.31)	(0.43)	(-0.70)	(0.60)		
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
Weak	-1.76**	0.06	0.25	0.07	-0.09	-0.07*	0.28***	0.28	49
	(-2.19)	(0.92)	(1.10)	(0.85)	(-1.19)	(-1.68)	(2.66)		
Strong	0.50*	-0.10*	0.15	0.06	0.03	-0.04	0.05	0.07	49
	(1.79)	(-1.77)	(0.83)	(1.29)	(0.47)	(0.78)	(0.73)		
				Panel B: By the IPR index					
	Constant	INITIAL	MF	GOV	EDU	NGD	IPR	R^2	N
Weak	-1.35*	0.09	0.20	0.07	-0.09	-0.02	0.27*	0.08	49
	(-1.89)	(1.18)	(0.91)	(0.72)	(-1.33)	(-0.12)	(1.66)		
Strong	-0.25	-0.01	0.40*	0.03	-0.00	-0.11**	-0.38*	0.16	49
	(-0.76)	(-0.24)	(1.94)	(0.45)	(-0.03)	(-2.41)	(-1.66)		
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
Weak	-1.26*	0.06	0.07	0.06	-0.07	0.09	0.37***	0.24	49
	(-1.92)	(0.77)	(0.36)	(0.74)	(-1.14)	(0.51)	(4.31)		
Strong	-0.28	-0.03	0.33	0.02	-0.02	-0.10**	-0.03	0.09	49
	(-0.78)	(-0.56)	(1.60)	(0.49)	(-0.25)	(-2.23)	(-0.28)		

The dependent variable is GROWTH, the difference between the log of 2005 GDP per capita and the log of 1995 GDP per capita, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1995 to 2005, respectively. MIPR = IPR × Fraser. White's (1980) procedure is used to calculate standard errors to take possible heteroskedasticity into account.

4.3 Discussion

Our result that IPRs and private property rights work together to promote economic growth can help explain some otherwise puzzling phenomena. For instance, Sakakibara and Branstetter (2001), Qian (2007) and Lerner (2009) find that enhancing IPRs alone does not promote innovation, particularly in developing countries. This puzzle can be explained within our context. Specifically, strengthening IPRs without enhancing private property rights may not significantly increase the incentive to invent in developing countries because poorly-developed capital markets due to weak private property rights may fail to provide firms with the necessary financing for their investment needs. Furthermore, IPRs work by temporarily creating market power, via the granting of exclusive rights to the IPR owner to exploit an invention or creation commercially.

Thus, in a situation where IPRs are strong but private property rights are weak and markets are distorted, due to say limited competition or price distortions, IPRs could potentially magnify the inefficiencies associated with 'monopoly' and thus weakly stimulate, if not stifle, innovation. In the presence of these distortions, IPRs may simply augment the economic rents of existing firms and/or be used to create entry barriers, rather than provide incentives to create new products or processes of production that may displace existing products or render them obsolete.

To test our conjecture, we estimate the following two equations:

$$R\&D_i = a_0 + a_1 \log(INITIAL_i) + a_2 \log(MF_i) + a_3 \log(GOV_i) + a_4 \log(EDU_i) + a_5 NGD_i + a_6 \log(IPR_i) + e_i \quad (5)$$

and

$$R\&D_i = a_0 + a_1 \log(INITIAL_i) + a_2 \log(MF_i) + a_3 \log(GOV_i) + a_4 \log(EDU_i) + a_5 NGD_i + a_6 \log(MIPR_i) + e_i \quad (6)$$

If private property rights and capital markets are essential for innovation in developing countries, we expect that MIPR, which takes into account private property rights, will be more significant than IPR for developing countries (i.e. L and LM). The results are reported in Panel A of Table 7, and support our conjecture. For robustness, we also consider two alternative versions of the modified IPR protection measures as in Section 4.2. The results are reported in Panel B of Table 7, and are consistent with those in Panel A. Thus, the law and finance perspective helps explain the innovation puzzle.

