Measuring the Effect of Intellectual Property Rights on Global Patent Quantity and Quality

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ABSTRACT: This paper extends current analysis regarding potential non-linearities in the relationship between the strength of a country's intellectual property rights (IPRs) and their level of innovation by introducing patent quality as an additional measurement of innovative output. The fixed effect regression models assess the effect of IPR strength on the number of granted patents per capita and the quality of those granted patents for 78 countries in the years 1985-2015. The results do not identify a threshold of IPR strength, and instead find a generally linear relationship between IPR strength and the number and quality of innovative outputs. Additionally, the results show that countries with low rates of GDP growth have a more positive response to increases in IPR than high growth rate countries.

I. Introduction

Innovation benefits economies through improving standards of living, disseminating knowledge, spurring economic growth, and enhancing overall productivity. For these reasons, effectively incentivizing innovation is critical to promoting economic growth and overall welfare. Patent systems and international intellectual property treaties are the primary regulatory tools of governments to protect and encourage domestic and international innovation. Previous economic literature establishes the relationship between the strength of intellectual property rights (IPR) and innovation, specifically that there is a strong positive relationship between IPR strength and the quantity of innovative outputs, namely Daran and Ufuk 2012, and Chen and Puttitanun 2005. However, recent literature suggests that there may be a threshold of IPR, after which innovation may be adversely affected (Cadot & Lippman 1995, O'Donoghue & Zweimuller 2004, Shapiro 2001, Park 2008). Stringent IPR may prevent competitors from entering the market and thereby stifle future innovation, causing an economic slowdown within an industry. The presence of a threshold of IPR is likely dependent on the type of IPR policy, enforcement, and the level of development for a given country (Falvey, et al. 2006, Eicher & Penalosa 2008). This paper extends current analysis regarding potential non-linearities in the relationship between IPR strength and innovation by introducing patent quality as an additional measurement of innovative output. The analysis will assess the existence of a threshold of IPR after which innovative output declines.

It is important to determine if there is a threshold at which IPR disincentivizes innovation, in order to ensure IPR policies and treaties are effectively enhancing investments in research and development. Domestic and international patent systems provide monopolies to patent owners, granting them complete control over their invention and barring other entities form using the specifications in their products for up to 20 years. Patent applications are published after several months, giving the public access to the knowledge contained in that patent. Therefore, the quantity of patents represents the volume of knowledge and scientific discovery generated within a time period. Similarly, the quality of patents identifies the value of knowledge contained in those patents, representing an alternative and less traditional method to measure innovative output and compare innovation across countries. This paper analyzes the effect of IPR strength on the total number of granted patents and the quality of those patents. In

addition, IPR as a squared term, as well as dummies for low, medium, and high IPR were used as checks for nonlinearities. The results do not identify a threshold of IPR, and instead find a generally linear relationship between IPR and the number and quality of innovative outputs.

II. Literature Review

A. Related Works

A multitude of economic analysis examines the effect of IPR on overall research investments, innovation, economic growth, development, and productivity. Policy makers and economists have been particularly interested in discovering the relationship between these economic indicators and IPRs in order to determine the optimal level of IPRs for a given economy. Acemoglu and Akcigit (2012) attempt to discover the relationship between IPR and innovation by searching for the optimal level of patent protection within an economy. Through the use of a dynamic mathematical framework, the authors find a steady state equilibrium which demonstrates that a very high level of patent protection diminishes competition and innovative behavior. Additionally, the paper empirically models the different effect of uniform versus state-dependent IPR policy on industry level growth and overall welfare. The authors propose a state-dependent policy scheme which favors the top echelon of firms within an industry, in order to increase R&D incentives for all innovators and therefore increase competition.

Similarly, Shapiro (2001) provides a summary of the literature and examines patent thickets in the United States. Patent thickets are a negative term referring to when one or more entities obtain an extensive number of patents in a certain technological field, inhibiting other inventors from entering that field. Shapiro (2001) argues that at some point, patent protection may be too strong, allowing patent thickets, and inhibiting future innovation that would have otherwise developed. In the same way, Cadot and Lippman (1995) examine the relationship between patent term and innovation. The patent term is the length of patent protection, generally, this is 20 years from the earliest filing data. Like Shapiro (2001), the authors theorize that a longer patent term stifles future innovation by decreasing incentive for the patent owner to invest in further innovation and also prevents competitors from entering the market

Empirically, Park and Ginarte (1997), analyze the effect of IPR on economic growth in 110 countries from 1960- 1990. In order to conduct this analysis, the authors generate an index to measure the strength of a country's IPR. The index ranges from 0 to 5 and considers a country's membership in international patent agreements (such as the PCT), patent duration, patent

coverage, enforcement, and legal protection from 1960-1990 (Park and Ginarte 1997, 52). The authors explore the effect of IPR on economic growth through a series of 4 regressions where growth, investment, education, and research and development are the dependent variables, using an "initial" term for GDP which represents the GDP in 1960. The growth equation utilizes investment, education, and research and development as controls, representing the inputs of growth. The regressions find a statistically significant positive effect of IPRs on the inputs of growth but not on overall growth itself, meaning that the IPRs indirectly promote economic growth. The results imply that increasing IPR strength increases investments in innovation and human capitol which lead to economic growth in the long-run (Park & Ginarte 1997).

It is important to note that since the 1997 paper, Park has updated the IPR index to include 122 countries through 2015 from the help of the Property Rights Alliance (Park 2008). Park notes that the top and bottom quartiles show small variation over time since 1990 due to very high patent protection in developed countries as a result of international treaties such as TRIPS and very low patent protection in small developing countries.

If an inverted u-shaped relationship between IPRs and innovation exists, as suggested by Shapiro (2001) and Cadot and Lippman (1995), it is important to find the optimal threshold of IPRs to appropriately incentivize invention in research and development without stifling future innovations. Falvey, et al. (2006) use a threshold regression analysis to determine the effect of IPR strength on economic growth and discern the optimal level of IPR protection within a panel of 79 countries from 1975-1994 (years are broken into 4-subperiods). In their model, economic growth is the dependent variable, IPR is the independent variable of interest, and GDP per capita, gross domestic investment, years of secondary education, trade, and inflation are controls. The Park and Ginarte index (1997) is used as the measurement of IPR. The authors additionally search for nonlinearities in the relationship between IPR and growth by testing a squared term for IPR and utilizing an interaction term between IPR and GDP, neither of which yielded statistically significant results. The regression results show that IPR protection increases economic growth in high and low-income countries, where high-income countries generate the majority of innovation and the technology flows to the low-income countries. Interestingly, middle-income countries are not benefited in this model. The results suggest an inverted u-shaped relationship between IPR and economic growth, dependent on a given country's level of development.

