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Exploring the link between research and economic growth: an empirical study of China and USA

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Abstract In this paper, we explore the link between scientific and technical research and economic growth in China and USA over the sample period 1981–2012 using the extended Cobb–Douglas model with capital per worker and the quantity of scientific and technical journal articles (research publications) per worker. We examine the cointegration relationship and present the short-run and long-run results using the autoregressive distributed lag bounds procedure. Further, we examine the direction of causality between research publications per worker results and economic growth variables using the Toda and Yamamoto (J Econom 66(1–2):225–250, 1995) procedure. Our results indicate for both countries research publications per worker positively influence the output per worker both in the short-run and the long-run. The causality results for China indicate a bi-directional causality between research publications per worker and output per worker, duly emphasizing the mutually reinforcing effect. In case of USA, we note a unidirectional causation output per worker to research publications per worker indicating that output Granger cause research publications.

Keywords Research publications · Scientific and technical journal articles · Economic growth · China · USA

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1 Introduction

The factors contributing to the landscape of growth and development are dynamic and evolving. Subsequently, the role of innovation, creativity and knowledge accumulation are not only self-perpetuating and transformational but also a critical driver of growth. Inevitably, when new and refined knowledge through scientific research are created, the effects are pervasive and permeating. However, only little empirical research has been done to investigate the effects of research on economic growth. This article therefore contributes in that direction with evidence from USA and China. Moreover, this article further extends the current study in this area by applying the extended Cobb–Douglas model and intuition from Solow (1956) model where the role of capital and labor are pivotal, to examine the impact of scientific research on the economic growth of the two countries, respectively.

In a number of studies, scientific publication has been considered an indicator of creative effort and a reliable indicator of knowledge accumulation (de Solla 1978; Schubert and Telcs 1986). Arguably, knowledge creation is an imminent source of human development, productivity and growth (Barro and Sala-i-Martin 1992; Romer 1986; Lucas 1988; Tamura 1991; Schumpeter 2000).

However, we must concede that the quantity of publications is not necessarily a fully convincing indicator for knowledge creation, even though the papers are published in SCI or SSCI journals. The limitation is that the quality of papers and journals differs strongly and it would be more convincing to weight the journals by their impact factor and then to calculate the weighted sum of publications from both countries. Unfortunately, the corresponding data is to our knowledge not available. A second limitation is caused by the fact that the incentive mechanisms for scholars to publish in international peer-reviewed journals are very different in China and the USA (Franzoni et al. 2011). The US incentive mechanism is based on faculty incentives, so that the promotion, tenure and compensation of scientists depend strongly on the scientists' publication records (Stephan and Levin 2001).

In contrast to the US incentive mechanism, Chinese scientists receive a monetary bonus for each publication, where the size of the bonus depends on the international reputation of the journal in which the paper is published (Ding 2001; Shao and Shen 2011).¹ Different incentive mechanisms for scholarly publications in peer-reviewed journals lead according to the empirical work of Backes-Gellner and Schlinghoff (2008, 2010) and Franzoni et al. (2011) to different efforts to publish and to different outcomes regarding the acceptance ratio (number of accepted papers related to the number of submitted papers).² Taking the cited studies into account, it seems to be that the US incentive mechanism is superior to all other incentive mechanisms applied by universities with respect to the quantity of publications in international peer-reviewed journals.

Additionally, there are other reasons why the quantity of publications is not an optimal indicator for knowledge creation. For example outcomes of research projects for public or private institutions are not necessarily published in journals or contributions to scientific books are ignored. Despite these limitations, the quantity of publications (per worker or capita) is the best which is available at this time. Therefore, our results must be interpreted

¹ For example the bonus for the main author of a publication in Science or Nature amounts to \$32,566 at the Zhejiang University (own calculation based on Shao and Shen 2011).

² It must be noted that the study of Franzoni et al. (2011) take only the journal Science for the period 2000–2009 into account.

carefully.³ The quantity of publications includes the scientific and technical journal articles, that is, the number of scientific and engineering articles published in the fields of physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences from journals classified by the Institute for Scientific Information's Science Citation Index (SCI) and Social Sciences Citation Index (SSCI) (World Bank 2013).

With respect to scientific and technical publications, the recent data published by the World Bank (World Bank 2013) show USA is the leading country followed by China which, although second in rank, is well below USA (Leydesdorff and Wagner 2009). The number of scientific publications as a share of the world for USA is on average, close to 26 % over the 2008–2012 periods whereas for China, the average share is about 11 % over the same period. Moreover, over the same periods, we note that research publications per worker (in percent) are 0.08 % for China and 0.11 % for USA.

The literature focusing on scientific and technical publication viz. growth is growing, albeit slowly. Nevertheless, the availability of data from sources like World Bank (2013) is likely to spur more studies in the area of scientific publication and its plausible effects on key economic variables. Moreover, research outputs measured through the number of publications is a reflection of both quality of human capital and accumulated new knowledge (Hart and Somerfeld 1998; De Moya-Anegon and Herrero-Solana 1999; King 2004; Vinkler 2008; Lee et al. 2011).

Other notable studies that examine the nexus between research and economic growth includes De-Moya Anegon and Herrero, Fedderke 2005, Fedderke and Schirmer 2006, Pouris and Pouris 2009 and Inglesi-Lotz and Pouris 2013. De-Moya Anegon and Herrero (1999) find significant correlation between the gross domestic product (GDP) of Latin American countries in 1995 and the number of articles in journals indexed in the 1996 SCI. Fedderke (2005) argues the quality of human capital is the most important aspect for economic growth. Besides using indexed journal articles, another indicator often used to explain the role of human capital in growth process is expenditure on research and development (R&D) (Fedderke and Schirmer 2006). However, some authors consider academic publication as an objective and straight forward measure of innovation and research performance of a country than input measures (Pouris and Pouris 2009) because the latter is collected through surveys and hence cannot be repeated and verified, and resources allocated to R&D may not result in useful output especially if there are intermittent bottleneck in research progress and funding (Inglesi-Lotz and Pouris 2013).

