Journal of Institutional Economics (2023), **19**, 526–547
doi:10.1017/S1744137422000509

CAMBRIDGE UNIVERSITY PRESS

RESEARCH ARTICLE

Frontier academic research in OECD countries: the role of institutional factors

Thanh Le[1]*, Ngoc Vu Bich[2] and Sau Mai[3]

[1]School of Business, Faculty of Business and Law, University of Wollongong, Northfields Avenue, NSW 2522, Australia, [2]Ho Chi Minh City Open University, Ho Chi Minh City, Vietnam and [3]Academy of Policy and Development, Hanoi, Vietnam
*Corresponding author. Email: thanhl@uow.edu.au

(Received 2 November 2021; revised 2 December 2022; accepted 2 December 2022; first published online 6 January 2023)

Abstract

This paper examines the effect of frontier academic research on technological development and the way institutional quality influences this impact. Using a dataset that covers 18 OECD countries over the 2003–2017 period, we find that frontier academic research exerts an important influence on total factor productivity. First, frontier academic research induces technological change by directly enhancing production processes and management methods. Second, frontier academic research stimulates industrial innovations, which in turn improves productivity. Regarding the moderating effect of institutional variables on these relationships, we find that positive moderation only exists for some, not all, of the institutional variables. In that case, a higher level of these variables is found to strengthen the way countries reap benefits from frontier academic research and industrial innovation. However, the moderation of institutions is much less clear with the process that turns frontier academic research into industrial innovations.

Keywords: Frontier academic research; industrial R&D; institutions; total factor productivity

JEL Classification: O32; O33; O43; O47

1. Introduction

R&D-based endogenous growth models, starting with Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992), have demonstrated that technological progress relying on cumulative R&D expenditure accounts for much of output growth in the last century. Given that this proposition is mostly about industrial R&D, it raises an intriguing question about the contributions of academic research to this economic development process. In the OECD area, member countries have injected substantial funding into research conducted in academia every year (OECD, 2021). Many economists have attempted to explore the effect of academic research on our economy and society. So far, the results obtained are mixed. In particular, there are several papers that find evidence on the spillovers from academic research to industrial innovations (e.g. Cohen *et al.*, 2002; Jaffe, 1989; Le *et al.*, 2022). Studies by Mansfield (1991, 1998) indicate the important role of academic research in developing new products and processes, as well as in contributing to greater social benefits. Meanwhile, there are also studies that report a negative relationship between scientific research and innovative output produced by the industry (e.g. Gittelman and Kogut, 2003; Partha and David, 1994). Those that advocate academic research point out that, thanks to its widespread through publications in scientific journals, academic research knowledge resembles a public good and creates important scientific foundations for technological progress in the industry. Besides scientific papers channel, this knowledge can diffuse to industrial production in other ways, such as through the mobility of students and scientists (Zucker *et al.*, 2002), R&D collaborations between universities and companies (Jaffe *et al.*, 1993) or direct licensing from universities to private firms (Jensen and Thursby, 2001; Thursby and Kemp, 2002). This diffusion process can help enhance productivity (Le *et al*., 2022). In that respect, Berggren and Bjornskov (2022) point out that academic freedom is beneficial for long-term economic development because it allows creative and productivity-enhancing ideas to be developed and diffused to the industry without interference. Meanwhile, proponents of academic research argue that academic research is mostly aimed at recognition and promotion in academia and, hence, has little economic value (Dasgupta and David, 1994). This means that the issue on the role of academic research, especially academic research at the top or frontier level, in affecting economic performance continues to be a highly debatable topic.

Against this background, the main goal of this paper is to shed further light on the debate about the role that frontier academic research plays in affecting total factor productivity (TFP). Our argument is that frontier academic research is not just limited within the aim of promoting the reputation of the authors, but more importantly, it paves the way for industrial innovations to flourish, which in turn improves technological development. Using a dataset that covers 18 OECD countries over the 2003–2017 period, we find evidence that frontier academic research exerts an important effect on TFP. We find statistical support to the direct effect of frontier academic research on TFP. We also find significant evidence that frontier academic research affects TFP via the industrial R&D channel. As such, our empirical results confirm that industrial R&D is an important conduit through which frontier academic research induces TFP.

In examining the conversion from research and innovation into technological progress, we extend our empirical analysis to consider the impact of institutional factors on these processes. In that respect, our purposes are twofold: (i) evaluating the impact of institutional factors on the degree to which frontier academic research is absorbed into industrial innovation; and (ii) assessing the extent to which industrial R&D is materialised into TFP. We focus on the economic aspect of institutional quality by using an index of economic freedom and different dimensions of this index. This index is composed by the Fraser Institute in an attempt to measure the degree to which an economic and political system allows people to specialise and trade.[1] We find that countries with a relatively higher level of economic freedom tend to reap more benefits from frontier academic research. However, different dimensions of economic freedom alter the way countries enjoy the benefit from frontier academic research differently. On the frontier academic research and industrial R&D nexus, there is little evidence that institutional quality enhances the efficiency of the process that turns frontier academic research into industrial innovations. Regarding the effect of industrial innovations on TFP, we find that the effect is strengthened with an increase in the degree of economic freedom. Nevertheless, the corresponding moderating effect of different components of this index is mixed. In particular, while the moderation is positive and significant with government size and the conduct of monetary policy, it is negative and significant with the protection level of private property rights. As for free trade and limited regulation measures, the moderating effects are insignificant.

Our paper contributes to two different strands of literature. *First*, it contributes to the literature examining the economic impact of academic research. These studies indicate several ways through which academic research can induce technological change such as education and training (e.g. Bekkers and Freitas, 2008; Jones and de Zubielqui, 2017; Rosenberg and Nelson, 1994), university–firm research collaborations (e.g. Acs *et al*., 1992; Audretsch *et al*., 2012; Cohen *et al*., 2002; Faulkner and Senker, 1994; Lai, 2011; Thursby and Kemp, 2002; Wirsich *et al*., 2016) and academic publications (e.g. Audretsch, 2013; Lundberg, 2017; Zucker *et al*., 1998). *Second*, this paper contributes to the literature considering the impact of institutional factors on economic development. According to Guellec and van Pottelsberghe de la Potterie (2004), institutional settings affect the contribution of knowledge to productivity. Tebaldi and Elmslie (2013) and Krammer (2015) point out that the effects of institutional quality on R&D activities and economic performance vary across countries and institutional elements. Taking Chinese economy as an example for a transitional economy, a study by Hou

[1]More details on the composition of this index are provided in Section 2.

et al. (2021) shows that poor institutional quality such as administrative interventions and limited degrees of freedom can adversely affect the universities' tendency to explore technology transfer channels and conduct academic entrepreneurship actively. Meanwhile, better institutions with a more business-friendly environment and lower barriers to trade and investment may amplify the positive impact of R&D spending on multi-factor productivity (Égert, 2016). Similarly, strong judicial accountability is an important condition for academic freedom to contribute to economic growth (Berggren and Bjornskov, 2022). Although there is a growing body of literature confirming institutions as deep determinants of growth (e.g. Acemoglu *et al.*, 2001; Rodrik *et al.*, 2004), a much smaller number of papers attempt to investigate the roles of institutions within an R&D-based context. Notable exceptions include Coe *et al.* (2009) and Krammer (2015) with an assessment of how institutions affect R&D spillovers. They find that a higher quality of institutions is associated with larger international R&D spillovers. To a broader extent, given that a large proportion of academic R&D comes under the form of public investment, this paper is also related to the literature assessing the productivity effect of public R&D (e.g. Guellec and van Pottelsberghe de la Potterie, 2004; Soete *et al.*, 2020a, 2020b). Studies in this strand of literature point out the important complementarity between public and private R&D.