Chen and Puttitanun (2005) conduct a similar analysis to Falvey, et al. (2006), focusing solely on 64 developing countries in order to determine the effect of IPR stringency on innovation from 1985 - 2000. Additionally, the authors use the Park and Ginarte index (1997) as their measure of patent protection which is measured every 5-years. Two models are used to analyze the relationships between IPR and growth and IPR and innovation. Both models use a first difference analysis to account for unobserved time-invariant characteristics of countries and includes time dummies. The second model additionally uses an interaction term for IPRs and GDP per capita in order to determine the effect of different levels of income on innovation. In the first model the IPR index is the dependent variable, GDPCAP is the independent variable, and education, economic freedom, trade, and membership in the World Trade Organization are controls. In the second model the number of patents filed in the US by each country per year is the dependent variable, IPR index is the independent variable of interest, and GDP per capita, education, economic freedom, and trade over time are controls. The authors find a statistically significant positive effect of IPR on innovation within the developing countries and suggest increasing IPR in a developing country increases domestic innovation. The results also show that IPR and economic growth have an inverse u-shaped relationship.

B. The America Invents Act

The United States government recently altered the U.S. IPR regulation through the America Invents Act (AIA). The AIA was the most significant reform to the United States patent system since 1952, signed into law by Barack Obama in 2011, and implemented in March 2013. Meant to spur American inventive activity, the AIA altered the patent application fee structure, added a post-grant review, and includes prior commercial use as direct infringement. In addition, the AIA changed the U.S. patent system from a first-to-invent to a first-to-file patent system in order to match the patent systems of other developed countries. A first-to-invent patent system gives priority to inventors that can prove inventorship pre-dated to any other claims on the invention, whereas the first-to-file system gives the patent to whoever can prove inventorship and who filed first.

In order to predict how the change in IPR might impact the American economy, a study completed by Lo and Sutthiphisal (2009) analyzes the 1987 Canadian Legislation which, like the AIA, changed the Canadian patent system from first-to-invent to first-to-file system. The authors utilize R&D at the industry and firm levels as a measure of inventive input and the number of

patent grants as a measure for inventive output in order to determine how the IPR shift will change inventive activity. Additionally, their model controls for country differences in GDP per capita and trade exports and uses industry level dummies to remove the effect of different industry trends over time. The authors employ a difference in difference regression analysis where Canada is the treatment group and American is the control group. The analysis demonstrates that the change in IPR structures did not change inventive inputs (investments in research and development) overall but did cause a decline in inventive output (intellectual property) from domestic industries in Canada. Therefore, the paper serves as evidence against the America Invents Act, suggesting that the AIA may harm U.S. inventive output (Lo and Sutthiphsal 2009).

Miyagiwa (2015) similarly explores the impact of the AIA on American innovation by creating a dynamic mathematical model of the patent race between firms. The author finds that a first-to-invent system is weakly more effective at incentivizing innovation over the first-to-file. Each of these studies suggests that the change in IPR will harm U.S. inventive activity by decreasing investment in research and development and thereby decrease the quantity of patent applications from inventors. Each of these papers implies that the AIA may be shifting the U.S. patent system away from an 'optimal threshold' and thereby decreasing innovative inputs and outputs.

C. Patent Quantity

Empirical literature analyzes the effect of patent systems on innovation by using patent application quantity as a proxy for innovative output. A patent application represents that the expected value of the monopoly generated by the patent is greater than the cost of obtaining that patent (Griliches 1990). While the quantity of applications does not necessarily equate to the total innovative output within an economy (measurement issues arise such as some inventions are not patentable or inventors who do not file patents and/or instead choose to file as a trade secret, or cannot file due to financial barriers), it is possible to observe trends in innovation through changes in actor patenting behavior (government, university, and industry) over time (Stek et al. 2015).

The quantity of patent applications can be used to generally indicate the amount of knowledge created by an economic agent (Pakes et al. 1980), however, not all knowledge is patentable, i.e. laws of nature, physical phenomena, abstract ideas, naturally occurring DNA, or

steps performed by a generic computer. Therefore, the quantity of patent applications is more useful to trends of knowledge production over-time but not as an absolute measure.

Hanley et al. (2015) utilizes a measurement of the number of patent applications from Chinese inventors to analyze a policy change in China which increases the availability of credit. The authors employ several panel data analyses using region and time fixed effects, where the dependent variable is patent applications and the independent variable is the credit to GDP ratio, controlling with lagged financial ratios. Interestingly, for each province, the credit to GDP ratio of a similar province is used as an instrumental variable. Each province is matched to another province with a highly correlated credit to GDP ratios. The instrumental variable is constructed in this way in order to remove the effect of other province-dependent factors that affect the credit to GDP ratio within a province. The panel data results are statistically significant and conclude that inventors are more likely to invest in R&D if credit is readily offered.

Surprisingly, the quantity of patent applications does not necessarily trend with the quantity of patents granted due to requirements for patent grants which vary across national patent offices (Griliches 1990). For this reason, patent applications may not be an accurate measure of novel and non-obvious innovation within an economy but instead, represent the general quantity of innovation generated by an economy's research and development efforts.

D. Patent Quality

Recent literature, inspired by drastic increases in Chinese resident patent applications, asks whether an increase in patent applications and/or grants signifies a corresponding increase in patent quality and how the Chinese experience compares to other countries. Fisch et al. (2014) utilize a panel of 151 Chinese Universities to analyze the effect of subsidy programs on the quantity and quality of patent applications. The authors use the number of patent applications and the number of forward citations received by those patents as their measures of quantity and quality for dependent variables. The independent variables include dummies for the presence of a subsidy program and for if the university choose to participate in the subsidy. The results find that subsidy programs increase Chinese patent quality and also find a divergent relationship between patent quantity and patent quality; in recent years Chinese patent quality has trended down while patent applications have soared.

Patent quality can be a useful economic indicator of innovation because it is more effective than a patent count at explaining the economic value and knowledge content of a

patent. Additionally, the quality of a patent is proven to be a close proxy for the technological complexity and value of a patent (Lanjouw et al. 2014) and reveals the social value of the invention (Trajtenberg 1990).