Another qualitative aspect is that R&D expenditures include in general private expenditures and public expenditures, although the outcome differs in general. Usually, if private firms invest in R&D the outcome is often a corporate secret and is transformed into patents, which guarantees that only the patent holder has the right to exploit the knowledge economically. The research outcome of universities and public research institutions on the other hand is usually published and is accessible for everyone. Of course, in some instances, the knowledge created by universities may not be applied directly to produce consumption or investment goods or improve production processes. In this regard, majority of the scientific publications are therefore research that leads to knowledge creation which is accessible for everyone at little costs. It is also true that a vast majority of the scientific publications are provided by public institutions which are in principle financed by tax money. Moreover, since mostly the English written publications have the characteristic of a global public good, the problem of an under provision arises where individual countries

³ We thank the anonymous reviewer for raising this point.

have an interest to favor international scientific publications because the number of publications of a country related to the world output signals the high potential of the domestic labor force and makes a country attractive for domestic and foreign investments of high technology companies, consequently leading to well-paid working places and overall economic growth. Evidently, the role of academia and public research institutions are transformative and require effective linkage with industry and the state. Using the Triple Helix model, Etzkowitz and Leydesdorff (2000), Leydesdorff and Meyer (2006) and more recently Kim et al. (2012) among others argue the dynamic role and positive externalities networking and synergy between academia–industry–state or university–industry–government can bring about and concurrently create knowledge infrastructure and knowledge-based economies.

The nexus between research output and economic growth is controversial because of the nature of the link between research and growth which tends to depend on a number of factors such as the development stage of a country, the degree of emphasis on various scientific disciplines, and the method of analysis. Some studies have used the number of citations for each article as a measure of research output and innovation (Haiqi and Yuhua 1997; Butler 2003; Pouris 2003). Vinkler (2008) and Lee et al. (2011) find that there is no significant correlation between economic performance and research performance for developed countries however, the correlation is significant for developing countries. In a recent study, Meo et al. (2013) compare the impact of GDP per capita, R&D spending, number of universities and indexed scientific journals on the total number of research papers, citations per document and Hirsch index in among Asian countries. They find that R&D expenditure, number of universities and indexed journals have positive correlation with number of published documents, citations per document and H-index in various science and social science subjects. However, there is no association between per capita GDP and research outcomes. In a recent study, Inglesi-Lotz and Pouris (2013) argue that the potential drawbacks of using citations as an indicator is the possibility of author self-citing his/her own articles in future research; and that the articles from developing countries may not receive visibility equal to the developed countries. In their study, Inglesi-Lotz et al. (2015) examine the causal relationship between the growth and research output of the Brazil, Russia, India, China, and South Africa (BRICS) from 1981–2011, and find a bi-directional causation between growth and research output for India and absence of any causal relationship for other countries.

We examine the long-run association and the causation between research, measured by the relative number of scientific publications, and the growth for China and USA. The underlying assumption is that research is a form of human creativity, innovation and knowledge accumulation, and hence will enhance economic growth. In this regard, we explore the nexus between scientific and technical publications and economic growth for China and USA. There are two reasons for choosing these two countries: first, USA and China are global leaders in scientific publication and second, noting that China and USA is representative of developing and developed countries respectively, exploring the influence of scientific publication on their economic growth will be vital from research policy perspectives.

We use the augmented Solow framework and the autoregressive distributed lag (ARDL) procedure to determine the short-run and long-run effects of research on output per worker in each country. Moreover, we also examine the direction of causality between research and output per worker. The rest of the article is outlined as follows. In Sect. 2, we present the modeling strategy. In Sect. 3, we present the results and in Sect. 4 we conclude.

2 Modelling strategy

2.1 Framework

For the purpose of modeling and analysis, we use an approach introduced by Sturm et al. (1998) and Rao (2010) which are related to the augmented Solow (Solow 1956) framework.⁴ The initial equation is defined as:

$$Y_t = A_t R W_t^\theta K_t^\alpha L_t^\beta \quad (1)$$

where A_t is stock of technology, K_t is the capital stock, and L_t is the labor stock at specific time, t , respectively, and α and β are the capital and labor share, respectively. Naturally, the shares add up to one: $\alpha + \beta = 1$. The variable $R W_t$ is an indicator for the relative number of published scientific and technical journal research articles as a percentage of the labor stock (workers). The parameter $\theta > 0$ measures the production elasticity of the publication indicator. This indicator is a proxy for relative creativity, innovation and knowledge accumulation of a country. Dividing (1) by the labor stock gives the per capita production function:

$$y_t = A_t R W_t^\theta k_t^\alpha \quad (2)$$

where k_t is capital per worker. The variable $R W_t$ can be interpreted as a shift variable to capture the effects on total factor productivity (TFP). To complete the approach we assume:

$$A_t = A_o e^{gT} \quad (3)$$

and therefore after substituting (3) in (2) we get:

$$y_t = (A_o e^{gT} R W_t^\theta) k_t^\alpha \quad (4)$$

Taking the log of (4), we can obtain the log-linear equations for estimation as:

$$\ln y_t = \pi + \alpha \ln k_t + \theta \ln R W_t + \gamma_i X_{-} T_b + \varepsilon_t \quad (5)$$

where π is the constant term, α is the capital share, θ is the elasticity coefficient of research output per worker, γ_i is the coefficient of the respective series structural break dummy, $X_{-} T_b$, and ε is the error term.

2.2 Data

The sample data is the aggregate data over the periods 1981–2012 available from the *World Development Indicators and Global Development Finance* (World Bank 2013). We use perpetual inventory method to build data for capital stock.⁵ We assume depreciation rate (δ) of 8 %; initial capital stock (K_0) for China and USA is computed as 1.1 times the real GDP of 1964, and 1960, respectively. The gross fixed capital formation is used as a proxy for investment (I_t). Aggregate labor stock is estimated using the average employment

⁴ Note that if a Cobb–Douglas function is used, the form of neutrality of technical progress (Harrod-neutral, Solow-neutral, and Hicks-neutral) does not play a role since the effect remains the same.

