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Abstract

This study examines the persistence of software piracy with internet penetration vis-à-vis of PC users, conditional on Intellectual Property Rights (IPRs) institutions. The empirical evidence is based on a panel of 99 countries for the period 1994-2010 and the Generalised Method of Moments. The main finding is that, compared to internet penetration, PC usage is more responsible for the persistence of global software piracy. Knowing how technology affects the persistence of piracy is important because it enables more targeted policy initiatives. We show that the sensitivity of software piracy to IPRs mechanisms is contingent on the specific technology channels through which the pirated software is consumed.

JEL Classification: F42; K42; O34; O38; O57
Keywords: Piracy; Business Software; Software piracy; Intellectual Property Rights

1. Introduction

There are two main motivations for the positioning of our inquiry on technology and persistence in global software piracy, notably: the growing role of the knowledge economy (KE) in the 21st century development and the gaps in the literature on fighting global software piracy. There is a broad consensus in the position that a key driver of contemporary global economic development is KE: a phenomenon that is essential in competitive economic development because it represents policies associated with the production and distribution of knowledge for economic development (Hashim, 2014; Asongu *et al*., 2018a).

An essential factor of competition is the degree to which Intellectual Property Rights (IPRs) and Intellectual Property (IP) are consolidated within an economy[1]. It follows that mechanisms of IPRs and IP protection play a key role in competition needed for KE in cross-country comparative economic development of nations in the world[2]. The underlying linkages are relevant in the perspective that IPRs and IP are closely connected to the four dimensions of the World Bank's KE index, namely: information and communication technology (ICT), economic incentives and institutional regime, innovation and education (Asongu, 2014a)[3]. Accordingly, IPRs and IP laws affect the production and distribution of knowledge. When they are less stringent, they limit the production of knowledge but increase the distribution of the knowledge. This is essentially because less tight IP limits incentives to knowledge production because those producing such knowledge do not have enough incentives to continue innovating because they are not sufficiently compensated through the protection of their attendant IPRs. Conversely, when such IPRs and IP laws are more stringent, they increase the production of knowledge and limit the distribution of such knowledge. This is also because of limited distribution owing to the fact that upholding IPRs restrict the distribution of knowledge exclusively to those in society who can afford to pay in order to benefit from the knowledge. Hence, the nature of IPRs and IP laws is closely associated with KE because KE is how a society benefits from the way knowledge is produced and distributed for economic development.

In light of the above, the importance of KE today extends a relevant debate on the essence of IPRs in the development process. Whereas there is some consensus in the literature that the tightness or stringency of IPRs should move hand-in-hand with economic development, some scholars still maintain that strict IPRs are core in the transition from developing to developed countries (Mansfield,1994; Maskus & Penubarti, 1995; Seyoum, 1996; Lee & Mansfield, 1996). To put the argument into more perspective, there is a broad stream of literature

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[1] This assertion may be true sometimes, but not always as manifested in the rise of the competitive Chinese economy, which has a poor record of intellectual property protection (Ang *et al*., 2014).

[2]The IPRs channels include: inclusion of property rights in a country's constitution, *IPR law*, *main IP law*, World Intellectual Property Rights Organization (*WIPO) treaties*, *bilateral treaties* and *multilateral treaties.*

[3](i) ICT facilitates the effective creation, processing and dissemination of information. (ii) An economic incentive and institutional regime provides the motivation for the flourishing of entrepreneurs and efficient utilization of new knowledge. (iii) Innovation represents an efficient innovation system of consultants, research centers, firms, universities and other organizations to utilize the burgeoning stock of global knowledge, create new technology and adapt as well as assimilate these to local needs. (iv) Education entails a skilled and an educated population that use and share existing knowledge efficiently, as well as create knowledge.

maintaining that in order to enhance catch-up processes of development, reverse engineering in developing countries is important, at least in the short run. The argument essentially builds on the reality that technology in less developed countries is more adaptive and imitative in nature (Maskus & Penubarti, 1995; Mansfield 1994; Seyoum, 1996; Lee & Mansfield, 1996)[4]. This has motivated the proliferation of technologies that are employed to pirate, imitate and copy KE commodities (Asongu et al., 2019). Upon reviewing contemporary literature on the subject, while there are considerably and justifiable issues surrounding software piracy[5], a consensus is lacking in the debate on the consolidation of IPRs in the industry of software.

Central to the debate on IPRs protection are two main schools of thought. The first school maintains that adherence to tight IPRs encourage economic progress and development catch-up (Gould & Gruben 1996; Falvey et al., 2006). The school argues that the positive relationship between tight IPRs and economic development is facilitated by the positive externalities of strict IPRs on factors of productivity. In other words, the school maintains that stringent IPRs encourage innovation and improvements in total factor productivity because IPRs holders are provided with more incentives to innovate and produce new knowledge. It is also important to note that while the first school favors the production of knowledge, it reduces the smooth distribution of knowledge produced. This is essentially because stringent IPRs discourage replication and innovation that are essential for the dissemination of existing innovation and knowledge for economic development. Conversely, the second school perceives the adoption of stringent IPRs as unfavorable to economic progress and development catch-up (Yang & Maskus, 2001; Andrés & Goel 2011, 2012). The argument which extends to the ratification of international IPRs and IP treaties is relative to the short-run because, the narratives in support of the school of thought maintain that strict IPRs are needed to discourage complacency in innovation as economic development is gradually achieved. According to this school, while stringent IPRs are essential to encourage innovation, the period during which exclusive IPRs are held by innovators should be short in order to enable society to benefit from free acquisition and