Furthermore, should IPRs result in new inventions or innovations, their impacts on productivity growth will be registered if the new innovations are actually utilized in the marketplace, are commercialized, or lead to a diffusion of new knowledge or technological spillovers economy-wide. This is where private property rights can also matter – namely creating the incentives and opportunities to commercialize the innovations. Strong private property protection is associated with not only well-

Table 7. R&D and IPR: 1995-2005

	Constant	INITIAL	MF	GOV	EDU	NGD	IPR	R^2	N
				Panel A: Benchmark measure					
All	-2.81**	0.38***	-1.05	0.48**	0.01	0.23	1.69***	0.48	82
	(-2.24)	(4.40)	(-1.59)	(2.51)	(0.04)	(1.26)	(5.50)		
L & LM	2.56***	-0.14**	-0.93**	-0.09	-0.03	-0.33***	0.16	0.33	35
	(3.14)	(-2.26)	(-2.33)	(-0.69)	(-0.46)	(-3.24)	(0.83)		
UM & H	-4.52**	0.60***	-1.63*	0.67**	0.53	0.45	1.90***	0.50	47
	(-2.19)	(3.69)	(-1.76)	(2.53)	(1.47)	(1.44)	(3.54)		
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR	R^2	N
All	-2.08*	0.14	-1.33**	0.38**	0.10	0.19	1.35***	0.54	82
	(-1.93)	(1.58)	(-2.33)	(2.23)	(0.66)	(1.06)	(5.99)		
L & LM	2.31***	-0.17**	-1.02***	-0.09	-0.02	-0.29***	0.35***	0.41	35
	(2.79)	(-2.54)	(-2.86)	(-0.75)	(-0.26)	(-3.20)	(2.99)		
UM & H	-3.85*	0.40**	-2.00**	0.56**	0.44	0.39	1.45***	0.50	47
	(-1.89)	(2.33)	(-2.18)	(2.07)	(1.11)	(1.29)	(4.06)		
				Panel B: Alternative measures					
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR (simple average)	R^2	N
All	-3.22***	0.15*	-1.32**	0.39**	0.08	0.19	2.73***	0.54	82
	(-2.92)	(1.69)	(-2.32)	(2.27)	(0.54)	(1.10)	(6.16)		
L & LM	2.02**	-0.16**	-1.01***	-0.08	-0.02	-0.29***	0.68***	0.40	35
	(2.30)	(-2.51)	(-2.79)	(-0.72)	(-0.37)	(-3.20)	(3.06)		
UM & H	-4.97**	0.40**	-2.00**	0.57**	0.43	0.41	2.97***	0.50	47
	(-2.45)	(2.31)	(-2.22)	(2.12)	(1.09)	(1.34)	(4.10)		
	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR (weighted average)	R^2	N
All	-2.16*	0.21**	-1.32**	0.43**	0.04	0.24	2.59***	0.53	82
	(-1.91)	(2.41)	(-2.25)	(2.44)	(0.28)	(1.31)	(6.85)		
L & LM	2.41***	-0.15**	-1.01***	-0.08	-0.03	-0.30***	0.54**	0.37	35
	(2.94)	(-2.37)	(-2.68)	(-0.66)	(-0.54)	(-3.17)	(2.57)		
UM & H	-3.84*	0.44***	-1.91**	0.62**	0.46	0.45	2.76***	0.51	47
	(-1.91)	(2.78)	(-2.12)	(2.35)	(1.22)	(1.48)	(4.55)		

The dependent variable is R&D, the fractions of output invested R&D, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1995 to 2005, respectively. White's (1980) procedure is used to calculate standard errors to take possible heteroskedasticity into account. We use the World Bank's country classification system, which classifies countries into four groups based on gross national income per capita. The groups are low income (L), lower middle income (LM), upper middle income (UM), and high income (H). *, ** and *** denote 10% level of significance, 5% level of significance and 1% level of significance, respectively.