Our paper proceeds as follows. In section 2, we describe data collection as well as the way we construct data series for the empirical investigation. We also present summary statistics of the data used. In section 3, we discuss our empirical strategy. We conduct some preliminary data analysis using panel cointegration in section 4. In section 5, we present estimation results on the nexus among frontier academic research, industrial R&D and TFP. While section 6 is devoted to the examination of the moderating effects of institutions, section 7 discusses robustness check results. We end the paper with some concluding remarks in section 8.

2. Data construction and summary statistics

2.1. The measures of frontier academic research

Our measure of national frontier academic knowledge is computed based on the data on research capability of Top 500 universities worldwide known as Academic Ranking of World Universities (ARWU) published by Shanghai Jiaotong University (since 2003).[2] Research strengths of universities are assessed and scored according to six indicators: the number of alumni awarded Nobel prizes and Fields medals, the number of staff awarded Nobel prizes and Fields medals, the number of highly cited researchers, the number of papers published in *Nature* and *Science*,[3] the number of papers indexed in Science Citation Index (Expanded) and Social Science Citation Index, and the per capita academic performance of these indicators. Although more than 1,000 universities are surveyed each year, only the rankings and scores accompanying the rankings of the Top 500 universities are reported. Among these indicators, it is arguable that for academic knowledge, publications are the most influential factors on technological development. On this ground, we focus on the scores on indexed publications.[4] If we denote Pub_{kjt} as publication scores for ARWU-listed university k that is located in

[2]Besides the ARWU, other comparable datasets of similar scale includes the World University Rankings published by the Times Higher Education (THE) and the QS World University Rankings published by Quacquarelli Symonds (QS). Among those indicators used to assess the performance of universities worldwide, the QS and the THE also include some subjective measures such as academic peer review and employer peer review (QS) or research reputation peer review (THE). Their data series is only available from 2011 for the THE and 2012 for the QS (before this time only the rankings were made available, not the scores).

[3]For universities with high specialisation in humanities and social sciences, the weight of this indicator is allocated to other indicators.

[4]Billaut *et al.* (2010) point out several problems associated with the way the ARWU measure is calculated including a flawed aggregation technique. While we do not dispute with the authors of that paper on these problems, we decide to proceed with the resources associated with the ARWU ranking given the unavailability of a better alternative measure. To overcome the aggregation flaw, we only use the publication component. Doing so will also allow us to focus on academic research output.

country j and in year t, by aggregating the scores of all listed universities for each country over the same year we obtain the national stock of frontier academic publications as follows:

$$Pub_{jt} = \sum_k Pub_{kjt}. \quad (3)$$

This variable is considered to contain a substantial level of frontier academic knowledge as it measures academic research conducted at leading academic institutions in the world.[5]

2.2. The measure of industrial R&D

To construct the measure of industrial R&D, we follow the steps of calculating total R&D capital stocks suggested by Coe and Helpman (1995) and used by subsequent papers (e.g. Bayoumi *et al.*, 1999; Engelbrecht, 1997; Le, 2008, 2010, 2022; Le and Bodman, 2011) in the R&D-based growth literature. After getting data on nominal industrial R&D expenditure from OECD Statistical Database, we deflate it by an R&D price index to generate real R&D expenditure, *RD*, before moving on to calculate the R&D capital stock, *SD*, such that $SD_{it} = (1 - d)SD_{it-1} + RD_{it-1}$ (the depreciation rate d is chosen to be 5%). The stock at the beginning of the period is specified as $S_{i0} = RD_{i0}/d + g$ where g is the annual average growth rate from 2003 to 2017 generated within the data.

2.3. The measures of institutional quality

To characterise institutions, we collect data on the degree of economic freedom of countries on a 0–10 scale composed by the Fraser Institute. This measure of institutions has been used extensively for conducting institutional analysis (e.g. Berggren and Nilsson, 2021; Bergh, 2020; Dean and Geloso, 2022; Graafland, 2020; Kufenko and Geloso, 2021; Moellman and Tarabar, 2022). The index is calculated based on 41 indicators that can be categorised into five different areas: (i) government size (government spending, tax burden and fiscal health); (ii) private property rights (property rights, government integrity and judicial effectiveness); (iii) sound money (monetary policy and control of inflation); (iv) free trade (tariffs, quotas, financial capital controls and international travel); and (v) limited regulations (business freedom, labour freedom and monetary freedom). We will first consider the effect of institutions through the use of the aggregate index before examining each area of specialisation in greater details as each aspect of institutions is likely to affect innovation and technological development path in a different way.

2.4. The measure of total factor productivity

We use TFP to proxy for technological improvement of a country because this is the factor that explains cross-country differences in GDP per capita over the last century (Caseli, 2005; Hall and Jones, 1999). To calculate this variable, we start with the Cobb–Douglas production function: $Y_{it} = F_{it}K_{it}^{\gamma}L_{it}^{1-\gamma}$ where Y_{it} is the value-added, F_{it} is TFP, K_{it} is capital stock and L_{it} is employment in the business sector. Data for Y, K and L are extracted from the World Development Indicator Database provided by the World Bank. From this data series, we regress the value-added on capital stock (constructed from data on capital formation) and employment to get γ. After that, we calculate TFP for each country in the sample using the following formula: $\log(F_{it}) = \log(Y_{it}) - \gamma\log(K_{it}) - (1 - \gamma)\log(L_{it})$. The computed series is then converted to an index in which the value in 2011 is set equal to one.[6]

[5]As an output-based measure, our frontier academic knowledge indicator is comparable to the one used by Kerr (2010) that focuses on the top 1% of US patents. Because not all research output is patented, our measure is expected to cover the missing bit in the form of top-level academic publications.

[6]Our regression results are unaffected by this choice of the base year.

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

2.5. Other variables

Data on human capital stock are extracted from the Penn World Table (version 9.0). This variable will be used as a control variable in all of our regressions. Available data include an index of human capital per person, which is computed based on information on average years of schooling as per Barro and Lee (2013) as well as that on return to education as per Psacharopoulos (1994).[7]

Another control variable is trade openness. According to Miller and Upadhyay (2000), larger trade facilitates the adoption of more efficient techniques of production leading to faster growth of TFP. We collect data on trade openness (i.e. sum of exports and imports) as percentage of GDP from the World Bank.

We establish our sample based on the conditions that the selected countries must have had a large number of universities listed in the ARWU over the whole 2003–2017 period. They also need to have recorded data on industrial R&D expenditure. In the end, we obtain a balanced panel data set that covers 18 OECD countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom and the United States.

2.6. Summary statistics

In Table 1, we provide a summary of key data series for 18 OECD countries over the 2003–2017 period. It can be seen that TFP slightly decreased in most countries except for Finland, Ireland, Netherlands and Spain where there was a small increase and Norway and the US with roughly no change. Meanwhile, industrial R&D capital stock increased substantially in all countries with highest increment recorded in Denmark, followed by Ireland and Australia. By contrast, Japan and Italy experienced the slowest expansion of industrial R&D.