[4] According to this strand of the literature, more stringent regimes in IPRs regimes should be adopted as nations make the transition from 'developing countries' to 'developed countries'. Such strict IPRs regimes are likely to, *inter alia*: (i) favour technology transfer and innovation (Lee & Mansfield, 1996); (ii) boost exports (Maskus & Penubarti, 1995) and (iii) increase the possibility of investments from multinational corporations (see Mansfield, 1994; Seyoum, 1996). This is also broadly consistent with a recent stream of literature on relevance of ICT on development outcomes in developing countries (Afutu-Kotey et al., 2017; Asongu & Boateng, 2018; Bongomin et al., 2018; Gosavi, 2018; Hubani & Wiese, 2018; Isszhaku et al., 2018; Minkoua Nzie et al., 2018; Muthinja & Chipeta, 2018; Abor et al., 2018).

[5] Throughout this study, the terms 'piracy' and 'software piracy' are employed interchangeably.

distribution of knowledge once the period of exclusive IP is over. The perspective supported by this school is consistent with contemporary software piracy literature notably that software piracy boosts: copyright holders' gains (Tunca & Wu, 2012); scientific publications (Asongu, 2014a) and pro-poor development (Asongu, 2014b). The two schools of thought are apparent in both qualitative literature on the relevance of IPRs protection (Peitz & Waelbroeck, 2006; Lau, 2006) and a growing stream of literature on drivers of piracy in the copyright industry (Andrés, 2006a; Bezmen & Depken, 2006; Banerjee et al., 2005; Bezmen & Depken, 2004; Goel & Nelson, 2009).

More contemporary literature on the fight against piracy in the software industry can be discussed in three main strands. The first deals with non-legal mechanisms by which software piracy can be mitigated, namely: community engagements, online-only, 'making legal easier' and digital rights management channels (Holm, 2014); self-control and social learning (Burruss et al., 2018; Omar & Ahmed, 2018) and a block chain approach (Bhawna et al., 2018). In the second, we find studies on common strategies for the harmonization of IPRs against software piracy (Asongu, 2013a; Andrés & Asongu, 2016). The third focuses on other mechanisms through which piracy can be curbed, namely: (i) good governance (Andrés & Asongu, 2013a); (ii) good institutions and human progress (Driouchi et al., 2015); (iii) Software User Identity Module (Adu et al., 2014); (iv) perceptions of equity and fairness (Glass & Wood, 1996; Douglas *et al*., 2007); (v) informal institutions like religion (El-Baily & Gouda, 2011); (vi) lawsuits targeting peer-to-peer networks and corresponding customers (Tunca 2012); (vii) knowledge about punishment at stake (Yoo et al., 2011); (viii) democratic standards (Piquero & Piquero, 2006) and (ix) IPRs protection channels (Asongu *et al*., 2018), especially those that are contingent on codes of knowledge ethics in learning institutions (Santillanes & Felder, 2015) and legal origins (Asongu, 2015). It is important to note that the above strands also entail: (i) the relevance of behaviour, psychology and norms; (ii) the influence of easy availability and utility of software tools that facilitate piracy and (iii) the influence of easy availability and utility of software tools that facilitate piracy.

Noticeably, the above literature leaves space for improvement in understanding the role of technology in the persistence of software piracy. Knowing how technology affects the persistence of piracy is important because it enables more targeted policy initiatives on technology that accounts for more addiction to (or persistence in) software piracy relative to technology with which less pirated software is used. Two main technologies are employed in this study, namely: internet penetration and PC users. Therefore, the research question this inquiry seeks to address is the following: are PC users or internet penetration more responsible for the persistence of piracy in the software industry?

The theoretical underpinnings of persistence in software piracy are in line with the convergence literature which has been considerably documented within the framework of neoclassical models of growth (Swan, 1956; Barro, 1991; Solow, 1956; Baumol, 1986; Mankiw et al., 1992; Barro & Sala-i-Martin, 1992, 1995) and recently extended to other fields of economic development, notably: financial markets (Fung, 2009; Narayan et al., 2011; Bruno et al., 2012); human development (Mayer-Foulkes, 2010; Asongu, 2014c) and software piracy (Andrés & Asongu, 2013b, 2016). Convergence in software piracy that is contingent on technology adoption and IPRs can be expected for a multitude of reasons, *inter alia*: (i) the migration of experts and training of workers and students abroad (Kim & Nelson, 2000; Mowery & Sampat, 2005; Morrison et al., 2009); (ii) the changing nature of science and technology (D'Este & Patel, 2007; Mazzoleni & Nelson, 2007) which is facilitating cross-country collaboration and (iii) the phenomenon of globalization which is enhancing cross-country diffusion of knowledge (see Asongu & Nwachukwu, 2016a). In summary, there is a wealth of literature on KE catch-up and/or persistence (Esler & Nelson 1998; Albuquerque, 2000; Jelili & Jellal, 2002; Wolff & Jellal, 2003; Mowery & Sampat 2005; Murray & Stern, 2005; Mazzoleni, 2008).