Table 8. Investment, R&D and private property rights: 1995-2005

	Panel A: Investment and R&D								
	Constant	INITIAL	MF	GOV	EDU	NGD	R&D	R^2	N
All	33.07***	-0.21	1.16	-1.93	2.79	3.72***	0.67	0.06	82
	(2.69)	(-0.17)	(0.19)	(-1.00)	(1.55)	(3.32)	(0.77)		
L & LM	-8.48	3.34**	7.73	0.60	2.02	7.20**	9.82	0.02	35
	(-0.28)	(2.06)	(0.58)	(0.20)	(0.89)	(2.46)	(1.57)		
UM & H	41.71	-1.98	5.62	-3.15	3.93	3.67*	1.04	0.10	47
	(1.58)	(-0.80)	(0.72)	(-1.28)	(0.99)	(1.87)	(1.02)		

	Panel B: Investment, R&D and private property rights									
	Constant	INITIAL	MF	GOV	EDU	NGD	R&D	R&D × Fraser	R^2	N
All	22.42	0.41	3.69	-1.57	2.49	4.10**	11.24	-5.12	0.06	82
	(1.62)	(0.35)	(0.56)	(-0.80)	(1.40)	(3.53)	(1.27)	(-1.27)		
L & LM	10.41	1.41	5.24	0.42	2.81	6.11**	-28.58	21.89**	0.08	35
	(0.35)	(0.81)	(0.40)	(0.16)	(1.21)	(2.30)	(-1.64)	(2.24)		
UM & H	13.11	-0.25	10.56	-3.04	3.89	3.02	19.25**	-8.82**	0.18	47
	(0.50)	(-0.10)	(1.37)	(-1.34)	(1.06)	(1.51)	(2.03)	(-2.01)		

The dependent variable is INVEST, the fractions of output invested physical capital, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, R&D, and Fraser – are the market freedom index, the ratio of government consumption to GDP, R&D, and the Fraser index averaged over the sample period from 1995 to 2005, respectively. White's (1980) procedure is used to calculate standard errors to take possible heteroskedasticity into account. We use the World Bank's country classification system, which classifies countries into four groups based on gross national income per capita. The groups are low income (L), lower middle income (LM), upper middle income (UM), and high income (H). *, ** and *** denote 10% level of significance, 5% level of significance and 1% level of significance, respectively.

developed financial markets but also strong rules of law, particularly governing market exchange and contract enforcement, and the right to appropriate the benefits of market trade and commercialization. In this regard, we argue that intellectual property rights matter in conjunction with general property protection to affect economic growth. In the framework of the Romer (1990) growth model, two important phases are associated with economic growth: in the first phase, the research sector produces new innovative ideas (e.g. blueprint). In the second phase, the innovations must be commercialized. In the Romer model, an intermediate goods sector produces a capital good based on a blueprint design and sells or rents the capital good to the final goods producers who in turn manufacture goods using the capital good as an input. Other variations of this model setup exist, but the important point is that innovations affect economic growth if they are utilized in the marketplace (whether as an input or a final good). Thus, at each phase, some form of property rights is important. In the early invention phase, it is likely that IPRs are relatively more important for rewarding innovators and enabling them to appropriate the returns to their investments in R&D. In the next phase of commercialization, IPRs will still be important but it is also likely that general property rights will have a greater weight in the decision to go forward – to invest further in product development, seek and attract financing, and ultimately take the product to the marketplace.[1] Once the innovations are put to use, economic production and growth would then be affected. To recap, IPRs do not work alone, but complementarily with other institutional and environmental factors, in particular with private property rights.[2]

To test our conjecture, we run the following two regressions:

$$INVEST_i = a_0 + a_1 \log(INITIAL_i) + a_2 \log(MF_i) + a_3 \log(GOV_i) + a_4 \log(EDU_i) + a_5 NGD_i + a_6 R\&D_i + e_i \quad (7)$$

and

$$INVEST_i = a_0 + a_1 \log(INITIAL_i) + a_2 \log(MF_i) + a_3 \log(GOV_i) + a_4 \log(EDU_i) + a_5 NGD_i + a_6 lR\&D_i + a_7 R\&D \times \log(Fraser) + e_i \quad (8)$$

If private property rights (Fraser) are critical for commercializing innovations particularly in developing countries (given weak private property rights), we expect that the interaction term in

[1] It is of interest to note that not all innovations are commercialized. Each year, hundreds of thousands of patents are granted, of which a small fraction is actually commercialized. This indirectly shows that patent rights and general property rights are two different concepts. Strong patent rights are a key factor as to why there is such high propensity to patent, yet just a small percentage of patented innovations are turned into commercial goods and services. Thus, something more is needed to incentivize and generate opportunities for commercialization.