Changes in frontier academic publication scores are not as dramatic as industrial R&D. While Australia experienced the fastest expansion of more than twofold, Japan and Italy faced a sharp fall of this research stock. Other countries are divided, either enjoying a slight increase in scores, like Belgium or Denmark, or seeing a small downturn, like Canada or the UK.

As for human capital stock, all countries had moderate improvements. These improvements exhibit a somewhat homogeneous pattern across countries. Italy and Spain enjoyed the largest increases while Australia and Germany only had modest rises.

Turning to trade openness as a percentage of GDP, all countries experienced substantial improvements over the time horizon except for Canada with a small decrease. The biggest winner is Japan, followed by Ireland and Germany.

Regarding variables capturing institutional quality, change in the aggregate index of economic freedom, alongside with that for the five component areas, is reported for all countries in the sample. No single countries advanced in all areas of consideration although they made some improvements overall. Countries that enjoyed biggest increments overall include Australia, Germany and Norway. Meanwhile, the UK, Spain and the US are those experiencing most deterioration in the aggregate index.

3. The empirical model

Our interest is to investigate the way through which frontier academic knowledge contributes to technological development of a country and how institutional quality affects this process. Because academic research is often considered to provide basic scientific results that lay the foundation for technology to flourish, we hypothesise that frontier academic knowledge exerts its effect on technological improvement through different channels. In the direct channel, frontier academic research stimulates

[7]An important aspect of human capital is cognitive skills (Hanushek and Woessmann, 2008; Hanushek *et al.*, 2015). Existing data sets (e.g. PIAAC or PISA) in this direction mostly rely on academic tests. While they somewhat capture the quality of education, they are essentially an 'input' measure. By contrast, the data series used in this paper is an 'output' measure that captures both quantity and quality of education and perhaps the on-the-job training aspect of human capital.

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

Table 1. Summary statistics

	The ratios of 2017–2003										
Country	*F*	*SD*	*Pub*	*Hucap*	*Open*	*Gov*	*PPR*	*Money*	*Trade*	*Reg*	*EF*
Australia	0.998	1.849	2.021	1.005	1.042	1.042	0.982	1.031	1.038	1.033	1.024
Austria	0.998	1.473	0.839	1.061	1.214	1.003	1.011	0.956	0.945	0.988	0.978
Belgium	0.997	1.389	1.073	1.035	1.246	0.930	1.093	0.954	0.940	1.036	0.989
Canada	0.944	1.647	0.915	1.044	0.932	0.990	1.045	1.037	0.882	1.027	0.996
Denmark	0.999	2.134	1.205	1.066	1.273	1.092	0.957	1.014	0.966	1.040	1.005
Finland	1.006	1.449	0.872	1.086	1.103	0.975	0.984	0.956	0.947	1.041	0.979
France	0.999	1.339	1.091	1.085	1.239	1.078	1.058	0.968	0.954	1.017	1.005
Germany	0.996	1.351	0.836	1.022	1.410	0.986	0.967	0.966	0.921	1.300	1.013
Ireland	1.010	2.045	1.192	1.083	1.502	1.046	1.022	0.961	0.951	1.029	0.997
Italy	0.999	1.108	0.772	1.100	1.270	0.951	0.982	0.965	1.001	1.155	1.008
Japan	0.999	1.054	0.482	1.054	1.614	0.899	0.979	0.990	0.975	1.098	0.991
The Netherlands	1.004	1.410	1.101	1.059	1.394	1.004	1.010	0.965	0.985	1.052	1.001
Norway	1.000	1.607	1.248	1.068	1.039	1.066	0.978	1.066	0.937	1.023	1.009
Spain	1.010	1.545	1.015	1.097	1.247	0.881	1.021	0.958	0.942	1.093	0.976
Sweden	0.997	1.373	1.033	1.057	1.129	1.068	0.971	0.970	0.952	1.077	0.998
Switzerland	0.998	1.624	1.141	1.036	1.338	0.989	1.003	1.031	0.874	1.039	0.987
UK	0.994	1.521	0.995	1.054	1.225	0.944	0.970	1.015	0.914	1.000	0.970
US	1.000	1.498	0.891	1.036	1.200	0.934	0.945	0.998	0.953	1.042	0.977

Notes: *F*, *SD*, *Pub*, *Hucap* and *Open* are TFP index, industrial R&D, frontier academic publication scores, human capital and trade openness respectively. *EF* denotes the aggregate index of economic freedom that consists of five different areas: *Gov* (government size), *PPR* (private property rights), *Money* (sound money), *Trade* (free trade) and *Reg* (limited regulations).

technological progress by directly providing knowledge that helps improve management efficiency and production methods. Meanwhile in the indirect channel, the contribution of frontier academic knowledge is seen through its stimulation to industrial R&D and innovations, which, in turn, enhances technological change.[8] In both processes, institutions can matter as they may create either barriers or opportunities for research (either academic or industrial) to materialise into technological improvement. Figure 1 below provides a graphical representation of the channels.

Path A in the figure captures the total effect of frontier academic knowledge on TFP. To explore this path, we run the following regression:

$$\log(F_{it}) = \alpha_i + \alpha_1 \log(Pub_{i,t-2}) + \alpha_2 INS_{i,t-1} + \alpha_3 INS_{i,t-1} \times \log(Pub_{i,t-2}) + \delta X_{i,t-1} + \gamma_t + \varepsilon_{i,t}, \quad (4)$$

where F is the TFP index, Pub is the frontier academic research capital stock measured in terms of publication scores, INS is an indicator of institutional quality, X is the vector of control variables such as stock of human capital and trade openness, α_i is a country fixed effect that picks up effects of time-invariant factors on technological progress such as culture or climate, γ_t is a time fixed effect that absorbs time-varying characteristics such as macroeconomic shocks, and ε is an error term. Given that frontier academic research is not performed by the industry, a longer delay is expected before it can affect technological level so it enters the equation with a 2-year lag.[9]

Path B implies that frontier academic knowledge may induce industrial R&D with the moderating effect of institutions. To examine this possibility, we put forward a regression equation as follows:

$$\log(SD_{i,t-1}) = \alpha_i + \alpha_4 \log(Pub_{i,t-2}) + \alpha_5 INS_{i,t-1} + \alpha_6 INS_{i,t-1} \times \log(Pub_{i,t-2}) + \gamma_t + \varepsilon_{i,t}, \quad (5)$$

where SD is the measure of industrial R&D capital stock.

Path C in the figure helps reveal the impact of industrial R&D on TFP. This path can be explored by the regression equation below:

$$\log(F_{it}) = \alpha_i + \beta_1 \log(SD_{i,t-1}) + \beta_2 INS_{i,t-1} + \beta_3 INS_{i,t-1} \times \log(SD_{i,t-1}) + \delta X_{i,t-1} + \gamma_t + \varepsilon_{i,t}. \quad (6)$$

The direct effect of frontier academic knowledge on TFP is captured by path D with the following regression equation:

$$\log(F_{it}) = \alpha_i + \beta_4 \log(SD_{i,t-1}) + \alpha_7 \log(Pub_{i,t-2}) + \alpha_8 INS_{i,t-1} + \beta_5 INS_{i,t-1} \times \log(SD_{i,t-1}) + \alpha_8 INS_{i,t-1} \times \log(Pub_{i,t-2}) + \delta X_{i,t-1} + \gamma_t + \varepsilon_{i,t}. \quad (7)$$

4. A preliminary analysis using panel cointegration

In this paper, we will conduct our estimation using panel cointegration methods. Since inception, panel cointegration has been used widely in the R&D-based growth literature to establish long-run relationship between non-stationary variables (Coe *et al.*, 2009; Coe and Helpman, 1995; Le, 2010, 2012; Le *et al.*, 2022). For that purpose, we first implement panel unit root tests on the variables. At 10% level of significance, Hadri's (2000) and Im *et al.*'s (2003) tests, reported in Table 2, indicate

[8]The issue of direct and indirect effects of public R&D investment is also discussed in Jaumotte and Pain (2005a, 2005b) when analysing 19 OECD countries over the period 1982–2001.