⁵ Note the choice of δ and K_0 , are arbitrarily determined as long as the output per worker and capital per worker exhibit diminishing returns to scale, and hence the steady-state convergence.

rate and the population data for respective years. The share of scientific and technical journal articles as a percent of the total labor stock (RW_t) is used as a proxy for creativity, innovation and knowledge accumulation.⁶ We also consider the log of the total number of research publications, and total number of research publications as a percent of the world total in our estimation for experiment purpose. In both cases, we find the regression results with these two measures are qualitatively similar. A notable difference is that in case of the former, we note some serious issues with the diagnostic results which distort the overall results; and in case of the latter, although the diagnostic tests gets improved, we note that the results give unclear and mixed outcomes.

Moreover, both the indicators are relatively poor measure of research productivity compared to research output per worker (or in per capita terms). Further, research output per worker closely reflects the impact in growth as the research is divided by the labor stock. Intuitively, we expect the first order effect of research on growth to be at domestic level and the second order effect at international level. The reasoning behind this intuition is based on the observation that business university cooperation takes mostly place between firms and universities, which are located relative close to each other (Huffman and Quigley 2002; Ranga 2013). Additionally, the same language and culture lowers the transaction costs of knowledge transfer from universities to business and accelerate the transfer. In this regard, research output per worker (or capita) is a better proxy. Consequently, we use the research output per worker (in percent) and note both improvement in diagnostic results and overall results in explaining the impact on output per worker—the latter being the proxy for growth. The formal definition of the scientific and technical journal articles is that it includes the number of scientific and engineering articles published in the fields of physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences; and the counts are from journals classified by the Institute for scientific information's SCI and SSCI (World Bank 2013). The data is duly transformed into natural log form before proceeding to the analysis. The descriptive statistics of the respective sample in its original form is provided in Table 1.

2.3 Modelling strategy

2.3.1 ARDL bounds results

Using (5), we specify the ARDL model as (6) for the underlying relationship.

$$\begin{aligned} \Delta \ln y_t = & \beta_{10} + \beta_{11} \ln y_{t-1} + \beta_{12} \ln k_{t-1} + \beta_{13} \ln RW_{t-1} + \beta_{14}^i X_{t-1} T_b \\ & + \sum_{i=1}^p \alpha_{11i} \Delta \ln y_{t-i} + \sum_{i=0}^p \alpha_{12i} \Delta \ln k_{t-i} + \sum_{i=0}^p \alpha_{13i} \Delta \ln RW_{t-i} + \varepsilon_{1t} \end{aligned} \quad (6)$$

The ARDL approach is used to examine the cointegration because it is relatively simple and recommended for small sample size (Ghatak and Siddiki 2001; Pesaran et al. 2001). The requirement is that all variables should be at most $I(1)$, that is preferably stationary in first difference. Moreover, examining the unit root provides information on the maximum lags which can be used in testing for Granger non-causality (Toda and Yamamoto 1995). In what follows, we use the traditional unit root tests: augmented Dickey–Fuller (ADF),

⁶ We thank the anonymous reviewers for suggesti to use research output per capita (or worker) to appropriately model and estimate the impact of research in explaining the growth of the two economies.

Table 1 Descriptive statistics and correlation matrix

	Panel a: China			Panel b: USA		
	<i>y</i>	<i>k</i>	<i>RW</i>	<i>y</i>	<i>k</i>	<i>RW</i>
Mean	1593.24	3426.92	0.0645	57998.92	88889.12	0.1124
Median	1203.43	2208.05	0.0652	57552.67	82543.17	0.1129
Maximum	4570.51	11800.91	0.0884	71111.85	122259.7	0.1263
Minimum	312.55	504.000	0.0429	40983.88	57815.44	0.0939
SD	1243.26	3175.32	0.0128	9724.63	22857.73	0.0095
Skewness	0.9997	1.1917	−0.0095	−0.1665	0.2562	−0.6936
Kurtosis	2.8611	3.3858	2.1777	1.6684	1.5640	2.8611
Jarque–Bera	5.3554	7.7724	0.9020	2.51213	3.0995	2.5914
Probability	0.0687	0.0205	0.6370	0.28477	0.2123	0.2737
<i>y</i>	0000	–	–	1.0000	–	–
<i>k</i>	9970	1.0000	–	0.9764	1.0000	–
<i>RW</i>	9335	0.9115	1.0000	0.2308	0.1288	1.0000

Phillips–Perron (PP) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS). To examine the structural break in series, we use Perron (1997) and Zivot and Andrews (1992) tests. As noted in Eq. (6), a dummy variable (X_{T_b}) represents a specific structural break in the series. When the respective series break period dummy, X_{T_b} , is statistically significant, then it is appropriate to include it in the ARDL specification to compute a relatively robust bound statistics. However, when the break period dummy is not statistically significant which is detected through initial stages of estimation, then the break period dummy need not be included, to avoid computing erroneous bound statistics. The steps of computing the F- and W-statistics are as follows: first, Eq. (6) is estimated by ordinary least squares (OLS) technique. Second, the existence of a long-run relationship is traced by imposing restrictions on all estimated coefficients of lagged level variables equating to zero. Hence, bounds test is based on the F-statistics (or W-statistics) with the null hypothesis of no cointegration ($H_0 : \beta_{i1} = \beta_{i2} = \beta_{i3} = 0$) against its alternative hypothesis of a long-run relationship ($H_1 : \beta_{i1} \neq 0; \beta_{i2} \neq 0; \beta_{i3} \neq 0$). If the computed F- or W-statistics falls above the respective upper critical bound, then the null hypothesis of no cointegration is rejected at the respective levels of significance. Alternatively, if the F- or W-statistics falls below the lower bounds, then the null hypothesis is accepted with the given level of significance. In case when the F- or W-statistics falls within the upper and lower bounds, the outcome is inconclusive. The computed F- and W-statistics and the upper and the lower critical bounds are dependent on sample size, model specification, and the lag-length. Moreover, there are some studies that provide the critical bounds. However, this needs to be used with caution. For instance, the Pesaran et al. (2001) F-statistics critical bounds are computed for sample size of more than 80 (Pesaran and Pesaran 1999), and the Narayan (2005) F-statistics critical bounds are computed for a smaller sample size (between 30 and 80) and reported in the intervals of five. Both of these critical bounds does not account for structural breaks in series. In this regard, critical bounds derived from other model specification or estimation can be misleading if the bounds are not computed specific to the sample size. To overcome these limitations, Pesaran and Pesaran (2009) developed an algorithm which is a built-in function in Microfit 5.01 (and also in Eviews 9.0) that computes the F- and W-statistics and