It is important to articulate why the internet and Personal Computers (PCs) are the adopted mechanisms of technology in this study on the one hand and on the other, which of the mechanisms is theoretically projected to be more influential. The indicator of software piracy is measured based on pirated software installed in PCs and the internet is a mechanism through which pirated software can be downloaded and distributed. It is anticipated that software piracy is more persistent through PCs compared to the internet because, as apparent in the next section, the conception and definition of software piracy is directly linked to the installation of pirated software in PCs.

The rest of the study is structured as follows. Section 2 discusses the data and methodology while Section 3 presents the empirical results. Section 4 concludes with implications and future research directions.

2. Data and Methodology

2.1 Data

This inquiry examines a sample of 99 countries with data from three main sources, namely from the: World Intellectual Property Organisation (WIPO); Business Software Alliance (BSA) and World Bank Development Indicators (WDI). The periodicity is from 1994 to 2010. Restrictions to the number of countries and periodicity are essentially due to constraints in data availability at the time of the study.

The outcome indicator which is pirated software is defined as "*the unauthorized copying of computer software which constitutes copyright infringement for either commercial or personal use*" (SIIA, 2000)[6]. From a multidimensional spectrum, software piracy can be understood as organised individuals' piracy and commercial or business piracy. There are three main types of software piracy, namely: counterfeiting, downloading and end-user copying. In the light of these differences in the conception of software piracy, the concern about deriving an appropriate indicator of software piracy has been longstanding in the literature. The present study defines software piracy as the variation between the demand for new software applications (which are computed on the basis of PC shipments) and software piracy that is actually supplied legally. Therefore, pirated software is measured as the percentage of software that is illegally installed annually (without a license) in a given country. The underlying variable ranges from 0% (a scenario of no piracy) to 100% (a scenario where all software installed is of pirated origin). More insights into information on the measurement of software piracy can be found in BSA (2007, 2009)[7]. Though it is the object of some upward bias, software piracy data from BSA has been widely employed in the literature[8].

Given that we are modeling the persistence of software piracy, our independent variable of interest is the estimated lagged value of software piracy. Three sets of independent variables are employed, notably: (i) technology indicators, (ii) IPRs laws and treaties and (iii) macroeconomic variables

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[6] SIIA stands for Software and Information Industry Association.

[7] For the most part, data from the BSA measures commercial software piracy. More insights into the reliability of the piracy data are available in the wealth of literature on the subject *inter alia*: Traphagan and Griffith (1998) and Png (2008).

[8] The adopted software piracy measurement has been substantially employed in the literature (Marron & Steel, 2000; Andrés, 2006b; Goel & Nelson, 2009; Banerjee et al., 2005).

First, two variables of technology are adopted, namely: internet penetration and the number of Personal Computers (PCs). Whereas the choice of PCs is in accordance with the definition of software piracy, internet penetration is consistent with both intuition and recent KE literature (Tchamyou, 2017). The justification of this choice of technology variables has been provided in the penultimate paragraph of the introduction.

Second, the study considers six IPRs channels, namely: *constitution*, *IPR law*, *main IP law*, *WIPO treaties*, *bilateral treaties* and *multilateral treaties*. The choice of the variables is in line with the literature on the close linkage between IPRs laws and software piracy, which also embodies international treaties and legal frameworks (Holm, 2003; Andrés, 2006a; Van Kranenburg & Hogenbirk, 2005; Ki et al., 2006; Baghci et al., 2006; Asongu, 2013; Driouchi et al., 2015; Andrés & Asongu, 2016). The source of the IPRs indicator is the WIPO. The IP law and main IP law are laws that are enacted by the legislature and enforced by governance institutions while WIPO administered treaties are considered from the day they are enforced by the contracting nations. The relevant multilateral and bilateral agreements or treaties are computed in accordance with the day that they are enforced by the contracting parties. The main rationale for the inclusion of IPRs channels in the conditioning information set is that these are logically designed to enhance IPRs and by extension, the enhancement of IPRs entails the fight against software piracy. The choice of these IPRs control variable is consistent with recent literature (Asongu, 2015).

Third, three macroeconomic variables are also considered, namely: Population density, Gross Domestic Product (GDP) and Research and Development (R& D) expenditure. The choice of these variables is in line with recent literature on software piracy (see Andrés & Goel, 2011, pp. 7-8; Asongu et al., 2018b). Whereas the last two are anticipated to reduce software piracy, the first intuitively has the opposite effect. In essence, nations reflecting higher levels of GDP per capita are linked with relatively lower software piracy levels. This is for the most part because in less developed nations, citizens often lack the financial resources to buy the correct/legal software (Goel & Nelson, 2009; Moores & Esichaikul, 2011). The narrative of this expected sign also doubles as a justification for the anticipated impact of R&D. This is essentially because nations with high R&D expenditure are also likely to be comparatively wealthier nations. On the grounds of intuition, a growing population is very likely to be positively associated with aggregate software piracy because more citizens become exposed and tempted to use pirated goods and services. It is important to note that this intuition is contingent on the stringency of IPRs laws and effectiveness of institutions. For instance, rates of piracy are much higher in Russia, which has a declining population than in the United States, which has a growing population. Beyond the rationales and intuition provided, the adopted control variables have been used in recent literature on the determinants of software piracy (Asongu *et al*., 2018b).