[2] This echoes the point made in Chen and Puttitanun (2005, p. 490) that "the positive effects of IPRs on domestic innovations … should be viewed as part of broader effects on entrepreneurial activities."

Eq. (8) to have a strongly positive influence in developing countries. On the other hand, diminishing returns to private property rights protection may suggest a negative coefficient for the interaction term for developed economies. The results are presented in Table 8, and are consistent with our conjecture. Taking all the evidence in Tables 7 and 8 together, strong private property rights in developing countries not only increase incentive to invent but also help commercialize innovations.

5. Quantile regressions results

Previous studies suggest that there may be considerable heterogeneity across countries in terms of the IPR-growth relationship. For instance, this relationship is shown to depend on technological sophistication (Furukawa, 2007), trade (Gould and Gruben, 1996), foreign direct investment (Dinopoulos and Segerstrom, 2010; Branstetter and Saggi, 2011), and the level of economic development (Falvey, Foster, and Greenaway, 2006; Kim et al., 2012). In the previous section, we take into account only one relevant country characteristic, namely income. In this section, we utilize the quantile regression technique proposed by Koenker and Bassett (1978) to simultaneously take into account all the relevant characteristics in a reduced-form fashion.

The economic intuition of quantile regression is as follows. If there is heterogeneity in the IPR-growth relationship, it means that conditional on a particular level of IPR protection, the IPR-growth relationship could be different across countries depending on their growth experience. A natural approach to take into account such heterogeneity is to estimate the IPR-growth relationship by grouping the countries with similar growth experience (i.e., among countries with similar GDP growth, conditional on a particular level of IPR protection), which is precisely what quantile regression does.[3]

In principle, one could also take a structural approach by including relevant interaction terms. However, the major challenge of this approach is that researchers have to be able to identify all the relevant country characteristics that drive the heterogeneity of the IPR-growth relationship, which is not a trivial task. Furthermore, the impact of relevant country characteristics on the IPR-growth relationship may be more complicated than what the interaction terms describe. Thus, a structural approach such as the threshold regression in Falvey et al (2006) may be less advantageous.

[3] There has been a tremendous growth in applications of quantile regression in various disciplines: economics, finance, genetics, population biology, medicine, environmental pollution studies, political science, education, demography, ecology and internet traffic. See, for instance, Koenker and Hallock (2001), Cade and Noon (2003), Yu, Lu and Stander (2003), and Koenker (2005). Coad and Rao (2008) apply quantile regression to an analysis of innovation and firm growth.

The quantile regression model of Eq. (4) can be specified as

$$GROWTH_i = a_0^\tau + a_1^\tau \log(INITIAL_i) + a_2^\tau \log(MF_i) + a_3^\tau \log(GOV_i) + a_4^\tau \log(EDU_i) + a_5^\tau NGD_i + a_6^\tau \log(MIPR_i) + e_i \quad (9)$$

where a^τ's are the τ -th quantile regression coefficients. The quantile regression coefficient for a particular τ measures the impact of a one unit change in the corresponding independent variable on the τ -th quantile of the dependent variable holding constant the effects of all the other independent variables. Eq. (3) can be specified in the same way. Following the common practice in the QR literature, we use a jump of 0.1 for quantile regressions. Note that all data points are used in estimating the quantile regressions. That is, 10% of all the data points will fall below the $\tau = 0.1$ quantile regression hyperplane while 20% will fall below the $\tau = 0.2$ quantile regression hyperplane, and so forth. Hence, the median ($\tau = 0.5$) quantile regression hyperplane bisects all the data points into two halves, each conditioned on the included independent variables.