the corresponding critical bounds at 90 and 95 % levels. The critical bounds are computed by stochastic simulations using 2000 replications with the given sample size. Accordingly, we use Microfit 5.01 to compute the relevant F- and W-statistics and the corresponding sample and model specific critical F- and W-bounds.

2.3.2 The Toda–Yamamoto approach to Granger non-causality

Furthermore, we examine the direction of causality using the Toda and Yamamoto (1995) non-Granger causality tests. It is important to highlight that when the economic series are of different orders, then relying on the error-correction model (ECM) for Granger causality assessment is not recommended, and the standard (pair-wise) Granger causality test may not give robust results since taking the first difference of the series in the effort to achieve stationarity of variables also results in loss of information. In this regards, the Toda and Yamamoto (1995) procedure is extremely useful as it enables one to test for the presence of non-causality irrespective of whether the variables are $I(0)$, $I(1)$ or $I(2)$, not cointegrated or cointegrated of an arbitrary order. Moreover, using this procedure, one can also examine the ‘combined’ or the conjoint effects of the parameters (excluded variables) on the target variable. At best, the statistical significance of the combined variables (all excluded variables) on the target variable indicates that as a group, all excluded variables cause the target variable. Therefore, in case of where any specific excluded variable is not statistically significant can be said to have a ‘weak causation’ on the target variable provided the combined effect (which includes all the individual excluded variables) is statistically significant within the conventional 1–10 % level. In order to carry out the Granger non-causality test, the model is expressed as a vector autoregressive (VAR) system, which is as follows:

$$\begin{aligned} \ln y_t = & \alpha_0 + \sum_{i=1}^k \alpha_{1i} \ln y_{t-i} + \sum_{j=k+1}^{d \max} \alpha_{2j} \ln y_{t-j} + \sum_{i=1}^k \eta_{1i} \ln k_{t-i} + \sum_{j=k+1}^{d \max} \eta_{2j} \ln k_{t-j} \\ & + \sum_{i=1}^k \varphi_{1i} \ln RW_{t-i} + \sum_{j=k+1}^{d \max} \varphi_{2j} \ln RW_{t-j} + \lambda_{1t} \end{aligned} \quad (7)$$

$$\begin{aligned} \ln k_t = & \beta_0 + \sum_{i=1}^k \beta_{1i} \ln k_{t-i} + \sum_{j=k+1}^{d \max} \beta_{2j} \ln k_{t-j} + \sum_{i=1}^k \theta_{1i} \ln y_{t-i} + \sum_{j=k+1}^{d \max} \theta_{2j} \ln y_{t-j} \\ & + \sum_{i=1}^k \vartheta_{1i} \ln RW_{t-i} + \sum_{j=k+1}^{d \max} \vartheta_{2j} \ln RW_{t-j} + \lambda_{2t} \end{aligned} \quad (8)$$

$$\begin{aligned} \ln RW_t = & \gamma_0 + \sum_{i=1}^k \gamma_{1i} \ln RW_{t-i} + \sum_{j=k+1}^{d \max} \gamma_{2j} \ln RW_{t-j} + \sum_{i=1}^k \phi_{1i} \ln y_{t-i} + \sum_{j=k+1}^{d \max} \phi_{2j} \ln y_{t-j} \\ & + \sum_{i=1}^k \mu_{1i} \ln k_{t-i} + \sum_{j=k+1}^{d \max} \mu_{2j} \ln k_{t-j} + \lambda_{3t} \end{aligned} \quad (9)$$

where the series are defined in (7)–(9). The null hypothesis of no-causality is rejected when the p-values fall within the (conventional) 1–10 % of level of significance. Hence, in (7), Granger causality from $\ln k$ to $\ln y$ and $\ln RW$ to $\ln y$ implies $\eta_{1i} \neq 0 \quad \forall i$ and $\varphi_{1i} \neq 0 \quad \forall i$, respectively. Similarly, in (8), $\ln y$ and $\ln RW$ Granger causes $\ln k$ if $\theta_{1i} \neq 0 \quad \forall i$ and

$\vartheta_{1i} \neq 0 \quad \forall i$, respectively; and from (9) $\ln y$ and $\ln k$ Granger causes $\ln RW$ if $\phi_{1i} \neq 0 \quad \forall i$ and $\mu_{1i} \neq 0 \quad \forall i$.

The Toda and Yamamoto (1995) non-Granger causality test requires that the maximum lags should not exceed the sum of the maximum order of integration (d) and the lag-length (l) selected for the ARDL estimation. Moreover, in conducting the causality tests, it is important to examine the properties of inverse roots of the AR (auto-regressive) characteristics polynomial diagram to ensure dynamic stability of the ARDL model. In order to obtain a robust causality result, the inverse roots, I_R , should lie within the positive and the negative unity, that is, $|I_R| \leq 1$. Where the I_R lies outside the unit circle, this needs to be corrected by using either: (1) appropriate lags greater than the ones selected for endogenous variables, (2) trend variable, and/or (3) the structural break period dummies as exogenous (instruments) variables in the VAR equation.