[9]Hall *et al.* (2010) provide a summary on lag distribution of R&D variables implemented by existing studies, ranging from as short as 1.2 years to as long as 30 years. Because our R&D variables are stock variables, the chosen lag structure seems appropriate. On another note, we also run the regressions using other lag length specifications but opt not to report their results here to save space. The results, which are qualitatively the same as those reported in the paper, are available upon request.

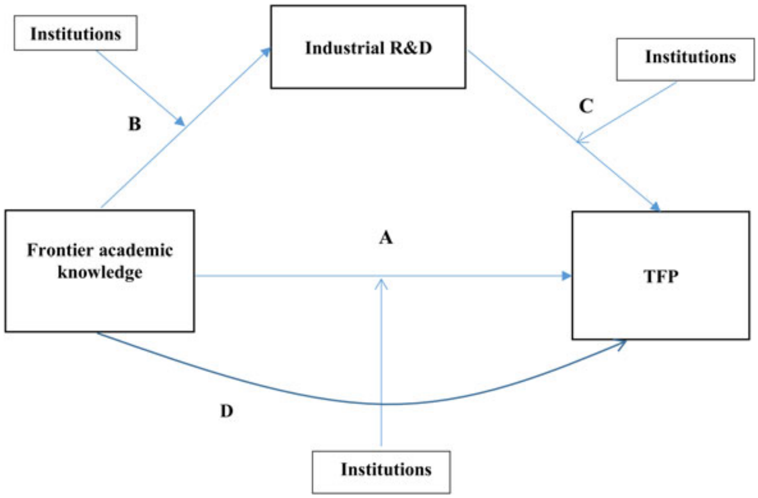

Figure 1. Influencing mechanism of frontier academic research on TFP in the presence of institutions.

Table 2. Panel unit root tests (at 10% level of significance, 18 countries, 2003–2017)

	Hadri's (2000) test		Im *et al.*'s (2003) test		
Variable	Statistics	Implication	Statistics	Implication	Decision
log (*F*)	4.652 (0.000)	*I*(1)	−1.517 (0.065)	*I*(1)	*I*(1)
log (*SD*)	12.464 (0.000)	*I*(1)	1.607 (0.946)	*I*(1)	*I*(1)
log (*Pub*)	10.030 (0.000)	*I*(1)	2.337 (0.990)	*I*(1)	*I*(1)
log (*Hucap*)	12.324 (0.000)	*I*(1)	2.037 (0.979)	*I*(1)	*I*(1)
log (*Open*)	7.159 (0.000)	*I*(1)	−2.532 (0.006)	*I*(0)	*I*(1)
log (*EF*)	2.812 (0.003)	*I*(1)	−2.949 (0.002)	*I*(0)	*I*(1)
log (*Gov*)	3.548 (0.000)	*I*(1)	−1.936 (0.027)	*I*(0)	*I*(1)
log (*PPR*)	3.530 (0.000)	*I*(1)	−2.440 (0.007)	*I*(0)	*I*(1)
log (*Money*)	1.712 (0.043)	*I*(1)	−1.439 (0.075)	*I*(1)	*I*(1)
log (*Trade*)	4.852 (0.000)	*I*(1)	−6.772 (0.000)	*I*(0)	*I*(1)
log (*Reg*)	3.820 (0.000)	*I*(1)	−1.009 (0.157)	*I*(1)	*I*(1)

Notes: log (*X*) is log of *X*; *F*, *SD*, *Pub*, *Hucap* and *Open* are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. Among institutional quality variables, while *EF* denotes aggregate index of economic freedom, *Gov*, *PPR*, *Money*, *Trade* and *Reg* denote different sub-components of this index including government size, private property rights, sound money, free trade and limited regulations. *p*-Values are in parentheses. *I*(0) and *I*(1) indicate the non-existence and existence of a unit root respectively.

the overall non-stationarity on the majority of variables. There are a few exceptions including trade openness as a percentage of GDP, aggregate economic freedom index and some of its sub-components such as government size, private property rights and free trade. For these variables, test results indicate non-stationarity under Hadri's (2000) test but stationarity under Im *et al.*'s (2003) test. In making our own judgement, we tend to rely more on the outcome from Hadri's test given our purpose of proving the variables to be non-stationarity. This is because Hadri's test has the null hypothesis of stationarity on the variable while Im *et al.*'s test projects the existence of an individual unit root process in the null hypothesis instead.

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

We next examine if the combination of the time series exhibits a co-integrating relationship. This is the statistical requirement for having meaningful estimations (i.e. regression results are not spurious). Reported results at 10% level of significance on two panel cointegration tests put forward by Pedroni (1999) in Table 3 reveal that this requirement is satisfied for most regressions as both tests confirm the existence of cointegration among variables. In a few cases involving some institutional variables, while the panel augmented Dickey-Fuller (ADF)-statistics indicates cointegration, the group ADF-statistics do not confirm such a relationship. To make a decision, we are inclined towards using the outcome of the panel ADF-statistics as the corresponding test pools the statistics along the within-dimension rather than averaging the results of individual country test statistics as the group ADF-statistics do.

According to Kao *et al.* (1999) and Tsionas (2019), in dealing with co-integrated panels, Ordinary Least Squares regression (OLS) results may be subject to a second-order asymptotic bias due to the endogeneity problem that is caused by the potential reverse causality between R&D variables and TFP. Following Kao and Chiang (2000) and also to save space, in what follows, we will only present regression results conducted using the dynamic OLS (DOLS) method.[10] The advantage of this method lies in its superior small sample properties, which are more suited with our sample. To preserve the number of observations, we choose one lead and one lag of the cointegrating regressors for all of our regressions.[11]

5. Frontier academic research, industrial R&D and technological development

In Table 4, we report DOLS results for regression equations (4)–(7) in which frontier academic publication scores are used to represent frontier academic knowledge. Note that in running these regressions, we withhold from considering the role of institutions in order to solely focus on the relationship between frontier academic research, industrial R&D and technological progress. Except for regression equation (5), all equations include human capital and trade openness-GDP ratio as control variables. They also include unreported country-specific fixed effects (FEs) to control for factors that affect TFP but do not vary little with time such as geographical and climate conditions. Additionally, time-specific FEs are used to take account of common and time-varying factors that potentially affect TFP across countries such as economic crisis or other macroeconomic shocks.

For equation (4) on the total effect of publications on TFP, column (4.1) indicates that frontier academic research has a positive and significant overall impact on TFP as captured by a positive and mostly significant coefficient of log (*Pub*). This result is in line with those previously obtained by Le and Tang (2015) and Le *et al.* (2022).