Appendix 1 provides definitions of variables as well as their corresponding sources. The number of sampled countries is also disclosed in the appendix. The summary statistics and correlation matrix are respectively disclosed in Appendix 2 and Appendix 3. From the summary statistics, it is apparent that the variables under investigation are comparable. Moreover, given the variations in the corresponding standard deviations, we can be confident that reasonable estimated linkages will emerge. The purpose of the correlation matrix is to avoid concerns of multicollinearity that can affect the signs of estimated coefficients.

2.2 Methodology

2.2.1 Generalized method of moments: justification and specification

In accordance with information development literature on persistence (Asongu & Nwachukwu, 2017), the empirical strategy is the Generalized Method of Moments (GMM). There are six main motivations underpinning the adoption of the estimation technique. The first is related to the line of inquiry, the second and third are requirements of the approach while the last three are advantages that are linked to the estimation strategy. First and foremost, the technique is consistent with the estimation of persistence because it is a dynamic process that involves the lagged dependent variable (Tchamyou *et al*., 2018). Second, the N(99)>T(17) criterion which is essential for applying the estimation technique is met because the number of cross sections (or countries) are substantially higher than the related number of years in each cross section (Efobi et al., 2018). Third, an exploratory analysis of the dependent variable reveals some evidence of persistence because the correlation between software piracy and its first lag (0.981) is above the 0.800 rule of thumb (Asongu *et al*., 2018c). Fourth, since the GMM strategy is in line with panel data structure, cross-country variations are included in the regressions (Arellano & Bover, 1995). Fifth, inherent biases in the *difference* estimator are considered in the *system* estimator (Blundell & Bond, 1998). Sixth, endogeneity is accounted-for by the estimation technique because the concern about simultaneity in the explanatory variables is tackled with an instrumentation process (Roodman, 2009a,b). Moreover, the employment of time-invariant omitted indicators also improves the control for endogeneity.

Consistent with Bond et al. (2001), the *system* GMM estimator (see Arellano & Bover, 1995; Blundell & Bond, 1998) has better properties of estimation compared to the *difference* estimator (see Arellano & Bond, 1991). In this inquiry, we opt for the Roodman (2009ab) extension of Arellano and Bover (1995) because it has been documented to: (i) limit instrument proliferation or restrict over-identification and (ii) control for cross-sectional dependence (see Love & Zicchino, 2006; Baltagi, 2008; Boateng *et al.*, 2018). Hence, instead of adopting first differences, the extended estimation procedure adopts forward orthogonal deviations.

A *two-step* procedure is adopted instead of a *one-step* approach because it addresses concerns of heteroscedasticity given that the *one-step* procedure only controls for homoscedasticity. The following equations in level (1) and first difference (2) summarise the standard *system* GMM estimation procedure.

$$SP_{i,t} = \sigma_0 + \sigma_1 SP_{i,t-\tau} + \sigma_2 T_{i,t} + \sigma_3 IP_{i,t} + \sigma_4 TIP_{i,t} + \sum_{h=1}^{3} \delta_h W_{h,i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t} \quad (1)$$

$$\begin{aligned} SP_{i,t} - SP_{i,t-\tau} = {} & \sigma_1 (SP_{i,t-\tau} - SP_{i,t-2\tau}) + \sigma_2 (T_{i,t} - T_{i,t-\tau}) + \sigma_3 (IP_{i,t} - IP_{i,t-\tau}) + \sigma_4 (TIP_{i,t} - TIP_{i,t-\tau}) \\ & + \sum_{h=1}^{3} \delta_h (W_{h,i,t-\tau} - W_{h,i,t-2\tau}) + (\xi_t - \xi_{t-\tau}) + (\varepsilon_{i,t} - \varepsilon_{i,t-1}) \end{aligned} , \quad (2)$$

where, $SP_{i,t}$ is software piracy of country i in period t, ∂ is a constant, τ represents the coefficient of auto-regression, ξ_t is the time-specific constant, $T_{i,t}$ represents the technology (PC users and internet penetration) of country i in period t, $IP_{i,t}$ denotes intellectual property mechanisms (*constitution*, *IPR law*, *main IP law*, *WIPO treaties*, *bilateral treaties* and *multilateral treaties*) of country i in period t, $TIP_{i,t}$ is the interaction between T(technology) and IP (intellectual property mechanism) of country i in period t, $W_{i,t}$ captures the vector of control variables (*GDP per capita, R&D expenditure and Population density*) of country i in period t, η_i is the country-specific effects and $\varepsilon_{i,t}$ is the error term. The specification which is based on interactive regressions is also designed to articulate the fact that the sensitivity of software piracy to IPRs mechanisms is contingent on the specific technology channel through which the pirated software is consumed.