3 Results

3.1 Unit root results

The overall conclusion from the unit root results indicate all variables are stationary at most in their first differences (Table 2), thus indicating the maximum order of integration is 1. We report the structural breaks in the series for respective country samples in Table 3. Notably, in case of China, the structural breaks in the output series at levels are in 2006 and 2007 and in 1988 and 2004 in the first difference, respectively; in capital stock series, break is noted in 1988 and 1989 in levels, and in 1989 and 1992 in the first difference, respectively; in the research publications per worker series, break is noted in 1998 in the level series, and in 1986 and 1995 in the first difference, respectively. In case of USA,

Table 2 Unit root tests results

Variables in log form	ADF		Phillips and Perron		KPSS	
	Level	First difference	Level	First difference	Level	First difference
<i>Panel a: China</i>						
$\ln y$	-3.8561 ^B	-4.1299 ^B	-1.6182	-2.7647 ^C	0.1016 ^A	0.0662 ^A
$\ln k$	-2.1765	-3.7227 ^A	-1.5217	-2.7488 ^C	0.1712 ^C	0.3992 ^B
$\ln RW$	-2.4107	-7.4484 ^A	-2.4962	-7.9202 ^A	0.1281 ^C	0.0487 ^A
<i>Panel b: USA</i>						
$\ln y$	-2.2155	-5.1143 ^A	-0.8899	-5.0934 ^A	0.1408	0.0939 ^A
$\ln k$	-3.3549 ^C	-2.3544 ^C	-1.4203	-1.4852	0.0900 ^A	0.1519 ^A
$\ln RW$	-8.4938 ^A	-3.6669 ^B	-1.9964	-6.0989 ^A	0.1409 ^B	0.2733 ^A

The ADF critical values are based on Mackinnon (1996)

The optimal lag is chosen on the basis of Akaike Information Criterion (AIC)

The null hypotheses for ADF and Phillips–Perron tests are that a series has a unit root (non-stationary) and for KPSS, the series is stationary, respectively

A, B and C denotes 1 5 and 10 % level of significance denotes the rejection (acceptance) of null in case of ADF and Phillips–Perron (KPSS) tests

Table 3 Unit root tests with break in intercept

Variables	Perron (1997)				Zivot and Andrews (1992)			
	Level		1st difference		Level		1st difference	
	PP-stat	T_B	PP-stat	T_B	ZA-stat	T_B	ZA-stat	T_B
Panel a: China								
$\ln y$	-5.1135 [3] ^C	2006	-4.1667 [3]	2004	-5.1292 [3]	2007	-4.7575 [1] ^B	1988
$\ln k$	-8.2515 [1] ^A	1988	-4.9566 [1] ^C	1989	-5.4664 [2] ^A	1989	-5.3748 [3] ^A	1992
$\ln RW$	-3.5336 [0]	1998	-12.871 [0] ^A	1986	—	—	-6.1761 [4] ^A	1995
Panel b: USA								
$\ln y$	-4.9332 [1]	2007	-5.9382 [0]	1991	-3.8090 [1]	2007	-5.6846 [0] ^A	1996
$\ln k$	-4.6288 [1]	2003	-3.9810 [1]	1995	-4.4984 [3]	2003	-3.8384 [1]	1996
$\ln RW$	-12.3948 [4]	1995	-14.5357 [0]	1986	-11.8016 [4]	1995	-7.0778 [0]	1991

T_B break period

A, B and C represents statistical significance at 1 %, 5 % and 10 %, level, respectively

breaks in the output per worker series is noted 2007, in levels, and 1991 and 1996 in the in the first difference, respectively; capital stock series has break in 2003 in the levels and 1995 and 1996 in the first difference series; and research publications per worker series has break in 1995 in the levels and in 1986 and 1991 in the first difference, respectively.

Table 4 Lag length selection

Lag	LL	Adj-LR	FPE	AIC	SC	HQ
Panel a: China						
0	66.66454	—	0.000525	-4.715892	-4.571910	-4.673078
1	68.16199	2.551206	0.000506	-4.752740	-4.560764	-4.695655
2	74.06561	9.620715	0.000353	-5.115971	-4.876001	-5.044615
3	74.66080	0.925858	0.000365	-5.085985	-4.798022	-5.000359
4	79.26215	6.816820 ^A	0.000281 ^A	-5.352752 ^A	-5.016794 ^A	-5.252854 ^A
5	80.26034	1.404852	0.000282	-5.352618	-4.968666	-5.238449
Panel b: USA						
0	65.97746	—	0.000552	-4.664997	-4.521015	-4.622184
1	76.16211	17.35162 ^A	0.000280	-5.345341	-5.153365	-5.288257
2	78.26508	3.427063	0.000259 ^A	-5.427043 ^A	-5.187073 ^A	-5.355687 ^A
3	78.62319	0.557072	0.000272	-5.379496	-5.091532	-5.293869
4	79.85013	1.817690	0.000269	-5.396306	-5.060349	-5.296408
5	80.01216	0.228037	0.000288	-5.334234	-4.950283	-5.220065

Source: Authors' estimation using Eviews 8 and Mfit 5.0

A indicates lag order selected by the criterion, *Adj-LR* adjusted sequential modified LR test statistic (each test at 5 % level), *FPE* final prediction error, *AIC* akaike information criterion, *SC* schwarz information criterion, *HQ* Hannan–Quinn information criterion

Next, we examine the optimum lag-length to be used for the ARDL estimation based on: Adj-LR—lag order adjusted sequential modified LR test statistic (each test at 5 % level), FPE—final prediction error, AIC—Akaike information criterion, SC—Schwarz information criterion, and HQ—Hannan–Quinn information criterion. We note the optimum lag-length that can be selected for ARDL estimation is 4 and 2 for China and USA, respectively (Table 4). We include break period dummy in (7) when carrying out the bounds procedure by setting the break period to one in the respective dummy variable. Testing for its statistical significance in the initial stage of experiment showed that the break period are not statistically significant within the conventional 1–10 % level, and therefore, we did not include the break dummies in the estimations.