Estimation result for equation (6) on the total impact of industrial R&D on TFP is given in column (4.2). It can be seen that industrial R&D strongly enhances technological improvement as the coefficient on log (*SD*) is positive and highly significant. This adds more evidence to the one previously established in the literature such as Coe and Helpman (1995) and Le *et al.* (2022).

Regarding the direct effect of frontier academic research on TFP as per equation (7), column (4.3) indicates no significant evidence for the existence of such an effect. While the coefficient of industrial R&D variable continues to be positive, it is insignificant. This means that in the presence of industrial R&D, the direct effect of frontier academic research on TFP is not clear.

As for regression equation (5), our estimation result is provided in column (4.4). In can be seen that frontier academic knowledge induces more industrial R&D as evidenced by a positive and significant coefficient of log (*Pub*). This implies a complementarity between frontier academic research and private sector R&D. This 'crowding-in' effect, as explained by Cassiman and Veugelers (2002), is partly due to the potential attraction to internationally mobile R&D. This includes factors related to prospects of high-quality collaboration, recruitment opportunities and technological transfer infrastructure.

[10]For robustness checks, we also run regressions using the OLS method but do not report them here to save space. These results can be made available upon request.

[11]Performing a higher order of leads and lags is not practical since we lose about four observation years each time we increase the lead and lag structure by one order. Meanwhile, the time span of our sample is only 15 years.

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

Table 3. Panel cointegration tests (at 10% level of significance, 18 countries, 2003–2017)

Variables	Panel ADF-statistics	Group ADF-statistics	Decision
log (*F*), log (*SD*), log (*Hucap*), log (*Open*)	−4.345 (0.000)	−3.970 (0.000)	*CI*
log (*F*), log (*Pub*), log (*Hucap*), log (*Open*)	−2.758 (0.003)	−1.633 (0.051)	*CI*
log (*F*), log (*SD*), log (*Pub*), log (*Hucap*), log (*Open*)	−3.173 (0.000)	−2.088 (0.018)	*CI*
log (*F*), log (*SD*), log (*Hucap*), log (*Open*), log (*EF*)	−3.191 (0.000)	−2.628 (0.004)	*CI*
log (*F*), log (*Pub*), log (*Hucap*), log (*Open*), log (*EF*)	−1.463 (0.086)	−0.387 (0.349)	*CI*
log (*F*), log (*SD*), log (*Pub*), log (*Hucap*), log (*Open*), log (*EF*)	−2.107 (0.018)	−1.205 (0.114)	*CI*
log (*F*), log (*SD*), log (*Hucap*), log (*Open*), log (*Gov*)	−3.136 (0.000)	−1.230 (0.109)	*CI*
log (*F*), log (*Pub*), log (*Hucap*), log (*Open*), log (*Gov*)	−2.779 (0.002)	−0.305 (0.380)	*CI*
log (*F*), log (*SD*), log (*Pub*), log (*Hucap*), log (*Open*), log (*Gov*)	−2.175 (0.015)	0.068 (0.527)	*CI*
log (*F*), log (*SD*), log (*Hucap*), log (*Open*), log (*PPR*)	−3.817 (0.000)	−3.048 (0.001)	*CI*
log (*F*), log (*Pub*), log (*Hucap*), log (*Open*), log (*PPR*)	−1.847 (0.032)	−0.747 (0.227)	*CI*
log (*F*), log (*SD*), log (*Pub*), log (*Hucap*), log (*Open*), log (*PPR*)	−2.592 (0.005)	−1.348 (0.089)	*CI*
log (*F*), log (*SD*), log (*Hucap*), log (*Open*), log (*Money*)	−4.433 (0.000)	−3.386 (0.000)	*CI*
log (*F*), log (*Pub*), log (*Hucap*), log (*Open*), log (*Money*)	−2.756 (0.003)	−1.548 (0.061)	*CI*
log (*F*), log (*SD*), log (*Pub*), log (*Hucap*), log (*Open*), log (*Money*)	−4.457 (0.000)	−1.953 (0.026)	*CI*
log (*F*), log (*SD*), log (*Hucap*), log (*Open*), log (*Trade*)	−3.639 (0.000)	−2.989 (0.001)	*CI*
log (*F*), log (*Pub*), log (*Hucap*), log (*Open*), log (*Trade*)	−1.743 (0.041)	−1.055 (0.146)	*CI*
log (*F*), log (*SD*), log (*Pub*), log (*Hucap*), log (*Open*), log (*Trade*)	−2.462 (0.007)	−1.216 (0.112)	*CI*
log (*F*), log (*SD*), log (*Hucap*), log (*Open*), log (*Reg*)	−2.905 (0.002)	−3.322 (0.000)	*CI*
log (*F*), log (*Pub*), log (*Hucap*), log (*Open*), log (*Reg*)	−1.429 (0.077)	−0.563 (0.287)	*CI*
log (*F*), log (*SD*), log (*Pub*), log (*Hucap*), log (*Open*), log (*Reg*)	−1.699 (0.045)	−1.832 (0.033)	*CI*

Notes: log (*X*) is log of *X*; *F*, *SD*, *Pub*, *Hucap* and *Open* are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. Among institutional quality variables, while *EF* denotes aggregate index of economic freedom, *Gov*, *PPR*, *Money*, *Trade* and *Reg* denote different sub-components of this index including government size, private property rights, sound money, free trade and limited regulations. *p*-Values are in parentheses. *CI* indicates cointegrated.

Table 4. Impact of frontier publication scores (DOLS, two-way fixed effects, 18 countries, 2003–2017)

	Dependent variable: log (*F*)			Dependent variable: log (SD_{t-1})
	(4.1)	(4.2)	(4.3)	(4.4)
log (SD_{t-1})		0.051*** (0.017)	0.028 (0.040)	
log (Pub_{t-2})	0.043*** (0.009)		0.025 (0.022)	0.363*** (0.019)
log ($Hucap_{t-1}$)	−0.035 (0.083)	0.016 (0.032)	−0.021 (0.059)	
log ($Open_{t-1}$)	0.041 (0.027)	0.014 (0.024)	0.029 (0.022)	
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.510	0.574	0.519	0.999
Observations	198	216	198	216

Notes: log (*X*) is log of *X*; *F*, *SD*, *Pub*, *Hucap* and *Open* are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. Robust standard errors are in parentheses. *, **, *** indicate parameters that are significant at 10%, 5% and 1% levels of significance respectively. All regressions include unreported country-specific and time-specific constants.

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

6. Institutions as a moderating factor

In this section, we examine if the estimated coefficients on the nexus between frontier academic research, industrial R&D and TFP vary due to the introduction of institutional variables. While the views on institutions are many, ranging from political to cultural and economic aspects (La Porta *et al.*, 1999), we focus only on the economic aspect of institutions. In particular, we pay attention to a broad-based index of economic freedom and its sub-components including the effectiveness of fiscal policy, the strength of private property rights, the effectiveness of monetary policy, the freedom of trade and the degree of regulatory control. Each of these variables could potentially affect the extent and direction in which frontier academic research and industrial R&D affect TFP.