While patent quality is a useful and important metric, it is difficult to capture. The Organization for Economic Cooperation and Development (OECD) summarizes the primary indicators of patent quality as patent family size, grant lag, backward citations, citations to non-patent literature, claims, and forward citations (Squicciarini, Dernis and Criscuolo 2013). Each indicator has been studied and forward patent citations are generally recognized as the strongest way to measure the market value of a patent. Forward citations are the number of times a published patent is cited after its publishing date. Trajtenberg (1990) demonstrates that the number of forward citations of a patent is closely associated with the market value of the invention. Similarly, Sterzi (2013) argues that the number of forward citations is linked to the profitability of a patent and also suggested that it is correlated with the knowledge content of a patent. While the number of forward citations is likely the strongest indicator, it is usually measured as the number of citations a patent receives with a 3- or 5-year period, making it difficult to measure current trends. Another measure of patent quality is the number of claims contained in a patent. A claim outlines the boundaries of the invention. While Lanjouw et al.(2004) find that the number of forward citations is best utilized to measure the value of drug patents, the number of claims best measures the value of the majority of other patent technological categories. Additionally, the "breadth" of a patent is contained in the number of claims, however, data regarding this measure is not readily accessible (Dang and Motohashi 2015). Finally, some argue that using multiple indicators is the most efficient method to demonstrate the value of a patent (Lanjouw et al. 2004, Thoma 2013, Fisch 2016). However, due to the limitations in available global data, forward citations are used as the measure of patent quality in this paper.

III. Data Collection & Analysis

The data includes up to 78 observations per year on various patent and IPR data at the country level for the years 1985-2015. There are two categories of models in this paper: patent quantity models and patent quality model. The dependent variables for the patent quantity models are patent grants, patent grants abroad, and patent grants filed in the United States. The

dependent variable for the patent quality models is forward citations. The controls capture GDP per capita, population, education, economic freedom, and research and development.

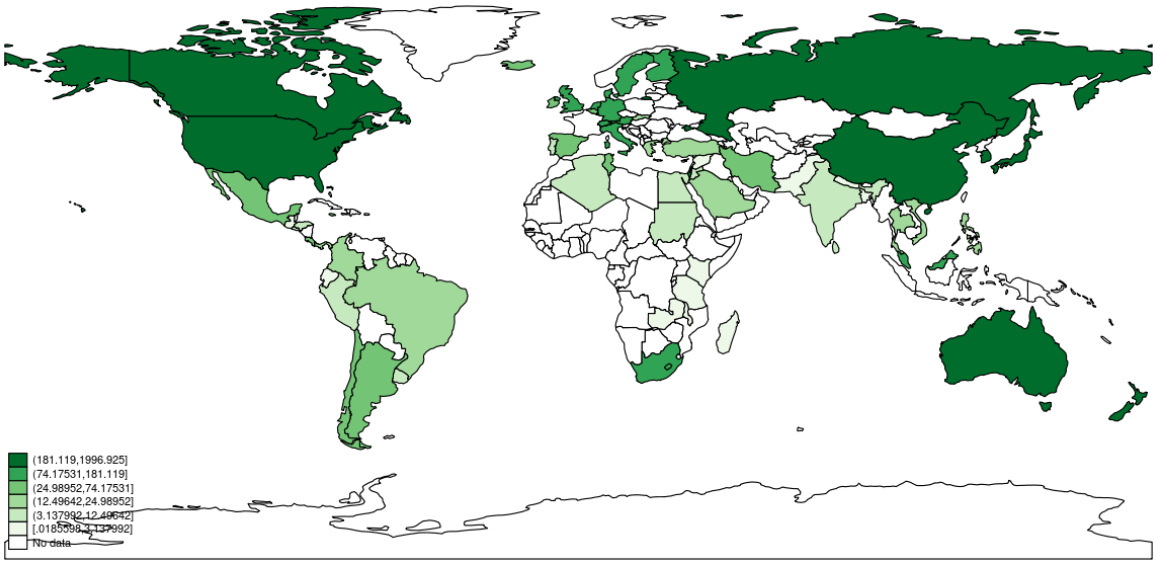
All patent quantity data is sourced from the World Intellectual Property Organization IP Statistics Data Center (WIPO 2018). Patent grants is measured as the total number of patents granted by a country's patent office within a year from 1985-2015. Patent grants abroad is measured as the total number of patents granted to citizens of one country in foreign countries from 1995-2015, and patent grants in the United States is measured as the total number of patents granted to citizens of one country in the United States from 1995-2015. Each of these variables are measured as a total count as well as a per capita count.

Table 1. Descriptive Statistics – *Mean and Standard Deviations*

	Quantity Models			**Quality Models**
	(1 & 2)	(3 & 4)	(5 & 6)	(7 & 8)
Patent Grants	5045.55			
	(17051.04)			
Patent Grants Per Capita	145.36			
	(145.36)			
Patent Grants Abroad		5656.51		
		(16384.8)		
Patent Grants Abroad Per Capita		176.96		
		(322.39)		
Patent Grants U.S.			1701	
			(5926.22)	
Patent Grants U.S. Per Capita			44.78	
			(69.79)	
Citations				63372.18
				(260793.10)
Citations Per Patent				0.59
				(1.66)
IPR	3.11	3.78	3.84	4.17
	(1.10)	(0.74)	(0.70)	(0.64)
Population	62.61	85.22	94.21	107.03
	(183.10)	(230.08)	(253.00)	(264.25)
GDP Per Capita	14.19	21.02	22.64	31.81
	(17.59)	(19.94)	(20.59)	(20.08)
Research and Development	1.27	1.46	1.40	1.92
	(1.57)	(1.54)	(1.49)	(1.23)
Education	35.56	46.70	48.23	53.94
	(25.64)	(24.42)	(23.34)	(23.83)
Economic Freedom	6.60	7.12	7.17	7.40
	(1.21)	(0.91)	(0.87)	(0.74)
N	452	271	217	131

Each of these three measures are included as dependent variables because they capture different aspect of patenting behavior in response to IPR changes. Patent grants measure the non-resident and resident patent grants filed within a country. Conversely, patent grants abroad measures the number of patents filed abroad by residents of a country. A change in IPR for a given country may spur domestic innovation, thereby increasing resident patents filed domestically and abroad. Additionally, a change in IPR may incentivize non-residents to apply for patents as well. Patent grants in the U.S. is the total number of patents filed in the U.S. by residents of another country. This measure is particularly useful to capture data for developing countries, which have limited domestic patent data.[1]

Chart 1. Map of Patents Granted Per Capita in 2015 – *Darker color indicates more patents*



As seen on Chart 1, it appears that more developed countries have a higher count of patents per capita compared to less developed countries. The countries with the highest value of granted patents per capita in 2015 are South Korea, Japan, Australia, The United States, and New Zealand, and the lowest are Rwanda, Uganda, Nepal, Malawi, and Tanzania.