The QR results for Eq. (3) are reported in Panel A of Table 9, and those for Eq. (4) are presented in Panel B. As we can see from Table 9, if private property rights are not taken into account, IPR has no significant impact on growth across all quantiles. However, once private property rights are taken into consideration, our modified IPR protection (MIPR) has significant impact across six out of nine quantiles (at the 5% level). Therefore, the QR results are consistent with those based on OLS.

We also conduct a series of robustness checks. First, we consider two alternative versions of the modified IPR protection measures as in Section 4.2. With these alternative modified IPR protection measures, we re-estimate Eq. (4) using quantile regression and report the results in Table 10. As we can see, the results are similar to those in Panel B of Table 9. Although the results based on the weighted average are weaker, the general pattern is nonetheless consistent.

Next, we consider a longer sample period as in Section 4.1. The number of countries for which we have data decreases to only 87, which may reduce the power of our test. The QR results for Eq. (3) are reported in Panel A of Table 11, and those for Eq. (4) are presented in Panel B. As we can see from Table 11, if private property rights are not taken into account, IPR has in general a negative impact on growth across six out of nine quantiles. However, once private property rights are taken into consideration, MIPR has a generally positive impact across all quantiles (with two coefficients significant at the 10% level). The weaker results may be due to the smaller sample size. However, the pattern is consistent with those in Table 9, and suggests that IPRs and private property rights work together to promote GDP per capita growth.

Table 9. IPRs and growth: quantile regression

τ	Constant	INITIAL	MF	GOV	EDU	NGD	IPR
0.1	-1.53***	0.07	0.44*	0.04	-0.09	0.02	0.09
	(-3.30)	(1.44)	(1.68)	(0.54)	(-1.24)	(0.27)	(0.55)
0.2	-0.99**	0.01	0.40*	0.03	0.00	-0.04	0.03
	(-2.57)	(0.33)	(1.82)	(0.39)	(0.02)	(-0.70)	(0.20)
0.3	-0.39	-0.00	0.12	0.02	0.02	-0.08	0.11
	(-1.20)	(-0.14)	(0.64)	(0.27)	(0.38)	(-1.61)	(0.94)
0.4	-0.22	-0.01	0.06	0.00	0.00	-0.07	0.15
	(-0.70)	(-0.25)	(0.35)	(0.07)	(0.09)	(-1.51)	(1.29)
0.5	-0.11	-0.03	0.14	-0.02	0.01	-0.08	0.12
	(-0.35)	(-0.78)	(0.76)	(-0.35)	(0.30)	(-1.62)	(1.04)
0.6	-0.09	-0.03	0.17	-0.04	-0.02	-0.15***	0.03
	(-0.27)	(-0.79)	(0.89)	(-0.72)	(-0.48)	(-2.90)	(0.25)
0.7	-0.11	-0.02	0.21	-0.06	-0.02	-0.15***	-0.03
	(-0.33)	(-0.59)	(1.09)	(-0.94)	(-0.38)	(-2.85)	(-0.29)
0.8	-0.08	-0.03	0.24	0.00	-0.03	-0.14**	-0.05
	(-0.22)	(-0.79)	(1.07)	(0.05)	(-0.41)	(-2.35)	(-0.40)
0.9	-0.27	-0.05	0.41	0.05	0.02	-0.16**	-0.11
	(-0.59)	(-1.15)	(1.56)	(0.62)	(0.21)	(-2.33)	(-0.67)
τ	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR
0.1	-1.36***	0.05	0.41	0.03	-0.07	0.02	0.07
	(-3.04)	(0.93)	(1.63)	(0.40)	(-0.96)	(0.36)	(0.73)
0.2	-0.60*	-0.02	0.27	0.01	0.01	-0.04	0.08
	(-1.67)	(-0.48)	(1.33)	(0.18)	(0.21)	(-0.74)	(0.97)
0.3	-0.31	-0.05	0.14	0.01	0.00	-0.09*	0.14*
	(-0.96)	(-1.34)	(0.78)	(0.25)	(0.00)	(-1.76)	(1.91)
0.4	-0.31	-0.05	0.15	0.01	-0.00	-0.08*	0.16**
	(-0.98)	(-1.40)	(0.83)	(0.10)	(-0.06)	(-1.67)	(2.19)
0.5	-0.29	-0.04	0.14	-0.01	-0.00	-0.07	0.16**
	(-0.93)	(-1.17)	(0.78)	(-0.26)	(-0.05)	(-1.51)	(2.31)
0.6	-0.09	-0.04	0.06	-0.05	-0.03	-0.09**	0.16**
	(-0.29)	(-1.10)	(0.33)	(-0.89)	(-0.70)	(-1.99)	(2.32)
0.7	0.50	-0.08**	-0.17	0.01	0.04	-0.10*	0.19**
	(1.40)	(-2.03)	(-0.84)	(0.20)	(0.65)	(-1.87)	(2.42)
0.8	0.47	-0.12***	0.02	-0.02	0.07	-0.08	0.24***
	(1.18)	(-2.60)	(0.11)	(-0.32)	(1.20)	(-1.27)	(2.66)
0.9	0.54	-0.16***	0.01	0.05	0.14*	-0.07	0.30***
	(1.12)	(-2.86)	(0.05)	(0.57)	(1.93)	(-0.90)	(2.81)