Estimation results for the aggregate index of economic freedom are reported in Table 5. We start with simple regressions that examine the direct effect of economic freedom on TFP while taking into account the influence of frontier academic knowledge (in column (5.1)) and industrial R&D (in column (5.3)). We then test the indirect effect of economic freedom on TFP by including an interaction term of this indicator with each of the technological knowledge variables in regressions (5.2) and (5.4) respectively. All of these regressions include human capital stock and trade openness as control variables. It can be seen that economic freedom exerts little direct effect on TFP since its estimated coefficient is mostly insignificant. Meanwhile, there is evidence that economic freedom indirectly affects TFP. This is because the estimated coefficients for the interaction terms of economic freedom with each of the technological knowledge variables are both positive and statistically significant. This means that greater economic freedom enhances the impact of technological knowledge, either academic or industrial, on productivity of countries. In columns (5.5) and (5.6), we investigate the effects of economic freedom on industrial R&D investment. While the direct effect is negative and statistically significant, the indirect effect (i.e. via frontier academic knowledge channel) is negative but insignificant.

The intuition for the above results is as follows. The economic freedom index captures a wide range of aspects related to doing business. It includes pro-business market reforms that make it easier for investors to start and run a business. While this stimulates entrepreneurship, it raises the level of competition among the firms. To thrive in the market, some firms may choose to imitate others' technology to improve their productivity at low cost instead of developing their own technology. This process will somehow chip away the potential monopoly profit earned by a future successful innovator. In response to this threat, firms may consider cutting down their R&D investment.

By construction, economic freedom also refers to the set of institutional standards such as rule of law and open mark regulations. An increase in this score implies changes that enhance efficient allocation of resources. Because firms and countries in our sample have already been enjoying a good environment that stimulates innovative capabilities,[12] they will gain little where there is a lower level of regulation or an enhancement of flexibility.

The result that there is a positive moderation of institutional variables on the relationship between frontier academic knowledge and TFP can be explained as follows. Because academic research resembles a public good, it is generally accessible by the public. However, the majority of academic research belongs to basic and theoretical science meaning that it is not ready to make a real impact on the economy in its original form. An improvement in economic freedom encourages entrepreneurship, which in turn leads to more application of scientific results into industrial innovation. This can be done in the form of university–industry R&D collaborations or education and training. As a result, firms in countries of higher economic freedom will reap more benefits from academic research.

In Table 6, we report results obtained from performing a similar test, however, using a component of the economic freedom index, namely government size. The results reveal a negative and statistical significant direct effect of government size on TFP. Nevertheless, the indirect effect is positive and significant. In addition, government size also influences industrial R&D but it does not affect the way that frontier academic research impacts industrial R&D. Clearly, a larger government size may well be

[12]Note that countries in our sample are all advanced OECD countries.

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

Table 5. Aggregate index: economic freedom (DOLS, two-way fixed effects, 18 countries, 2003–2017)

	Dependent variable: log (F)				Dependent variable: log (SD_{t-1})	
	(5.1)	(5.2)	(5.3)	(5.4)	(5.5)	(5.6)
log (SD_{t-1})			0.048** (0.019)	0.038*** (0.014)		
log (Pub_{t-2})	0.045*** (0.008)	0.044** (0.011)			0.377*** (0.022)	0.349*** (0.022)
log (EF_{t-1})	−0.135 (0.142)	−0.342* (0.196)	0.060 (0.121)	−0.087 (0.145)	−1.083** (0.288)	−0.926** (0.423)
log (Pub_{t-2}) × log (EF_{t-1})		0.225*** (0.070)				−0.016 (0.234)
log (SD_{t-1}) × log (EF_{t-1})				0.192** (0.082)		
log ($Hucap_{t-1}$)	−0.033 (0.078)	0.005 (0.084)	0.011 (0.036)	−0.002 (0.041)		
log ($Open_{t-1}$)	0.039 (0.024)	0.048** (0.023)	0.014 (0.024)	0.016 (0.024)		
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.519	0.546	0.577	0.602	0.999	0.999
Observations	198	198	216	216	216	198

Notes: log (X) is log of X; F, SD, Pub, $Hucap$ and $Open$ are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. EF denotes aggregate index of economic freedom. Robust standard errors are in parentheses. *, **, *** indicate parameters that are significant at 10%, 5% and 1% levels of significance respectively. All regressions include unreported country-specific and time-specific constants.

Table 6. Area 1: government size (DOLS, two-way fixed effects, 18 countries, 2003–2017)

	Dependent variable: log (F)				Dependent variable: log (SD_{t-1})	
	(6.1)	(6.2)	(6.3)	(6.4)	(6.5)	(6.6)
log (SD_{t-1})			0.074*** (0.021)	0.059*** (0.016)		
log (Pub_{t-2})	0.056*** (0.011)	0.043** (0.017)			0.347*** (0.023)	0.317*** (0.029)
log (Gov_{t-1})	−0.174** (0.067)	−0.158** (0.062)	−0.116** (0.057)	−0.120** (0.051)	0.266* (0.149)	0.490*** (0.147)
log (Pub_{t-2}) × log (Gov_{t-1})		0.074*** (0.019)				−0.022 (0.046)
log (SD_{t-1}) × log (Gov_{t-1})				0.065*** (0.022)		
log ($Hucap_{t-1}$)	−0.093 (0.099)	−0.084 (0.107)	−0.002 (0.039)	−0.013 (0.043)		
log ($Open_{t-1}$)	0.032 (0.025)	0.037 (0.023)	0.009 (0.025)	0.011 (0.025)		
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.552	0.575	0.586	0.616	0.999	0.999
Observations	198	198	216	216	216	198

***Notes*:** log (X) is log of X; F, SD, Pub, $Hucap$ and $Open$ are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. Gov denotes government size component of economic freedom. Robust standard errors are in parentheses. *, **, *** indicate parameters that are significant at 10%, 5% and 1% levels of significance respectively. All regressions include unreported country-specific and time-specific constants.

indicating a stronger role of the government in stimulating innovative activity, either through training or provision of funding for research (i.e. an indirect effect). Meanwhile, this may also be an indication of a higher government consumption and tax burden which suppresses productivity (i.e. a direct effect). These findings are relevant to the ongoing debate about the optimal government size since Barro (1991).

Another institutional variable that has received much attention from the literature is the strength of private property right protection. Regressions in Table 7 are devoted to examining the impact of private property right protection on productivity. The direct effect of private property rights is found positive but insignificant. Meanwhile, the indirect effect is negative and only significant with the industrial R&D channel. A higher level of private property protection also discourages investment in industrial R&D but has an insignificant effect on how frontier academic research is converted into industrial innovation. These results point out that overly sophisticated and strict private property right regimes may stiffen innovative activity by hindering technological catch-up in countries that have already been innovative (Qian, 2007). This may be because extra protection serves to increase rents accrued to patent holders rather than to reward new innovators (Qiu and Yu, 2010; Sharma *et al.*, 2022).

Next, we seek to explore the impact of the conduct of monetary policy on productivity. Results in Table 8 suggest that the conduct of monetary policy has an insignificant direct effect on TFP. By contrast, there is significant evidence that monetary policy positively affects TFP in an indirect way, either via frontier academic research or the industrial R&D channel. This is because a good control of inflation and interest rate is beneficial for long-term research projects (i.e. an indirect effect). Nevertheless, monetary policy is found to negatively affect industrial R&D investment both directly and by reducing the commercialisation of frontier academic research into industrial R&D.