The patent quality data is sourced from the EPO's PATSTAT database (2018) and is the total number of forward citations awarded to granted patents after three years of publishing at the country level from 1990-2015. This measure was also divided by total number of patents filed in each year at the country level, generating an average number of forward citations per patent per

[1] Chen and Puttitanun (2005) utilize the number of patent grants in the U.S. as their measure of innovative output.

country. In this paper, forward citations and forward citations per capita are used as outcome variables. Forward citation data is limited and not consistently measured across patent offices, therefore, the sample size for the patent quality data is 23 countries which is significantly smaller than of the patent quantity data. Furthermore, there is likely measurement error within the citation data. The reported number of citations for some countries is disproportionately low compared their number of patent grants, suggesting that citation data may be underreported. However, as long as the underreporting is consistent and is not correlated with any time varying country-level characteristic, this measurement error does not cause bias. For the purposes of this paper, it will be assumed that the citations measurement error does not pose an endogeneity problem.

` The measurement of IPR is sourced from the Park and Ginarte Index, which was updated by Park to include 110 countries through 2015 from the help of the Property Rights Alliance (Park 2008). The index ranges from 0 to 5 and measures the strength of a country's IPR by considering the country's membership in international patent agreements (such as the PCT), patent duration, patent coverage, enforcement, and legal protection from 1960-1990 (Park and Ginarte 1997, 52). This index was chosen because papers which use IPR as the independent variable of interest utilized the Park and Ginarte Index (1997) or the updated Park (2008) index. The Park and Ginarte Index yields a measurement of IPR every five years, therefore, the data in this paper is taken every five years as well (1985, 1990, 1995, 2000, 2005, 2010, 2015).

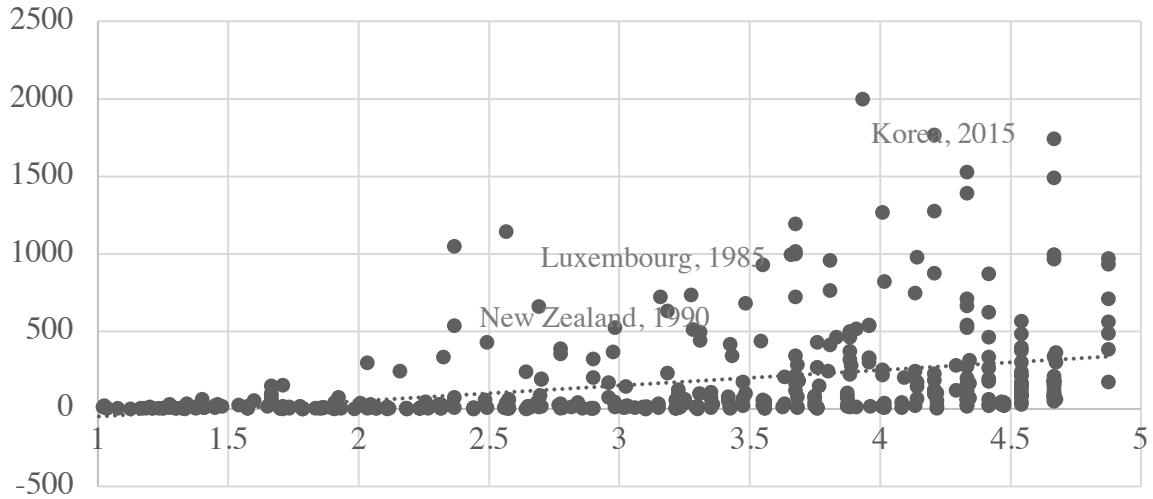
Data on GDP per capita and population are sourced from the World Bank Global Development Data (2019). GDP per capita is measured in millions of current US dollars and population is measured in millions of people. The mean GDP per capita increased when observations were dropped for the patent quality model because the missing data is from primarily low-income countries. Additionally, the mean IPR value also significantly increased in the quality data sample and there is less variation within the variable compared to the quantity data sample. For these reasons the model may not be externally valid for low GDP per capita and/or low IPR countries.

Education and research and development data are sourced from UNESCO Institute for Statistics (2019).[2] Education is measured in gross tertiary school enrollment as a percent of the population eligible to be enrolled in tertiary education. Research and development is measured as total expenditure on research and development as a percentage of GDP.

The variable for economic freedom was taken from the Economic Freedom Index created by The Heritage Foundation (2019) which considers: "Rule of Law (property rights, government integrity, judicial effectiveness), Government Size (government spending, tax burden, fiscal health), Regulatory Efficiency (business freedom, labor freedom, monetary freedom), and Open Markets (trade freedom, investment freedom, financial freedom)"(Heritage Foundation 2019). The index is from 0 to 10, where 10 is the most economic freedom and 0 is the least. The index is calculated through averaging each of the 12 types of economic freedom, each having equal weights.

Chart 2. Patent Grants Per Capita v. IPR - *Positively Correlated and Heteroskedastic*

Corr (GP Index, Patent Grants Capita) = 0.38



IPR and Patent Grants are positively correlated and have a correlation coefficient of 0.38. The outliers include New Zealand in 1990, Luxembourg in 1985, and Korea in 2015. In Chart 2 it is apparent that countries with an IPR score less than 3 are significantly less likely to have a

[2] Missing values for Education and Research and Development were imputed using the Poisson regression. The model was tested with and without these missing values and the results are similar. The results presented in this paper include the imputed values.

high value of patent grants per capita than those with an IPR score above 3. Additionally, the dispersion of the data increases with IPR, suggesting that the data may be heteroskedastic.

Chart 3 demonstrates that there may be an optimal window of IPR. Values of IPR between 3.5 and 4.4 have higher values of patent grants abroad per capita, after which patenting declines slightly. The main outliers within this data are countries with smaller populations and high GDP per capita, namely Luxembourg and Switzerland.