2.2.2 Identification and exclusion restrictions

Discussing properties of identification and articulating exclusion restrictions are important for a good specification GMM. Consistent with recent literature on the technique, all independent variables are acknowledged as suspected endogenous or predetermined indicators and only time-invariant omitted variables or year indicator are considered to exhibit strict exogeneity (see Boateng *et al.*, 2018; Asongu & Nwachukwu, 2016b; Tchamyou, 2018; Tchamyou & Asongu, 2017). The intuition for the underlying builds on the fact that it is not likely for the time-invariant omitted variables to become endogenous upon a first difference (Roodman, 2009)[9].

With the above in mind, the time-invariant omitted variables impact software piracy exclusive through the predetermined variables. Furthermore, the statistical validity of the exclusion restriction is examined with the Difference in Hansen Test (DHT) for instrument exogeneity. Accordingly, the alternative hypothesis of the DHT should not be accepted for the time-invariant omitted variables to explain the outcome variable exclusively via the predetermined indicators. Hence, in the results that are reported in Section 3, the assumption of exclusion restriction is validated if the null hypothesis of the DHT related to the instrumental variables (IV) (year, eq(diff)) is not rejected. This is broadly in accordance with the standard IV process in which, failure to reject the alternative hypothesis of Sargan Overidentifying Restrictions (OIR) test is an indication that the instruments affect the outcome variable through other mechanisms beside the suggested suspected endogenous variable channels (see Beck et al., 2003; Asongu & Nwachukwu, 2016c).

3. Empirical results

Table 1 and Table 2, present empirical findings corresponding to PC users and internet penetration, respectively. There are six specifications in each table corresponding to each IPR mechanism. For either table, the models are comparable because only technology variables change from one table to another. Hence, it can logically be deduced that the choice of the technology variable has a bearing on the estimated lagged dependent variable which is used to assess evidence of persistence in software piracy.

[9] Hence, the procedure for treating *ivstyle* (years) is 'iv (years, eq(diff))' whereas the *gmmstyle* is employed for predetermined variables.

Table 1: Personal Computer Users and IPRs

	Dependent variable: Software Piracy Rate					
Piracy (-1)	0.825	**0.861*** **	**0.817*** **	0.838	0.138	**0.844*** **
	(0.000)	**(0.000)**	**(0.000)**	(0.171)	(0.735)	**(0.000)**
Constant	0.672	0.434	0.722	0.838	**0.874*** **	0.825
	(0.527)	(0.133)	(0.235)	(0.171)	**(0.000)**	(0.196)
Personal Computer Users (PC)	0.017	0.024	0.009	-0.026	0.001	0.025
	(0.761)	(0.402)	(0.811)	(0.547)	(0.971)	(0.584)
Constitution	0.084	---	---	---	---	---
	(0.219)					
Main IP Law	---	**0.021** **	---	---	---	---
		(0.032)				
IP Law	---	---	**0.009* **	---	---	---
			(0.077)			
WIPO Treaties	---	---	---	-0.0005	---	---
				(0.971)		
Multilateral Treaties	---	---	---	---	0.0007	---
					(0.863)	
Bilateral Treaties	---	---	---	---	---	0.001
						(0.744)
Constitution×PC	-0.015	---	---	---	---	---
	(0.402)					
Main IP Law×PC	---	**-0.005** **	---	---	---	---
		(0.026)				
IP Law×PC	---	---	-0.001	---	---	---
			(0.173)			
WIPO Treaties×PC	---	---	---	0.002	---	---
				(0.602)		
Multilateral Treaties×PC	---	---	---	---	-0.0007	---
					(0.572)	
Bilateral Treaties×PC	---	---	---	---	---	-0.00007
						(0.949)
Gross Domestic Product	-0.106	**-0.101** **	-0.132	-0.136	-0.043	**-0.149* **
	(0.441)	**(0.030)**	(0.139)	(0.124)	(0.491)	**(0.071)**
Research & Development	-0.020	**-0.012* **	**-0.016* **	-0.015	**-0.015* **	**-0.013* **
	(0.052)	**(0.078)**	**(0.091)**	(0.201)	**(0.085)**	**(0.057)**
Population	-0.038	-0.012	-0.031	-0.025	**0.010*** **	-0.043
	(0.692)	(0.673)	(0.527)	(0.647)	**(0.777)**	(0.457)
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes
AR(1)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
AR(2)	**(0.161)**	**(0.142)**	**(0.151)**	**(0.158)**	**(0.166)**	**(0.153)**
Sargan OIR	**(0.472)**	**(0.482)**	**(0.385)**	(0.003)	(0.013)	**(0.378)**
Hansen OIR	**(0.668)**	**(0.425)**	**(0.639)**	**(0.603)**	**(0.189)**	**(0.456)**
DHT for instruments						
(a)Instruments in levels						
H excluding group	**(0.467)**	**(0.723)**	**(0.459)**	**(0.728)**	**(0.251)**	**(0.500)**
Dif(null, H=exogenous)	**(0.671)**	**(0.257)**	**(0.645)**	**(0.433)**	**(0.203)**	**(0.398)**
(b) IV (years, eq(diff))						
H excluding group	**(0.410)**	**(0.448)**	**(0.416)**	**(0.315)**	(0.027)	**(0.571)**
Dif(null, H=exogenous)	**(0.695)**	**(0.392)**	**(0.690)**	**(0.737)**	**(0.756)**	**(0.350)**
Fisher	**403.58**** **	**1194.22*** **	**574.85*** **	**554.51*** **	**1931.88*** **	**1459.05*** **
Instruments	36	39	39	39	39	39
Countries	84	84	84	84	84	84
Observations	702	702	702	702	702	702

*,**,***: significance levels of 10%, 5% and 1% respectively. IP: Intellectual Property. PC: Personal Computers. WIPO: World Intellectual Property Organisation. DHT: Difference in Hansen Test for Exogeneity of Instruments' Subsets. Dif: Difference. OIR: Over-identifying Restrictions Test. The significance of bold values is twofold. 1) The significance of estimated coefficients and Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) and AR(2) tests and; b) the validity of the instruments in the OIR and DHT tests.