From the initial estimations, we note the break periods are not statistically significant and therefore excluded them in the final estimation and reporting. The computed bound F-statistics for China and USA is 8.2253 (Table 5: panel a) and 7.9117 (Table 5: panel b), respectively, which exceed the upper critical bound of F- and W-statistics at 5 % level of significance thus confirming the presence of long-run cointegration.

3.2 Diagnostic results

After confirming the existence of a long-run association, we review the diagnostic tests from the ARDL lag estimates. The ARDL lag estimation results, which precedes the final long-run and short-run estimation is not included here to conserve space, however, we provide the diagnostic results in Tables 6 (Panel a) and 8 (Panel a) for China and USA, respectively. The tests include: Lagrange multiplier test of residual serial correlation (χ_{sc}^2), Ramsey's RESET test using the square of the fitted values for correct functional form (χ_{ff}^2), normality test based on the test of skewness and kurtosis of residuals (χ_n^2) and heteroscedasticity test based on the regression of squared residuals on squared fitted values (χ_{hc}^2). The results show the equations for both China and USA performed relatively well as the disturbance terms are normally distributed and serially uncorrelated with homoscedasticity of residuals (Tables 6, 7). The CUSUM and CUSUM of Squares plot indicates the parameters of the model are stable over time (Figs. 1a, b, 2a, b).

3.3 Short-run and long-run

3.3.1 China

The short-run results for China (Table 6: Panel b) show that the coefficient of research per worker is statistically significant at 10 % level ($\Delta \ln RW = 0.1471$), which implies *ceteris paribus*, a 1 % increase in research publications per worker results in 0.14 % increase in

Table 5 Results of bounds test at 5 % level

Dependent variable/independent variables	F-statistic	W-statistic
$\ln y \ln k, \ln RW$	Panel a: China	
	8.2253 [4.3272, 5.4779]	24.6760 [12.9817, 16.4336]
	Panel b: USA	
	7.9117 [4.2897, 5.4875]	23.7351 [12.8690, 16.4626]

Authors' estimation using Eviews 8 and Mfit 5.0

Table 6 Long-run and short-run results: China

Regressor	Coefficient	Standard error	t-ratio
Panel a: long-run—dependent variable $\ln y$			
$\ln k$	0.7309	0.01492	49.0070 ^A
$\ln RW$	0.4767	0.07873	6.0545 ^A
<i>Constant</i>	2.6823	0.33078	8.1091 ^A
Panel b: short-run—dependent variable ($\Delta \ln y$)			
$\Delta \ln y_{t-1}$	0.9582	0.14678	6.5282 ^A
$\Delta \ln y_{t-2}$	-0.3469	0.11101	3.1249 ^A
$\Delta \ln y_{t-3}$	0.4836	0.11488	4.2093 ^A
$\Delta \ln k_t$	1.2151	0.15782	7.6992 ^A
$\Delta \ln k_{t-1}$	-0.9047	0.19502	-4.6388 ^A
$\Delta \ln RW$	0.1471	0.07205	2.0417 ^C
ECM_{t-1}	-0.6353	0.13100	-4.8496 ^A

Panel a: ARDL(4,2,1); χ^2_{sc} : $\chi^2(1) = 8.7252^A$, $F(1, 17) = 7.6954^B$; χ^2_{df} : $\chi^2(1) = 0.2094$, $F(1, 17) = 0.1281$; χ^2_n : $\chi^2(2) = 0.8262$; χ^2_{hc} : $\chi^2(1) = 0.1102$, $F(1, 26) = 0.10270$; $SER = 0.0086$; $SSR = 0.0013$; $\bar{y}_y = 7.2440$; $\hat{\sigma}_y = 0.7060$; $AIC = 89.7362$; $SBC = 83.0752$; $LL = 99.7362$; $F - Stat.(9, 18) = 20381.2$; $DW - stat. = 2.8698$

Panel b: $R^2 = 0.92$; $\bar{R}^2 = 0.88$; $\bar{x}_{\Delta y} = 0.0855$; $\hat{\sigma}_{\Delta y} = 0.0247$; $F - Stat.(7, 20) = 29.3876$

A and C represents statistical significance at 1 % and 5 % level, respectively

short-run output per worker; The net effect of capital per worker is 0.3104 ($\Delta \ln k_t = 1.2151$; $\Delta \ln k_{t-1} = -0.9047$). The error correction term ($ECT_{t-1} = -0.6353$), which measures the speed at which prior deviations (errors) from equilibrium are corrected, has correct (negative) sign and is statistically significant at 1 % level. As noted, the error correction coefficient indicates that about 64 % of previous period errors is corrected duly indicating a relatively speedy convergence to long-run equilibrium.

From the long run results (Table 6: panel a), we note that capital share ($\ln k = 0.7309$) has the dominant contribution to the long-run economic activity in China. In other words, the capital share is positive and about 0.73. Notably, the coefficient of research is positive and significant in the long run ($\ln RW = 0.4767$). Hence, a 1 % increase in research publications per worker, *ceteris paribus*, results in about 0.48 % increase in output per worker.

3.3.2 USA

In the short-run (Table 7: panel a), we note a positive and statistically significant coefficient of research publication per worker in USA ($\Delta \ln RW_t = 0.0652$). In other words, a 1 % increase in research publication contributes about 0.07 % to output per worker, *ceteris paribus*. Notably, the net effect of capital per worker is positive (1.0946) ($\Delta \ln k_t = 2.6845$; $\Delta \ln k_{t-1} = -1.5899$), and statistically significant at 1 % level. The error correction term ($ECT_{t-1} = -0.3704$) has a correct (negative) sign and is significant at 1 % level duly indicating the correction of roughly 37 % of deviations from the previous (lag-one) period errors.

The long-run results (Table 7: panel a) for USA show the coefficient of research is positive and statistically significant ($\ln RW = 0.1760$) at 1 % level. In other words, the research contributes about 0.18 % to long-run output, holding other things constant. The coefficient of capital per worker is about 0.64 ($\ln k = 0.6367$) and is statistically significant at 1 % level, indicating that capital productivity has a dominating effect on long-run growth.