Chart 3. Patent Grants Abroad V. IPR - *Positively Correlated*

Corr (GP Index, Patent Grants Abroad) = 0.43

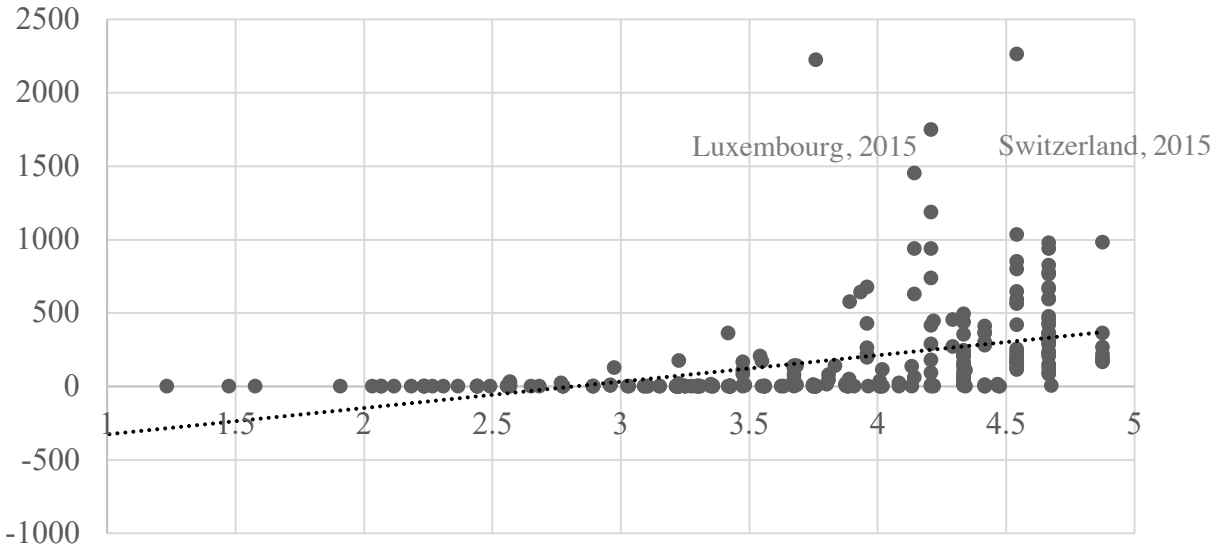


Chart 4 shows that GDP per capita and patent grants abroad per capita have a quadratic relationship with a correlation of .3539. GDP per capita squared and patent grants abroad have a correlation coefficient of 0.8030. As GDP per capita increases, patent grants abroad are increasing at an increasing rate. For this reason, a quadratic term will be used for GDP per capita in the regression equation.

Chart 4. Patent Grants Abroad Per Capita vs. GDP Per Capita – *A quadratic relationship*

Corr (GDP per capita, Patent Grants Abroad) = 0.3539

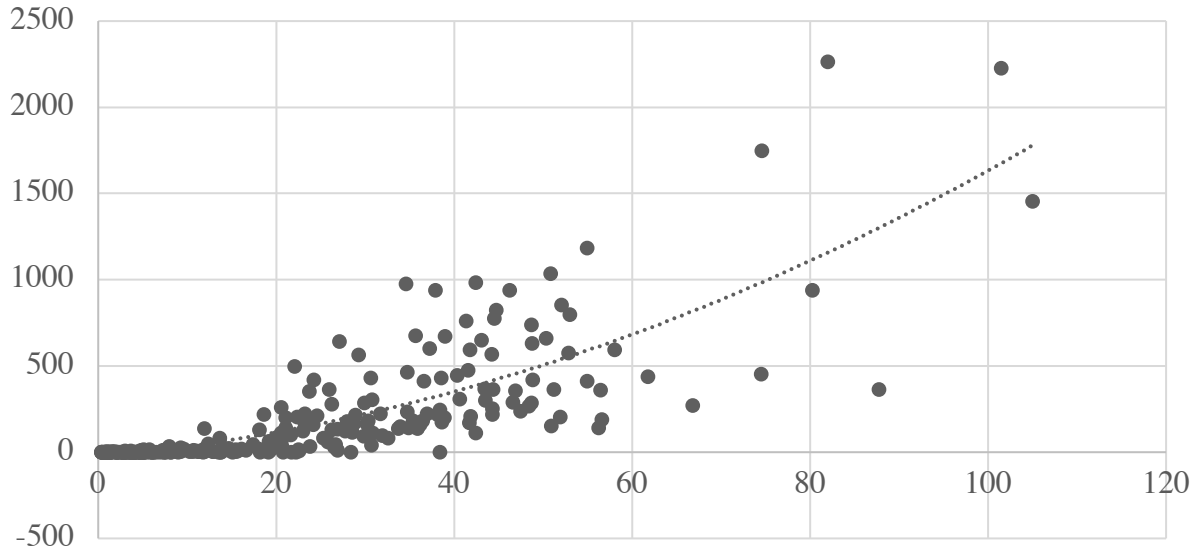
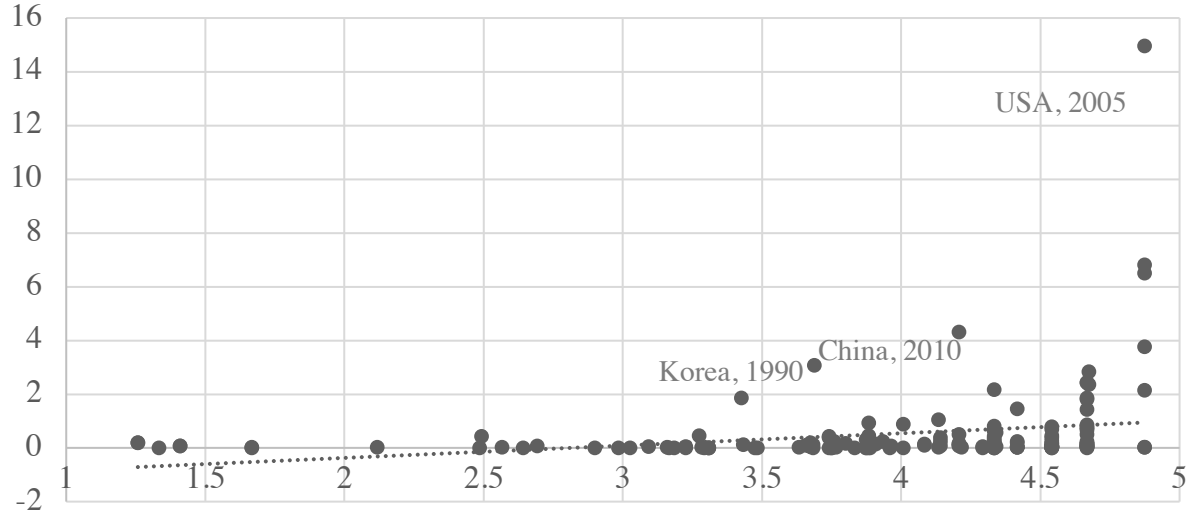


Chart 5 shows that the relationship between IPR and forward citations is not as strong as that of IPR and patent grants. IPR and forward citations per patent have a negative correlation coefficient of -0.2594, however, the linear fit yields a weakly positive relationship with a slope of 0.45. Additionally, the variation within the IPR term for each country is smaller in the quality sample, which can be seen on Chart 5 where data points form vertical lines for higher values of IPR.