Free trade is an important dimension of institutional quality that is widely discussed by economists. Table 9 conducts a test on how free trade impacts productivity in the presence of industrial R&D and frontier academic research. Obtained results indicate that free trade has a positive and significant direct effect, but an insignificant indirect effect, on TFP. In addition, free trade has little impact on the way frontier academic research induces industrial R&D, both in terms of direct effect and indirect effect. These results are in line with the strand of literature characterising the international knowledge diffusion via trade (e.g. Coe *et al.*, 2009).

Table 10 concludes the empirical exercise with the use of a measure on limited regulations (i.e. freedom such as business freedom or labour freedom). It can be seen that limited regulations weakly influence TFP either directly or indirectly. However, a reduction in regulations seems to discourage industrial R&D. According to Barbosa and Faria (2011), rigid regulations in the labour market make it harder for firms to flexibly adjust R&D personnel and wages, especially when the wages are sufficiently high. Meanwhile, stringent dismissal laws may encourage firms to provide more training to workers leading to their higher productivity. The offset of these effects will result in an insignificant impact of regulations. The obtained results are in accord with this reasoning.

Overall, obtained results confirm that frontier academic knowledge positively affects TFP. While the direct effect is strongly present, there is also evidence suggesting that frontier academic knowledge influences TFP indirectly, specifically via the industrial R&D channel. Institutional quality matters as institutions affect the way academic research is converted into practical innovation in the industry. To a certain extent, institutions also affect the process through which industrial R&D is materialised into technological development. However, different institutional elements affect this process differently. While government size and the conduct of monetary policy positively moderate this process, other dimensions mostly have no significant influence on it.

7. Robustness checks

We perform a number of robustness checks with results being included in the online Appendix. We first collect the research data published by the Times Higher Education (THE) and available from

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

Table 7. Area 2: private property rights (DOLS, two-way fixed effects, 18 countries, 2003–2017)

	Dependent variable: log (F)				Dependent variable: log (SD_{t-1})	
	(7.1)	(7.2)	(7.3)	(7.4)	(7.5)	(7.6)
log (SD_{t-1})			0.052*** (0.019)	0.063*** (0.018)		
log (Pub_{t-2})	0.042*** (0.010)	0.043*** (0.009)			0.369*** (0.023)	0.355*** (0.023)
log (PPR_{t-1})	0.022 (0.059)	0.016 (0.070)	0.066 (0.058)	0.031 (0.069)	−0.231*** (0.071)	−0.101 (0.094)
log (Pub_{t-2}) × log (PPR_{t-1})		−0.029 (0.025)				0.264 (0.163)
log (SD_{t-1}) × log (PPR_{t-1})				−0.068** (0.029)		
log ($Hucap_{t-1}$)	−0.040 (0.086)	−0.047 (0.083)	0.008 (0.034)	0.012 (0.032)		
log ($Open_{t-1}$)	0.041 (0.027)	0.038 (0.026)	0.013 (0.024)	0.007 (0.025)		
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.501	0.491	0.571	0.567	0.999	0.999
Observations	198	198	216	216	216	198

Notes: log (X) is log of X; F, SD, Pub, $Hucap$ and $Open$ are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. PRP denotes private property rights component of economic freedom. Robust standard errors are in parentheses. *, **, *** indicate parameters that are significant at 10%, 5% and 1% levels of significance respectively. All regressions include unreported country-specific and time-specific constants.

Table 8. Area 3: sound money (DOLS, two-way fixed effects, 18 countries, 2003–2017)

	Dependent variable: log (F)				Dependent variable: log (SD_{t-1})	
	(8.1)	(8.2)	(8.3)	(8.4)	(8.5)	(8.6)
log (SD_{t-1})			0.054*** (0.016)	0.067*** (0.016)		
log (Pub_{t-2})	0.049*** (0.008)	0.050*** (0.009)			0.375*** (0.019)	0.352*** (0.022)
log ($Money_{t-1}$)	−0.196 (0.132)	−0.247* (0.126)	−0.160 (0.126)	−0.219* (0.114)	−0.595** (0.266)	−0.254 (0.344)
log (Pub_{t-2}) × log ($Money_{t-1}$)		0.155* (0.085)				−0.203* (0.120)
log (SD_{t-1}) × log ($Money_{t-1}$)				0.214*** (0.077)		
log ($Hucap_{t-1}$)	−0.018 (0.083)	−0.005 (0.104)	0.054* (0.030)	0.049* (0.028)		
log ($Open_{t-1}$)	0.048* (0.026)	0.040 (0.025)	0.019 (0.024)	0.003 (0.024)		
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.540	0.545	0.598	0.624	0.999	0.999
Observations	198	198	216	216	216	198

Notes: log (X) is log of X; F, SD, Pub, $Hucap$ and $Open$ are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. *Money* denotes sound money component of economic freedom. Robust standard errors are in parentheses. *, **, *** indicate parameters that are significant at 10%, 5% and 1% levels of significance respectively. All regressions include unreported country-specific and time-specific constants.

Table 9. Area 4: free trade (DOLS, two-way fixed effects, 18 countries, 2003–2017)

	Dependent variable: log (F)				Dependent variable: log (SD_{t-1})	
	(9.1)	(9.2)	(9.3)	(9.4)	(9.5)	(9.6)
log (SD_{t-1})			0.068*** (0.018)	0.073*** (0.020)		
log (Pub_{t-2})	0.048*** (0.010)	0.050 (0.008)			0.349*** (0.016)	0.314*** (0.009)
log ($Trade_{t-1}$)	0.163*** (0.044)	0.197** (0.096)	0.155*** (0.042)	0.159** (0.067)	−0.277 (0.168)	−0.343** (0.156)
log (Pub_{t-2}) × log ($Trade_{t-1}$)		−0.050 (0.085)				0.017 (0.155)
log (SD_{t-1}) × log ($Trade_{t-1}$)				−0.007 (0.042)		
log ($Hucap_{t-1}$)	0.012 (0.078)	0.017 (0.082)	0.046 (0.033)	0.056 (0.039)		
log ($Open_{t-1}$)	0.038 (0.031)	0.042 (0.027)	0.010 (0.024)	0.011 (0.023)		
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.516	0.511	0.587	0.578	0.999	0.999
Observations	198	198	216	216	216	198

Notes: log (X) is log of X; F, SD, Pub, $Hucap$ and $Open$ are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. *Trade* denotes free trade component of economic freedom. Robust standard errors are in parentheses. *, **, *** indicate parameters that are significant at 10%, 5% and 1% levels of significance respectively. All regressions include unreported country-specific and time-specific constants.

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

Table 10. Area 5: limited regulations (DOLS, two-way fixed effects, 18 countries, 2003–2017)

	Dependent variable: log (F)				Dependent variable: log (SD_{t-1})	
	(10.1)	(10.2)	(10.3)	(10.4)	(10.5)	(10.6)
log (SD_{t-1})			0.061*** (0.018)	0.054*** (0.014)		
log (Pub_{t-2})	0.044*** (0.010)	0.040*** (0.012)			0.350*** (0.012)	0.329*** (0.016)
log (Reg_{t-1})	0.029 (0.048)	−0.002 (0.082)	0.066** (0.025)	0.044 (0.046)	−0.390*** (0.069)	−0.353*** (0.084)
log (Pub_{t-2}) × log (Reg_{t-1})		0.030 (0.059)				−0.001 (0.077)
log (SD_{t-1}) × log (Reg_{t-1})				0.028 (0.054)		
log ($Hucap_{t-1}$)	−0.055 (0.079)	−0.022 (0.097)	−0.019 (0.036)	−0.021 (0.039)		
log ($Open_{t-1}$)	0.032 (0.027)	0.029 (0.020)	0.010 (0.022)	0.010 (0.020)		
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.514	0.533	0.579	0.593	0.999	0.999
Observations	198	198	216	216	216	198

Notes: log (X) is log of X; F, SD, Pub, $Hucap$ and $Open$ are TFP index, industrial R&D capital, frontier publication scores, human capital and trade openness respectively. Reg denotes limited regulations component of economic freedom. Robust standard errors are in parentheses. *, **, *** indicate parameters that are significant at 10%, 5% and 1% levels of significance respectively. All regressions include unreported country-specific and time-specific constants.