Table 7 Long-run and short-run results: USA

Regressor	Coefficient	Standard error	t-ratio
Panel a: long-run—dependent variable ($\ln y$)			
$\ln k$	0.6367	0.01299	49.0042 ^A
$\ln RW$	0.1760	0.03606	4.8802 ^A
<i>Constant</i>	4.0825	0.14885	27.4261 ^A
Panel b: short-run—dependent variable ($\Delta \ln y$)			
$\Delta \ln k_t$	2.6845	0.1768	15.1872 ^A
$\Delta \ln k_{t-1}$	-1.5899	0.1779	-8.9376 ^A
$\Delta \ln RW$	0.0652	0.0221	2.9490 ^A
ECM_{t-1}	-0.3704	0.0750	-4.9407 ^A

Panel a: ARDL(1,2,0); χ^2_{sc} : $\chi^2(1) = 0.5000$, $F(1, 23) = 0.3898$; χ^2_{ff} : $\chi^2(1) = 6.5825^B$, $F(1, 23) = 6.4652^B$; χ^2_n : $\chi^2(2) = 1.7531$; χ^2_{hc} : $\chi^2(1) = 0.5061$, $F(1, 28) = 0.4808$; $SER = 0.00492$; $SSR = 0.0006$; $\bar{x}_y = 10.9752$; $\hat{\sigma}_y = 0.1569$; $AIC = 114.2217$; $SBC = 110.0181$; $LL = 120.2217$; $F - Stat.(5, 24) = 5894.6$; $DW - stat. = 2.1311$

Panel b: $R^2 = 0.94$; $\bar{R}^2 = 0.93$; $\bar{x}_{\Delta y} = 0.0179$; $\hat{\sigma}_{\Delta y} = 0.0184$; $F - Stat.(4, 25) = 95.8258$

A represents statistical significance at 1 % level

3.4 Granger causality results

From the unit root results (Tables 2, 3), we note that the maximum order of integration is 1 ($d_{max} = 1$), and using a set of criteria (Table 4: panel a, b), the optimal lag length (k) chosen is 4 for China and 2 for USA. Hence the maximum lags (l) that can be used to carry out the non-causality tests is 5 ($l = d_{max} + k \leq 5$ and 3 ($l = d_{max} + k \leq 3$ for China and USA, respectively. Given the maximum limits on lag-length for causality, we set $l = 1$ for China and $l = 3$ for USA, since these lags ensured that the causality model is dynamically stable, that is $|I_R| \leq 1$. The results of the causality tests are presented in Table 8 (panel a, b).

For China (Table 8: panel a), we find a bidirectional causality between output per worker, capital per worker and research publications per worker ($\ln y \leftrightarrow \ln k$; $\ln y \leftrightarrow \ln RW$; $\ln k \leftrightarrow \ln RW$). In other words, all variables are mutually reinforcing each other.⁷ In case of USA, we find a bi-directional causation between output per worker and capital per worker ($\ln y \leftrightarrow \ln k$); and a unidirectional causation from output per worker and research publications per worker ($\ln y \rightarrow \ln RW$)⁸ and from capital per worker to research publications per worker ($\ln k \rightarrow \ln RW$), respectively.

4 Conclusions and limitations

In this article, we use an approach introduced by Sturm et al. (1998) and Rao (2010) which are related to the augmented Solow (1956) framework and the ARDL bounds procedure to examine the effects of research publications per worker on output per worker for China and USA, which are the two leading economies in research of scientific and technical papers as a percent of World. The scientific and technical journal articles (research publications)

⁷ Our result for China is in contrast to Inglesi-Lotz et al. (2015), which find no causality between research output and GDP for China.

⁸ Our result for USA is similar to Inglesi-Lotz et al. (2014), which find a unidirectional causation from research output to GDP.

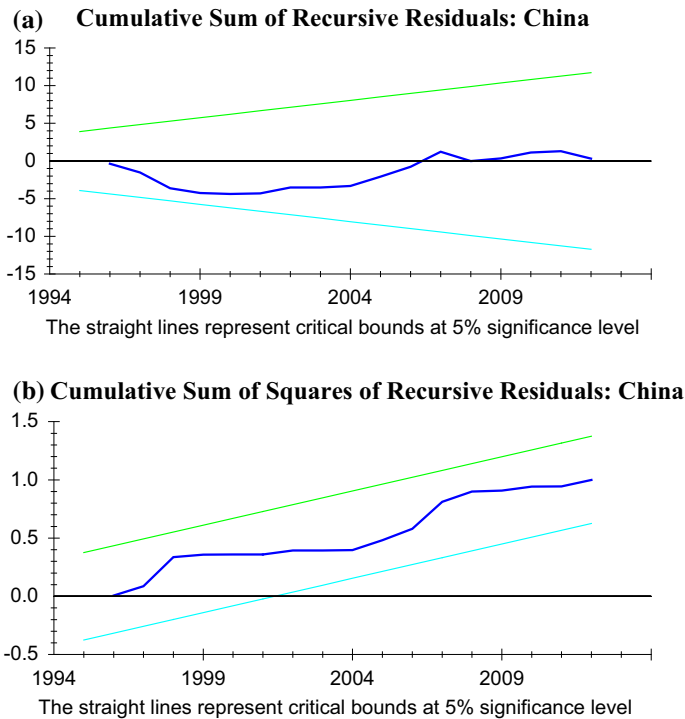


Fig. 1 **a** Cumulative sum of recursive residuals: China, **b** cumulative sum of squares of recursive residuals: China

includes the number of scientific and engineering articles published in the fields of physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences which are counted from, journals classified by the Institute for Scientific Information's SCI and SSCI (World Bank 2013). The results show evidence of cointegration and hence long-run association between research publications per worker and output per worker for both USA and China. Moreover, we note that the impact of research publications per worker is positive and statistically significant both in the short-run and the long-run for the two countries.