Chart 5. Forward Citations Per Patent v. IPR – *weakly negatively correlated*

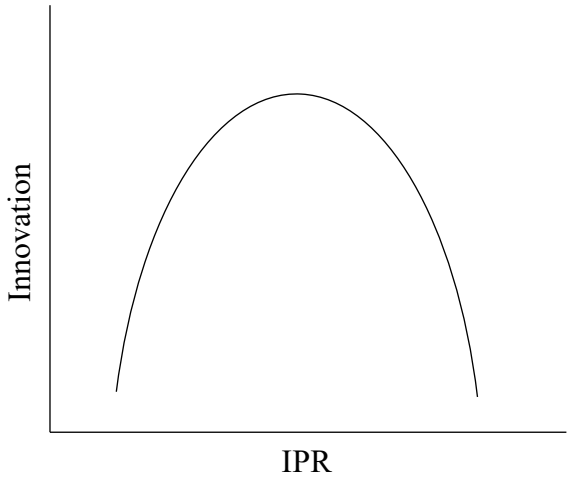
Corr (Forward Citations Per Patent, IPR = -0.2594



IV. Theoretical and Empirical Methodology

As described in the literature review, several researchers have theorized that there is some optimal threshold of IPR, after which innovation declines (Acemoglu and Akcigit 2012, Shapiro 2001, Cadot and Lippman 1995). A very high level of patent protection may diminish competition and innovative behavior (Acemoglu and Akcigit 2012). At this point, patent protection may be too strong, allowing patent thickets, and inhibiting future innovation that would have otherwise developed (Shapira 2001). For example, a longer patent term which may stifle future innovation by decreasing incentive for the patent owner to invest in further innovation and also prevents competitors from entering the market (Cadot and Lippman 1995). An optimal threshold of IPR is represented in Chart 6, as IPR increases innovation increases at a decreasing rate, until some optimal threshold, after which innovation declines. Before this threshold, as IPR increases, the marginal benefit of investing in research and development is greater than the marginal cost. After the threshold, the marginal cost of innovation is greater than the marginal benefit and innovation declines. It is possible that, given the current strengths of IPR present in 2015, there is not yet an existing level of IPR that disincentivizes innovation.

Chart 6. IPR and Innovation- *Inverse U-Shaped Relationship*



Falvey et al. (2006) empirically determined that there exists a u-shaped relationship between IPR and economic growth, dependent on a given country's level of development. The authors theorize that innovation flows from high to low income countries, and middle-income countries do not benefit from these flows.

Overall, economic theory suggest that IPR has a positive relationship with patenting; increased IPR protection incentivizes innovation and likely increases the quantity and quality of patenting. However, there may be a non-linear relationship between these variables, such as the "optimal threshold" outlined by Falvey et al. (2006), Shapiro (2001), Cadot and Lippman (1995). Perhaps, IPR and patenting have a quadratic relationship or the relationship between IPR and patenting is unique for low, medium, and high levels of IPR.

$$Innovation = f(IPR, IPR^2) \text{ or } Innovation = f(low\ IPR, medium\ IPR, high\ IPR)$$

In order to determine the effect of intellectual property rights on the quantity and quality of innovative output across countries and identify if there is an 'optimal threshold' of IPR, a log-level OLS panel regression with fixed effects was used.[3] Non-linear relationships between IPR and innovative output were tested using a binomial term for IPR and binary variables for low, medium, and high IPR. Using the previously mentioned data and the regression equations below the analysis will determine if the effect of IPR on innovation is statistically different from zero.

$$log(\mathbf{y_{it}}) = \beta_0 + \beta_1 IPR_{it} + \beta_2 IPR*Growth_{it} + \beta_3 Population_{it} + \beta_4 GDPCAP_{it} +$$

$$\beta_5 GDPCAP_{it}^2 + \beta_6 R\&D_{it} + \beta_7 Education_{it} + \beta_8 Economic\ Freedom_{it} + u_{\mathbf{it}}$$

For the quantity models, **y** captures the quantity of innovation as measured by Patent Grants (model 1), Patent Grants Per Capita (model 2), Patent Grants Abroad,(model 3) Patent Grants Abroad Per Capita(model 4), Patent Grants U.S. (model 5), Patent Grants U.S. Per Capita (model 6). For the quality models, which are models 7 and 8 respectively, **y** captures the quality of innovation as measured by forward citations (model 7) and forward citations per capita (model 8).

The dependent variables were logged in order to transform the data to a normal distribution. Originally, these variables were skewed strongly towards the left, where most values of patents per capita are greater than 0 and less than 1. The logged dependent variables also allows the IPR coefficient to be interpreted as a percentage change to the dependent variable for a 1-unit change in the explanatory variable. The total count and per capita counts are used separately as dependent variables to examine the effect of IPR on the volume of patent grants as well as to make the results externally valid for any population size by using the per capita term.

[3] The negative binomial regression model was also tested and yielded similar results to the log-linear OLS regression.

Additionally, an interaction term, IPR*Growth was created. Growth rate is measured as the percentage change in GDP over each 5-year period in the data. A dummy variable for growth was generated, where 1 represents being below the median growth rate and a 0 represents being above the median growth rate for the given year. Therefore, the IPR*Growth variable represents an interaction between below median growth rate countries and IPR.

GDP per capita is squared, motivated by the visual relationship illustrated by Chart 4. The GDP per capita quadratic term is statistically significant in two of the above regressions, providing further support for this relationship. GDP per capita and education variables were included because they are inputs to innovation. These variables are also utilized in the regression equations created by Chen and Puttitanun (2005).