The dependent variable is GROWTH, the difference between the log of 2005 GDP per capita and the log of 1995 GDP per capita, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1995 to 2005, respectively. MIPR = IPR × Fraser.

Table 10. Quantile regression and alternative measures of modified IPR protections

			Panel A; Simple average				
τ	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR
0.1	-1.38***	0.02	0.48*	0.03	-0.05	0.04	0.19
	(-3.14)	(0.41)	(1.88)	(0.45)	(-0.69)	(0.61)	(0.89)
0.2	-0.62*	-0.02	0.25	0.01	0.03	-0.05	0.15
	(-1.75)	(-0.51)	(1.22)	(0.15)	(0.46)	(-0.84)	(0.90)
0.3	-0.34	-0.06	0.13	-0.00	0.01	-0.08	0.32**
	(-1.06)	(-1.58)	(0.72)	(-0.09)	(0.15)	(-1.60)	(2.10)
0.4	-0.46	-0.05	0.16	0.01	-0.01	-0.08*	0.34**
	(-1.49)	(-1.47)	(0.87)	(0.17)	(-0.16)	(-1.66)	(2.25)
0.5	-0.36	-0.04	0.13	-0.02	-0.00	-0.08*	0.31**
	(-1.20)	(-1.17)	(0.76)	(-0.44)	(-0.07)	(-1.65)	(2.11)
0.6	-0.18	-0.04	0.05	-0.05	-0.03	-0.09*	0.31**
	(-0.57)	(-0.97)	(0.25)	(-0.85)	(-0.66)	(-1.92)	(2.04)
0.7	0.32	-0.07*	-0.15	0.01	0.03	-0.10*	0.36**
	(0.94)	(-1.82)	(-0.73)	(0.11)	(0.56)	(-1.80)	(2.13)
0.8	0.14	-0.10**	0.15	-0.01	0.04	-0.10*	0.30
	(0.36)	(-2.16)	(0.65)	(-0.09)	(0.69)	(-1.70)	(1.60)
0.9	0.29	-0.15***	0.00	0.05	0.13*	-0.09	0.56**
	(0.63)	(-2.65)	(0.01)	(0.59)	(1.73)	(-1.20)	(2.47)
			Panel B: Weighted average				
τ	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR
0.1	-1.39***	0.06	0.42	0.03	-0.07	0.03	0.13
	(-3.04)	(1.10)	(1.60)	(0.42)	(-0.97)	(0.40)	(0.62)
0.2	-0.75**	-0.00	0.30	0.02	0.02	-0.04	0.09
	(-1.98)	(-0.03)	(1.38)	(0.30)	(0.35)	(-0.76)	(0.53)
0.3	-0.29	-0.03	0.11	0.00	-0.01	-0.09*	0.25*
	(-0.87)	(-0.90)	(0.58)	(0.04)	(-0.24)	(-1.71)	(1.70)
0.4	-0.23	-0.05	0.14	0.01	0.00	-0.07	0.28*
	(-0.72)	(-1.28)	(0.74)	(0.12)	(0.09)	(-1.47)	(1.90)
0.5	-0.07	-0.04	0.05	-0.02	0.01	-0.08*	0.25*
	(-0.23)	(-1.00)	(0.29)	(-0.29)	(0.19)	(-1.66)	(1.75)
0.6	0.03	-0.04	0.07	-0.06	-0.04	-0.10**	0.26*
	(0.09)	(-1.06)	(0.37)	(-1.15)	(-0.72)	(-2.12)	(1.78)
0.7	0.14	-0.04	0.00	-0.02	-0.00	-0.11**	0.21
	(0.40)	(-0.96)	(0.00)	(-0.38)	(-0.06)	(-2.10)	(1.34)
0.8	0.02	-0.07*	0.28	0.01	0.01	-0.13**	0.09
	(0.05)	(-1.66)	(1.22)	(0.14)	(0.09)	(-2.12)	(0.52)
0.9	0.59	-0.14**	0.04	0.07	0.13*	-0.05	0.53**
	(1.15)	(-2.55)	(0.13)	(0.77)	(1.71)	(-0.68)	(2.29)