The causality nexus using the Toda and Yamamoto procedure show bidirectional causalities between output per worker, capital per worker and research publications per worker for China. In case of USA, we note a bidirectional causality between output per worker and capital per worker and a unidirectional causality from output per worker to research publications per worker, duly emphasizing the output Granger cause research.

The study highlights the significance of research output in the growth process and the subsequent need to maintain the momentum of knowledge creation innovation and accumulation through research publications. In regards to policy, a developing, large and emerging economy like China can leverage from research by devoting more resources in producing scientific research as well as applying the knowledge into productive activities. In case of USA, which is the world leader in research and innovation, progress in research will not only benefit the economy but also help other countries and especially the developing economies which continue to benefit from knowledge creation and innovation in

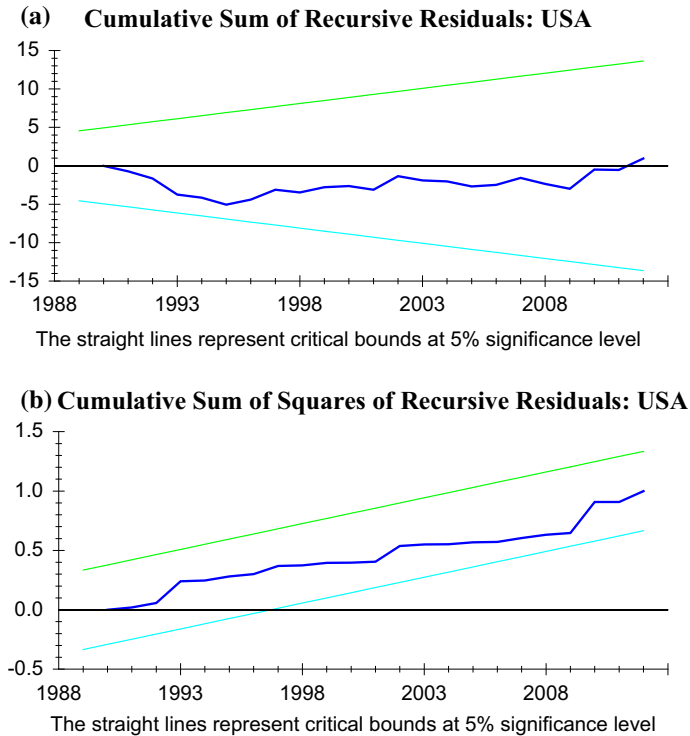


Fig. 2 **a** Cumulative sum of recursive residuals: USA, **b** cumulative sum of squares of recursive residuals: USA

science and technology emanating from USA. The positive effect of research both in the short-run and long-run shows USA economy is well placed in expanding frontiers in scientific knowledge and innovation.

Having discussed the results, we would like to highlight the plausible caveats to our results. First, the estimated capital share for both countries are different from the stylized value of one-third which is due to a couple of reasons: when (a) the capital and labor inputs tend to grow at relatively similar rates; (b) an economy is predominantly developing and hence a large number of self-employed persons earn income from both capital and their own labor (Gollin 2002) thus making it difficult to obtain meaningful measures of income shares; and (c) the quality and availability of data is weak and therefore making it difficult to compute or estimate the capital stock per worker (Bosworth and Collins 2008) that can perfectly exhibit decreasing returns to scale and conform to a desirable steady-state convergence process. We concur to all these reasons in case of this study. We used the scientific and technical publications per worker as a proxy of creativity, innovation and knowledge creation which has the characteristics of a public good. Our analysis and results suggests that research plays an important role for the economic growth at least in large economies like China and USA. To what extent our result are transferable to small economies, or to the rest of the world for that matter is not clear because country-specific characteristics will play a significant role and also in some cases, countries are likely to benefit from the research done in relatively advanced economies.

Table 8 Granger non-causality test for China and USA

Excluded variable	Panel a: Dependent variable (χ^2)—China		Panel b: Dependent variable (χ^2)—USA	
	ln y	ln k	ln y	ln k
ln y \rightarrow		15.3165 ^A (0.0001)		15.6195 ^A (0.0014)
ln k \rightarrow	3.6604 ^C (0.0557)	—	—	13.6304 ^A (0.0035)
ln RW \rightarrow	4.0486 ^B (0.0442)	5.2229 ^B (0.0223)	6.6565 ^C (0.0837)	8.7756 ^B (0.0324)
Combined	4.8366 ^C (0.0891)	15.6999 ^A (0.0004)	9.1134 (0.1673)	1.3379 (0.7202)
		18.47903 ^A (0.0001)	18.2849 ^A (0.0056)	17.9638 ^A (0.0063)

df = 2 for China and df = 3 for USA

The ' \rightarrow ' indicates causality running from the excluded variable to dependent variables at A = 1 %, B = 5 %, and C = 10 % level of significance respectively; p values are in the parenthesis

Finally, although we find that research have a growth enhancing effect, it is important to highlight that scientific publication per se is only an indicator of creativity and innovation (or novel contributions) which adds to the body of knowledge. Subsequently, a country's strength in translating or transmitting a scientific research or technical knowledge into productive uses and products will support growth in income and output in general. In this regard, the speed, accuracy and appropriate resources to translate and transmit the knowledge will be a critical decider of short-run and long-run growth. Hence, research in this direction with respect to other countries in the continuum of developed and developing and the use of alternative proxies for research (such as R&D expenditure) will provide greater insights on the impacts of research on economic growth. Additionally, determining the optimal level of scientific research of many developed countries will be an important area of future research since many developed countries (and the universities) in general over the last 30 years, have experienced a reduction in investments in public capital (Romp and de Haan 2007). It is also important to highlight that the research measured by the scientific and technical publications are research papers primarily written in English and excludes disciplines falling into social science and multidisciplinary areas. In this regard, we expect our results to only partially capture the role of research in influencing economic activities. On aggregate, we argue that scientific research is likely to support economic growth and that the country-specific effects may differ across the globe due to the priority given, resources allocated to, and the effective implementation of the scientifically researched and innovative ideas.

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