Country (i) and time (t) fixed effects were included in the models.[4] Using these fixed effects removes the impact of country and year-specific characteristics that are invariant over time. Therefore, these time invariant characteristics do not add endogeneity problems to the models.

In order to avoid omitted variable bias, the economic freedom index was used to account for country level characteristics not captured by GDP, education, or trade that are time variant. However, because these variables are difficult to capture and are opinion based, there is likely measurement error. Perhaps this may cause the classical-error-in-variables problem with the regressions, leading to attenuation bias. In this case, the coefficients may be biased towards zero.

The sample was created to match the countries included in the IPR index. However, several countries were dropped in my regressions due to missing data, representing primarily low-income countries. After countries were dropped, the median GDP per capita for the data increased by about $1000, meaning that the countries in the sample are not representatives all countries with IPR policy. Finally, the model was adjusted for heteroskedasticity using the STATA command ‘, robust’ in the case that the dispersion of the patent data varies across the values of IPR, as seen in Chart 2.

GDP Per Capita and innovation likely have a positive quadratic relationship, which is visualized in Chart 4. As found by Falvey et al. (2006)), the effect of IPR on economic growth is

[4] Fixed effect were additionally tested for the technological category of patents. For example, patenting trends for technology in one category may vary more over time or have a consistently higher rate of patenting compared to another category. However, this method lacked sufficient data because not all country’s file in every technological category every year. Therefore, these results were not statistically significant.

u-shaped, dependent on the country's GDP. Thus, the effect of IPR on innovation is likely also different for low, medium, and high-income countries, where high- and low-income countries are benefited the most from a one unit increase in IPR compared to middle income countries.

V. Results

The patent quantity results are similar to those of Chen and Puttitanun (2005), demonstrating that a one unit (approximately one standard deviation of IPR) increase in IPR will lead to a 32-45% increase in patent grants overall and a 25-40% increase in patent grants per capita, holding population, GDP per capita, research and development, education, and economic freedom constant.[5]

Table 2. Quantity Results: Patent Grants and IPR- *models 1 - 6*

	Log(Patent Grants)		**Log(Patent Grants Abroad)**		**Log(Patent Grants U.S.)**	
	Total	*Per Capita*	*Total*	*Per Capita*	*Total*	*Capita*
	(1)	(2)	(3)	(4)	(5)	(6)
IPR	**0.333****	**0.246***	**0.447****	**0.397***	**0.320****	**0.278***
	(0.115)	(0.115)	(0.155)	(0.152)	(0.117)	(0.119)
IPR * Growth	-0.0236	-0.0199	0.028	0.0269	**0.0842*****	**0.0826*****
	(0.0245)	(0.0246)	(0.0212)	(0.0205)	(0.0208)	(0.0206)
Population	0.0073	0.00689	**0.009*****	**0.00846****	**0.0120*****	**0.0113*****
	(0.00593)	(0.00589)	(0.00259)	(0.00254)	(0.00276)	(0.00274)
GDP/capita	-0.00678	-0.00699	**0.0825*****	**0.0751*****	**0.0707*****	**0.0647*****
	(0.0192)	(0.0185)	(0.0173)	(0.0162)	(0.0113)	(0.0108)
GDP/capita²	-0.000116	-0.000138	**-0.000524****	**-0.000493****	**-0.000507*****	**-0.000488*****
	(0.000182)	(0.000177)	(0.000197)	(0.000183)	(0.000099)	(0.000092)
R&D	-0.00915	-0.00576	0.0447	0.0428	**0.0794***	**0.0751***
	(0.0340)	(0.0344)	(0.0512)	(0.0488)	(0.0359)	(0.0343)
Education	0.00577	0.00576	**0.0134****	**0.0130****	**0.0105***	**0.00994***
	(0.00392)	(0.00378)	(0.00492)	(0.00472)	(0.00504)	(0.00479)
Economic Freedom	-0.199	**-0.267***	**0.448***	**0.438***	0.105	0.114
	(0.101)	(0.105)	(0.214)	(0.202)	(0.122)	(0.122)
N	452	452	271	271	217	217

* Significant at the 10% level , ** Significant at the 5% level , *** Significant at the 1% level

These results are additionally economically significant because a 32% increase in patents per capita for a country with the mean quantity of patents per capita, 145, represents an increase of 46.5 more patents per capita for a one unit increase in IPR, holding all else constant. The

[5] The models were tested dropping outliers: The United States, China, Japan, and South Korea. These results find that a one unit increase in IPR will lead to a 2241% increase in patent grants and a 36-60% increase in patent quality. Additionally, a 3-year lagged term was tested for IPR and there was not a real difference in results.

results of models 1-6 do not find an optimal threshold of IPR, but instead suggest that the relationship is linear.

The IPR term was originally squared, searching for the inverse threshold theorized by Cadot and Lippman 1995, O'Donoghue and Zweimuller 2004, Shapiro 2001, and Park 2008, however, the quadratic term was consistently statistically insignificant. Additionally, dummy variables were tried to separate IPR in 3, 4, or 5 categories (low-high), looking for a difference in innovative output for each level. However, these terms were also statistically insignificant.

The IPR*Growth interaction term is positive and statistically significant for models 5 & 6, where the outcome variable if patents grants filed in the U.S. For a one unit increase in IPR, a low growth country will experience an 8% increase in patents grants filed in the U.S. compared to a high growth country. Typically, developed countries have a low growth rate compared to developed countries, therefore, the results for models 5 and 6 imply that innovation in developed countries has a more positive response to changes in IPR than that of developing countries. However, the IPR*Growth term is small and negative for models 1 and 2, and not statistically significant.

The population coefficients are all small but positive, which is expected, because as the size of a population increase, there is more potential for collaboration and research and development within industries, which in turn generates more patents per capita.

The GDP per capita results are different from the expected outcome, modeled in Chart 4. The results from models 3-6 suggest that as GDP per capita increase, patent grants increase at a decreasing rate. This suggest that GDP per capita and innovation have a nonlinear relationship and decreasing marginal returns to innovation within an economy.

The results from model 7 and 8 find that increasing IPR by one standard deviation, 0.6, will increase forward citations total by 25% and forward citations per patent by 41%. The results from model 7 are similar to the quantity model results, therefore, the effect of IPR on patent quantity and quality is shown to be similar. Additionally, these results are economically significant, a 25% increase in forward citations for a country with the mean number of citations per patent, 0.57, represents a 0.23 increase in citations per patent, holding all else constant. The results from models 1-8 suggest that as patent quantity increase, patent quality increases at a comparable rate.