The dependent variable is GROWTH, the difference between the log of 2005 GDP per capita and the log of 1995 GDP per capita, INITIAL GDP per capita in 1995, EDU the average year of secondary schooling in 1995, and NGD the population growth rate plus 5%. The rest of the variables – MF, GOV, and IPR (MIPR) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1995 to 2005, respectively. In Panel A: MIPR = 0.5 (IPR × 2 + Fraser). In Panel B, MIPR = α × IPR + (1- α) × Fraser, where α = (1/var(IPR)/(1/var(IPR) + 1/var(Fraser)).

Table 11. Quantile regression: 1985-2005

τ	Constant	INITIAL	MF	GOV	EDU	NGD	IPR
0.1	-2.91***	0.18*	0.61	-0.12	-0.16	-0.38	-0.25
	(-3.26)	(1.73)	(1.38)	(-0.82)	(-1.20)	(-1.58)	(-0.94)
0.2	-2.11***	0.16*	0.36	-0.01	-0.02	-0.14	-0.15
	(-2.67)	(1.76)	(0.94)	(-0.08)	(-0.18)	(-0.67)	(-0.62)
0.3	-0.52	0.01	0.25	-0.05	0.03	-0.14	0.00
	(-0.81)	(0.10)	(0.80)	(-0.45)	(0.32)	(-0.84)	(0.02)
0.4	0.10	-0.05	0.18	-0.11	0.11	-0.28*	-0.11
	(0.17)	(-0.71)	(0.61)	(-1.05)	(1.23)	(-1.68)	(-0.61)
0.5	0.05	-0.05	0.30	-0.15	0.09	-0.30*	-0.17
	(0.08)	(-0.71)	(1.04)	(-1.52)	(0.98)	(-1.86)	(-0.97)
0.6	0.27	-0.07	0.34	-0.13	0.15	-0.32*	-0.29
	(0.44)	(-1.04)	(1.12)	(-1.29)	(1.63)	(-1.91)	(-1.61)
0.7	0.42	-0.16*	0.74**	-0.07	0.15	-0.22	-0.29
	(0.60)	(-1.92)	(2.17)	(-0.60)	(1.41)	(-1.14)	(-1.40)
0.8	0.83	-0.29***	0.70*	0.09	0.25**	-0.29	0.16
	(1.01)	(-3.07)	(1.73)	(0.68)	(1.96)	(-1.31)	(0.65)
0.9	0.41	-0.32***	0.86*	0.13	0.26*	-0.49**	0.10
	(0.44)	(-2.99)	(1.90)	(0.83)	(1.83)	(-1.97)	(0.36)
τ	Constant	INITIAL	MF	GOV	EDU	NGD	MIPR
0.1	-2.18**	0.18	0.34	-0.18	-0.14	0.03	0.20
	(-2.37)	(1.60)	(0.74)	(-1.16)	(-1.02)	(0.11)	(1.06)
0.2	-1.52*	0.07	0.43	-0.09	0.02	-0.08	0.08
	(-1.92)	(0.77)	(1.10)	(-0.70)	(0.17)	(-0.37)	(0.47)
0.3	-0.17	-0.04	0.18	-0.06	0.08	-0.12	0.10
	(-0.27)	(-0.58)	(0.57)	(-0.52)	(0.84)	(-0.72)	(0.74)
0.4	-0.19	-0.06	0.22	-0.04	0.08	-0.27	0.02
	(-0.31)	(-0.83)	(0.73)	(-0.40)	(0.89)	(-1.63)	(0.19)
0.5	0.12	-0.05	0.30	-0.17*	0.08	-0.17	0.01
	(0.20)	(-0.62)	(1.00)	(-1.72)	(0.89)	(-1.01)	(0.11)
0.6	0.89	-0.18**	0.36	-0.12	0.11	-0.09	0.17
	(1.38)	(-2.30)	(1.14)	(-1.18)	(1.19)	(-0.50)	(1.25)
0.7	1.16	-0.27***	0.59*	-0.09	0.20**	-0.13	0.15
	(1.64)	(-3.18)	(1.69)	(-0.76)	(1.95)	(-0.68)	(1.05)
0.8	0.88	-0.30***	0.45	0.06	0.23*	-0.26	0.28*
	(1.10)	(-3.17)	(1.14)	(0.47)	(1.92)	(-1.20)	(1.70)
0.9	0.55	-0.39***	0.63	0.16	0.22	-0.52**	0.33*
	(0.57)	(-3.45)	(1.33)	(1.01)	(1.57)	(-2.02)	(1.67)