Table 2: Internet penetration and IPRs

	Dependent variable: Software Piracy Rate					
Piracy (-1)	**0.828*****	**0.844*****	**0.817*****	**0.784*****	**0.821*****	**0.853*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Constant	**0.957****	**1.186*****	**1.276*****	**2.624*****	**1.752*****	**0.815****
	(0.019)	**(0.002)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.027)**
Internet Penetration (Internet)	**0.037****	**0.038****	0.025	0.008	**(0.030)***	0.022
	(0.020)	**(0.036)**	(0.112)	(0.689)	**(0.067)**	(0.148)
Constitution	**0.080****	---	---	---	---	---
	(0.034)					
Main IP Law	---	0.011	---	---	---	---
		(0.163)				
IP Law	---	---	0.0001	---	---	---
			(0.953)			
WIPO Treaties	---	---	---	**-0.040*****	---	---
				(0.008)		
Multilateral Treaties	---	---	---	---	**-0.008****	---
					(0.019)	
Bilateral Treaties	---	---	---	---	---	-0.003
						(0.583)
Constitution×Internet	**-0.016***	---	---	---	---	---
	(0.095)					
Main IP Law×Internet	---	-0.002	---	---	---	---
		(0.303)				
IP Law×Internet	---	---	0.0007	---	---	---
			(0.362)			
WIPO Treaties×Internet	---	---	---	**0.013*****	---	---
				(0.001)		
Multilateral Treaties×Internet	---	---	---	---	**0.002****	---
					(0.026)	
Bilateral Treaties×Internet	---	---	---	---	---	0.0008
						(0.577)
Gross Domestic Product	**-0.184*****	**-0.226*****	**-0.226*****	-0.404	**-0.285*****	**-0.173*****
	(0.002)	**(0.000)**	**(0.000)**	(0.004)	**(0.000)**	**(0.002)**
Research & Development	-0.010	-0.0002	-0.005	0.015	0.006	-0.002
	(0.252)	(0.974)	(0.553)	(0.276)	(0.459)	(0.764)
Population	-0.044	**-0.054***	**-0.058****	**-0.138*****	**-0.092*****	-0.027
	(0.126)	**(0.063)**	**(0.016)**	**(0.000)**	**(0.000)**	(0.274)
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes
AR(1)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
AR(2)	**(0.136)**	**(0.134)**	**(0.128)**	**(0.150)**	**(0.135)**	**(0.128)**
Sargan OIR	**(0.240)**	**(0.199)**	**(0.138)**	**(0.000)**	**(0.050)**	**(0.115)**
Hansen OIR	**(0.276)**	**(0.136)**	**(0.190)**	**(0.132)**	**(0.153)**	**(0.299)**
DHT for instruments						
(a)Instruments in levels						
H excluding group	**(0.578)**	**(0.181)**	**(0.211)**	**(0.248)**	**(0.117)**	**(0.633)**
Dif(null, H=exogenous)	**(0.180)**	**(0.203)**	**(0.262)**	**(0.155)**	**(0.304)**	**(0.183)**
(b) IV (years, eq(diff))						
H excluding group	**(0.133)**	**(0.101)**	**(0.606)**	**(0.177)**	(0.039)	(0.069)
Dif(null, H=exogenous)	**(0.527)**	**(0.314)**	(0.095)	**(0.204)**	**(0.579)**	**(0.739)**
Fisher	**1142.77*****	**1693.02*****	**1073.97*****	**481.70*****	**1548.36*****	**1728.85*****
Instruments	39	39	39	39	39	39
Countries	86	86	86	86	86	86
Observations	713	713	713	713	713	713

*,**,***: significance levels of 10%, 5% and 1% respectively. IP: Intellectual Property. PC: Personal Computers. WIPO: World Intellectual Property Organisation. DHT: Difference in Hansen Test for Exogeneity of Instruments' Subsets. Dif: Difference. OIR: Over-identifying Restrictions Test. The significance of bold values is twofold. 1) The significance of estimated coefficients and Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) and AR(2) tests and; b) the validity of the instruments in the OIR and DHT tests.

Four principal information criteria are employed to assess the validity of the GMM model with forward orthogonal deviations[10]. Based on the criteria, the following findings are established. First, software piracy is persistent in three of the six specifications in Table 1 whereas the corresponding persistence in Table 2 is not apparent in all of the six specifications because they are overwhelmingly stationary. In other words, the findings on PC users are weakly stationary. The assimilation of non-stationarity to persistence is consistent with Mishra and Smyth (2014). Second, most of the significant control variables have the expected signs.