Table 3. Quality Results: Forward Citations and IPR- *models 7 & 8*

	Log(Forward Citations)	
	Total	*Per Patent*
	(7)	(8)
IPR	0.249	**0.689****
	(0.219)	(0.211)
IPR * Growth	0.0281	0.044
	(0.0431)	(0.0408)
Population	**0.000385*****	**0.000204*****
	(0.000048)	(0.000044)
GDP/capita	-0.000509	-0.00668
	(0.0235)	(0.0267)
GDP/capita^2	-0.0000932	0.000057
	(0.000213)	(0.000254)
R&D	-0.105	**-0.179***
	(0.0797)	(0.0819)
Education	0.0126	0.00275
	(0.00746)	(0.00595)
Economic Freedom	**0.512***	**0.775*****
	(0.181)	(0.181)
N	131	131

* Significant at the 10% level , ** Significant at the 5% level , *** Significant at the 1% level

The IPR*Growth interaction term demonstrates that if a country has a below median growth rate, then if IPR increases by one standard deviation, innovation increases by 2.4% per capita. Similar to the IPR*Growth results for models 5 and 6, models 7 and 8 imply that innovation in developed countries is more sensitive to changes in IPR than that of developing countries.

VI. Conclusion

Incentivizing innovation is critical to promoting economic growth and welfare. IPR policies and treaties are a primary tool of governments to protect and encourage innovative behavior. However, stringent IPR protection may disincentive future innovation, causing an economic slowdown within an industry. Therefore, it is important to determine the optimal level of IPR to encourage innovative behavior, protect consumers, and also incentivize future innovations. Previously, economic literature suggests that increasing intellectual property rights has a positive effect on IP growth and innovation, however, recent literature presents conflicting evidence; at some level IPR may disincentivize innovation (Cadot & Lippman 1995, O'Donoghue & Zweimuller 2004, Shapiro 2001, Park 2008).

The results of all 8 regression equations in this paper demonstrate a positive linear relationship between IPR and the quantity and quality of patents. The models predict that as a country increases IPR by one standard deviation, patent quantity and quality will increase by 25-41%. An optimal level of IPR was not found across the range of IPR in the data, suggesting IPR cannot be too strong. These results imply that as patent quantity increases due to an increase in IPR, patent quality increases at a similar rate. Finally, the results demonstrate that low growth rate countries respond more positively to changes in IPR than high growth rate countries.

These results do not match the recent literature of Falvey et al. (2006), which find that there is a non-linear relationship . When a quadratic term was added for IPR, or high, medium, and low IPR dummy variable, they were statistically insignificant, not supporting a non-linear relationship between the two variables. As seen in charts 2, 3, and 5, there may not be a distinct optimal threshold of IPR within the data samples. Perhaps, there is a threshold of IPR which is represented by a value of IPR higher than what is found in the data used in this paper.

In the future, it would be helpful to breakdown each component of IPR Index and the Economic Freedom Index to further examine the relationship between specific type of IPR policy, time-varying country characteristics, and innovation. Likely, there are aspects of IPR which may disincentivize innovation, such as patent duration (Cadot & Lippman 1995), which are not picked up in regressions using an indexed value for IPR. Additionally, it is worth exploring different methods of quantifying patent quality and utilizing a measure of patent quality which contains several different methods.

VII. Appendix

Chart A. Countries Included in Each Model

Country	Patent Grants	Patent Grants Abroad	Patent Grants U.S.	Forward Citations
Argentina	X	X	X	
Australia	X	X	X	X
Austria	X	X	X	X
Belgium	X	X	X	
Bangladesh	X	X		
Brazil	X	X	X	
Canada	X	X	X	X
Switzerland	X	X	X	X
Chile	X	X	X	
China	X	X	X	X
Columbia	X	X	X	
Costa Rica	X	X	X	
Cyprus	X	X	X	
Germany	X	X	X	X
Denmark	X	X	X	X
Algeria	X	X	X	
Ecuador	X	X	X	
Egypt	X	X	X	
Spain	X	X	X	X
Finland	X	X	X	X
France	X	X	X	X
United Kingdom	X	X	X	X
Greece	X	X	X	
Guatemala	X	X	X	
Hong Kong	X	X	X	
Honduras	X			
Haiti	X			
India	X	X	X	
Ireland	X	X	X	
Iran	X	X	X	
Iceland	X	X	X	
Israel	X	X		
Italy	X	X	X	X
Jamaica	X	X	X	
Jordan	X	X	X	X
Japan	X	X	X	
Kenya	X	X	X	
Republic of Korea	X	X		X
Sri Lanka	X	X	X	

Luxembourg	**X**	**X**	**X**	**X**
Morocco	**X**	**X**	**X**	
Madagascar	**X**			
Mexico	**X**	**X**	**X**	
Mali	**X**	**X**	**X**	
Mauritius	**X**	**X**		
Malawi	**X**	**X**		
Malaysia	**X**	**X**	**X**	
Nicaragua	**X**	**X**		
Netherlands	**X**	**X**		**X**
Norway	**X**	**X**	**X**	**X**
Nepal	**X**	**X**		
New Zealand	**X**	**X**	**X**	
Pakistan	**X**	**X**	**X**	
Panama	**X**	**X**	**X**	
Peru	**X**	**X**	**X**	
Philippines	**X**	**X**	**X**	
Portugal	**X**	**X**	**X**	**X**
Russian Federation	**X**	**X**	**X**	**X**
Rwanda	**X**			
Saudi Arabia	**X**	**X**	**X**	
Sudan	**X**			
Singapore	**X**	**X**	**X**	
El Salvador	**X**	**X**		
Slovakia	**X**	**X**	**X**	
Sweden	**X**	**X**	**X**	**X**
Syrian Arab Republic	**X**			
Thailand	**X**	**X**	**X**	
Tunisia	**X**	**X**	**X**	
Turkey	**X**	**X**	**X**	
United Republic of Tanzania	**X**	**X**		
Uganda	**X**			
Uruguay	**X**	**X**	**X**	
United States of America	**X**	**X**		**X**
Venezuela	**X**	**X**	**X**	
Viet Nam	**X**	**X**		
South Africa	**X**	**X**	**X**	**X**
Zambia	**X**	**X**		
Zimbabwe	**X**	**X**		

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