The dependent variable is *GROWTH*, the difference between the log of 2005 GDP per capita and the log of 1985 GDP per capita, INITIAL GDP per capita in 1985, EDU the average year of secondary schooling in 1985, and NGD the population growth rate plus 5%. The rest of the variables – *MF*, *GOV*, and IPR (*MIPR*) – are the market freedom index, the ratio of government consumption to GDP, and the index of IPR and modified IPR averaged over the sample period from 1985 to 2005, respectively. MIPR = IPR × Fraser.

6. Conclusions

Although policy makers typically assume a positive relationship between IPRs and economic growth, the empirical evidence on the IPR-growth relationship is rather inconclusive (e.g. Andersen and Konzelmann, 2008). In particular, the evidence in Lerner (2009), among others, that strengthening IPRs alone does not promote innovation, particularly in developing economies, is troublesome. Our hypothesis in this paper is that the weak evidence on the impact of IPR on economic growth in previous studies is due to the neglect of the role of financial markets and private property rights. Our conjecture is motivated by the recent law and finance literature. Essentially, we argue that enhancing IPRs without strengthening private property rights will not significantly increase the incentive to invent and commercialize, particularly in developing countries, because poorly-developed capital markets due to weak private property rights may fail to provide firms with the necessary financing for their investment needs. We test our conjecture with a cross-section of 98 countries and find supporting evidence.

Our findings not only help explain the IPR-innovation puzzle in Lerner (2009), among others, but also have significant theoretical as well as policy implications. In terms of the theoretical implication, the extant literature has not taken into account the role of financial markets and private property rights in shaping the way IPRs work to stimulate innovation, commercialization, and economic growth. In related work, Kanwar and Evenson (2009) point out that the lack of financial capital and human capital may be a factor behind why developing economies provide weaker IPR protection. Our analysis indicates that the underdevelopment of markets also affects the utilization of IPRs for economic growth. In this regard, we suggest a fresh dimension for future research. In terms of the policy implication, our results suggest that, to promote innovation and growth, countries (particularly developing countries) should strengthen not only their IPRs but also their system of private property rights.

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