It is important to articulate the criterion for stationarity which is based on the estimated lagged dependent variable. Evidence of convergence or a stationary process is established when the absolute values of the lagged outcome indicator is in the interval of zero and one. This is consistent with Fung (2009, p.58) and Asongu (2013, p. 49). Such criterion has been used in recent information persistence literature (see Asongu & Nwachukwu, 2016b).

Accordingly, in order for persistence to be established, the estimated lagged endogenous or outcome variable should be significant on the one hand and on the other, satisfy the convergence criterion. Note should be taken of the fact that, the estimated coefficients related to the dependent variable can be directly reported. Alternatively, beta could be derived by subtracting one from the estimated lagged coefficient. Within this alternative framework, the criterion for establishing convergence is a beta that is less than zero. Hence, following recent literature, we have directly reported the estimated lagged dependent variables (Prochniak & Witkowski, 2012a, p. 20; Prochniak & Witkowski, 2012b, p. 23; Asongu & Nwachukwu, 2016d, p. 459).

Given the above insights, the criterion for establishing comparative persistence from PC vis-à-vis internet penetration is as follows: when the two tables are compared, the tables with estimated lagged coefficients reflecting higher magnitude are acknowledged to reflect more persistence. Accordingly, the relevance of magnitude in the estimated lagged value for the establishment of more persistence is consistent with recent literature (Asongu & Acha-Anyi,

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[10] "First, the null hypothesis of the second-order Arellano and Bond autocorrelation test (AR (2)) in difference for the absence of autocorrelation in the residuals should not be rejected. Second the Sargan and Hansen over-identification restrictions (OIR) tests should not be significant because their null hypotheses are the positions that instruments are valid or not correlated with the error terms. In essence, while the Sargan OIR test is not robust but not weakened by instruments, the Hansen OIR is robust but weakened by instruments. In order to restrict identification or limit the proliferation of instruments, we have ensured that instruments are lower than the number of cross-sections in most specifications. Third, the Difference in Hansen Test (DHT) for exogeneity of instruments is also employed to assess the validity of results from the Hansen OIR test. Fourth, a Fischer test for the joint validity of estimated coefficients is also provided" (Asongu & De Moor, 2017, p.200).

2018; Asongu, 2018). This is essentially because a lagged estimated magnitude translates how past values of software piracy influence future values of software piracy.

It is also important to elucidate how PCs and internet penetration used in conditioning information set contribute to persistence in software piracy. Accordingly, the specifications in Table 1 and Table 2 are comparable because, with the exceptions of PCs and the internet (which are our main variables of interest), the other variables in the conditioning information set are the same (Andrés & Asongu, 2013a). Whereas absolute persistence/convergence is modeled without variables in the conditioning information set, conditional persistence/convergence involves a set of control variables or variables in the conditioning information set (Narayan *et al.*, 2011). Conditional persistence is the type of persistence/convergence that occurs because of cross-country differences in factors that determined the outcome variables (or software piracy) (Narayan et al., 2011). Given that the main distinguishing feature between Table 1 and Table 2 are PCs and internet penetration, it is reasonable to infer that the changes in persistence across tables is traceable to the type of technology used in the regression.

4. Concluding implications, caveats and future research directions

This study has examined the persistence of software piracy with internet penetration vis-à-vis PC users, conditional on Intellectual Property Rights (IPRs) institutions. The empirical evidence is based on a panel of 99 countries for the period 1994-2010 and the Generalised Method of Moments with forward orthogonal deviations. The main finding is that, compared to internet penetration, PC usage is more responsible for the persistence of global software piracy.

Knowing how technology affects the persistence of piracy is important because it enables more targeted policy initiatives. We have shown that the sensitivity of software piracy to IPRs mechanisms is contingent on the specific technology channels through which the pirated software is consumed. As a main policy implication, the choice and design of IPR treaties/laws against software piracy should be contingent on technologies with which pirated software is used. As far as these findings are concerned, in the choice between internet penetration and PC usage, devoting resources to the targeting of the latter would contribute more towards reducing sustained software piracy. The conception and definition of software piracy should be extended (to other hardware such as mobile phones and internet-linked hardware applications) and not exclusively limited to PCs. Hence, while the study recommends that policy makers should focus more on PCs as opposed to internet penetration in order to limit the persistence of pirated software, it is also relevant to note that other contemporary hardware that use pirated software include: Iphones and Ipads which have most software-related technical facilities available in PCs. Moreover, policy should also be cautious of the fact that persistence in a development outcome is contingent on the variables used in the conditioning information set. Hence, it is relevant to engage many determinants of software piracy in the modelling exercise. This is essentially because conditional persistence (which we have modelled) is apparent when there are cross-country differences in factors that affect the outcome variable. Hence, the policy relevance of our findings is contingent on determinants involved in the conditioning information set.

In the light of the above, a caveat to this study is that technology has been conceived and measured in terms of personal computers (i.e. hardware) and internet penetration (i.e. software). However, there are many hardware and software associated with piracy. Considering these alternative factors (e.g. such as cloud computing) within the framework of future studies, as more data become available, is fundamental in improving the established findings and extant literature. Moreover, future research can improve the existing literature by assessing other technology and IPRs mechanisms. Another caveat of the study is based on data availability constraints at the time of the study. Hence the use of more contemporary data is warranted in future studies. These potential studies should also consider the heterogeneity of the dataset and the nature of the software industry which has changed since 1994.

Compliance with Ethical Standards
The authors are self-funded and have received no funding for this manuscript. The authors also have no conflict of interest. This article does not contain any studies with human participants or animals performed by the authors.

Appendices

Appendix 1: Definition of variables

Variables	Abbreviation	Definition of variables (Measurements)	Sources
Piracy	Piracy	Logarithm of Piracy rate (annual %)	BSA
Growth per capita	GDP	Logarithm of GDP per Capita, PPP (international constant dollars, 2005)	World Bank (WDI)
Research and Development	R & D	Research and Development Expenditure (% of GDP)	World Bank (WDI)
Internet Penetration	Internet	Logarithm of Internet Users per 1000	GMID
PC Users	PC	Logarithm of PC Users per capita	GMID
Population	Pop.	Logarithm of Population	World Bank (WDI)
Constitution	Const.	Dummy variable: Copyright is mentioned in the constitution	WIPO
Main_IP_law	MIPlaw	Main Intellectual Property Law	WIPO
IP_rlaw	IPlaw	Intellectual Property Rights Law	WIPO
Wipotreaties	WIPO	World Intellectual Property Organization	WIPO
Mutilateral	Multi.	Multilateral Treaties	WIPO
Bilateral	Bilat.	Bilateral Treaties	WIPO

WDI: World Bank's World Development Indicators. BSA: Business Software Alliance. GMID: Global Market Information Database. GDP: Gross Domestic Product. Log: Logarithm. WIPO: World Intellectual Property Organization.

Appendix 2: Summary Statistics (1994-2010)

Panel A: Summary Statistics

	Variables	Mean	S.D	Min.	Max.	Obs
Dependent Variable	Software Piracy rate (ln transformed)	0.255	0.449	-0.602	1.995	1500
Technology and control variables	GDP per capita (log)	4.006	0.433	3.008	4.924	1643
	Research & Development (R & D)	1.079	0.963	0.006	4.864	811
	Internet Penetration (log)	2.807	1.183	-1.000	5.622	1616
	Personal Computer Users (log)	3.009	0.837	0.698	5.464	1557
	Population (log)	7.063	0.712	5.424	9.126	1682
IPRs laws and treaties related	Constitution	0.242	0.428	0.000	1	1683
	Main IP Law	2.134	2.550	0.000	20	1683
	IP Law	2.260	4.669	0.000	47	1683
	WIPO Treaties	3.455	1.877	0.000	7	1683
	Multilateral Treaties	10.594	5.816	0.000	25	1683
	Bilateral Treaties	0.998	2.532	0.000	21	1683

Panel B: Presentation of Countries

"Albania, Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Belgium, Bolivia, Bosnia, Botswana, Brazil, Bulgaria, Cameroon, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Finland, France, Germany, Greece, Guatemala, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Lebanon, Lithuania, Luxembourg, Macedonia, Malaysia, Malta, Mauritius, Mexico, Moldova, Montenegro, Morocco, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Qatar, Romania, Russia, Saudi Arabia, Senegal, Serbia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Thailand, Tunisia, Turkey, Ukraine, UAE, United Kingdom, United States, Uruguay, Venezuela, Vietnam, Zambia".

S.D: Standard Deviation. Min: Minimum. Max: Maximum. ICT: Information and Communication Technology. Scandi: Scandinavian. Obs: Observations.

Appendix 3: Correlation Matrix

Piracy	GDP	R & D	Internet	PC	Pop.	Const.	MIPlaw	IPrlaw	WIPO	Multi.	Bilat.	
1.000	-0.766	-0.703	-0.503	-0.551	0.009	0.108	-0.405	-0.109	-0.215	-0.534	-0.180	Piracy
	1.000	0.653	0.386	0.482	-0.206	-0.173	0.285	0.067	0.077	0.376	0.160	GDP
		1.000	0.424	0.530	0.044	-0.161	0.221	-0.042	0.035	0.414	0.248	R & D
			1.000	0.897	0.609	0.145	0.284	0.196	0.119	0.316	0.299	Internet
				1.000	0.688	0.123	0.286	0.197	0.036	0.319	0.340	PCs
					1.000	0.269	0.068	0.179	-0.087	0.031	0.231	Pop.
						1.000	0.075	0.348	0.068	-0.098	0.241	Const.
							1.000	0.513	0.168	0.184	-0.087	MIPlaw
								1.000	0.209	0.147	-0.006	IPlaw
									1.000	0.569	0.176	WIPO
										1.000	0.078	Multi.
											1.000	Bilat.

GDP: GDP per capita. R&D: Research and Development. Internet: Internet penetration. PC: Personal Computer Users. Pop: Population. Const: Constitution. MIPlaw: Main Intellectual Property Law. IPrlaw: Intellectual Property Rights Law. WIPO: World Intellectual Property Organization Treaties. Multi: Multilateral Treaties. Bilat: Bilateral Treaties.

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