2011. We use three different research indicators provided by the THE: research scores (*RS*), citation scores (*CS*) and research and citation scores (*RCS*) with the last indicator equal to the sum of the two preceding ones. The correlation matrix in Table A1 indicates a strong correlation between the ARWU publication scores (*Pub*) and the THE research indicators. With similar regressions as those in Table 4, results reported in Table A2 reveal that while coefficient estimates for some alternative measures of frontier academic research are statistically significant, that for industrial R&D is insignificant across the regressions.[13]

We next make use of scores on publications in *Nature* and *Science*, the top two journals in science and engineering. This is because it is arguable that science and engineering are the most relevant fields for industrial production. It can be seen from Table A3 that corresponding results are qualitatively the same as those reported in Table 4 that use the publication scores.

In our third set of robustness tests, we employ research scores behind the field rankings published by ARWU over 2007–2017.[14] To capture the national frontier academic research capability for each country, we create an indicator called *STEM*, which is equal to the sum of scores on two different fields: *Natural Sciences and Mathematics* and *Engineering/Technology and Computer Sciences*. It can be seen from Table A4 that the coefficient estimates for *STEM* and industrial R&D are mostly similar to those obtained in Table 4. The only difference is that *STEM* negatively affects *SD* in column (A4.4). This may be because the time span is not sufficiently long to display any stable long-run relationship between the interested variables.[15]

8. Conclusion

This paper has been concerned with an enquiry into the effect of frontier academic research on technological development, the channel of the impact and the way institutional factors affect these channels. Using a sample of 18 OECD countries over the period of 2003–2017, we found that frontier academic research affects technological change, both directly and indirectly, via the transmission through industrial R&D. Institutions matter as they influence this transmission process as well as the effectiveness of both frontier academic research and industrial innovations on the advancement of TFP.

Our obtained results convey several important policy implications. In particular, policymakers should take frontier academic research more seriously in planning their innovation strategies. For instance, it is essential for governments to maintain and grow its support for university-based scientific research, such as ensuring sufficient and reliable funding for academic research, or reducing complex and unnecessary regulations placed on government-funded research projects, to name a few. Furthermore, investment in frontier academic research will work best if it is put in parallel with that in industrial R&D. In order to do so, policymakers should provide more feasible legislation, financial subsidies, policies and other measures to support and strengthen the collaboration between universities and industries. In addition, improving the right type of institutional quality will also enhance innovation and speed up the process that targets at improving the national productivity and achieving better long-term growth.

While frontier academic research can significantly induce technological progress, different types of academic research may affect productivity improvement in different ways. For example, it may be interesting to differentiate between research in applied natural science from that in basic natural science and that in humanities and social sciences. Owing to the limited time span of current data, we were not able to perform such investigations and had to reserve this exciting avenue for future

[13]Notice that due to the short time horizon of only seven years, we do not apply DOLS method with lead and lag structures (for every increase in the order of lead and lag specified, we lose about four observation years) but use the OLS method instead. We treat obtained results with a little caution because the short time horizons of seven years makes it difficult to capture in full the long-run relationship between the interested variables.

[14]The ARWU did not publish scores associated with field rankings until 2007.

[15]The period of 11 years is typically not long for executing DOLS regressions with lead and lag structures.

https://doi.org/10.1017/S1744137422000509 Published online by Cambridge University Press

research. Another research extension in the future is to examine the effects of institutional designs, those that shape the operation of the market economy such as the electoral system or the regulatory mechanism, besides institutional quality variables that are used in this paper. All these will certainly enrich our future research agenda.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1744137422000509

Acknowledgement. The authors would like to thank three anonymous referees for their constructive comments. We are also grateful to the Editor of this journal, Professor Geoffrey Hodgson, for the efficient handling of our submission. The usual disclaimer applies.

References

Acemoglu, D., S. Johnson and J. Robinson (2001), 'The Colonial Origins of Comparative Development: An Empirical Investigation', *The American Economic Review*, **91**(5): 1369–1401.

Acs, Z., D. Audretsch and M. Feldman (1992), 'Real Effects of Academic Research: Comment', *The American Economic Review*, **82**(1): 363–367.

Aghion, P. and P. Howitt (1992), 'A Model of Growth Through Creative Destruction', *Econometrica*, **60**(2): 323–351.

Audretsch, D. (2013), *Public Policy in the Entrepreneurial Society*, Cheltenham, UK: Edward Elgar Publishing.

Audretsch, D., M. Hülsbeck and E. Lehmann (2012), 'Regional Competitiveness, University Spillovers, and Entrepreneurial Activity', *Small Business Economics*, **39**(3): 587–601.

Barbosa, N. and A. Faria (2011), 'Innovations across Europe: How Important are Institutional Differences?', *Research Policy*, **40**(9): 1157–1169.

Barro, R. and J. W. Lee (2013), 'A New Dataset of Educational Attainment in the World, 1950–2010', *Journal of Development Economics*, **104**: 184–198.

Barro (1991), 'Economic Growth in a Cross Section of Countries', *The Quarterly Journal of Economics*, **106**(2): 407–443.

Bayoumi, T., D. Coe and E. Helpman (1999), 'R&D Spillovers and Global Growth', *Journal of International Economics*, **47**(2): 399–428.

Bekkers, R. and I. Freitas (2008), 'Analysing Knowledge Transfer Channels Between Universities and Industry: To What Degree Do Sectors Also Matter?', *Research Policy*, **37**(10): 1837–1853.

Berggren, N. and C. Bjornskov (2022), 'Academic Freedom, Institutions, and Productivity', *Southern Economic Journal*, **88**(4): 1313–1342.

Berggren, N. and T. Nilsson (2021), 'Economic Freedom and Antisemitism', *Journal of Institutional Economics*, **17**(2): 289–304.

Bergh, A. (2020), 'Hayekian Welfare States: Explaining the Coexistence of Economic Freedom and Big Government', *Journal of Institutional Economics*, **16**(1): 1–12.

Billaut, J., D. Bouyssou and P. Vincke (2010), 'Should You Believe in the Shanghai Ranking?', *Scientometrics*, **84**(1): 237–263.

Caselli, F. (2005), 'Accounting for Cross-Country Income Differences', in P. Aghion, and S. Durlauf (eds), *Handbook of Economic Growth*, (Vol. **1**), (1st edn), Chapter 9. Amsterdam: Elsevier, pp. 679–741.

Cassiman, B. and R. Veugelers (2002), 'R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium', *The American Economic Review*, **92**(4): 1169–1184.

Coe, D. and E. Helpman (1995), 'International R&D Spillovers', *European Economic Review*, **39**(5): 859–887.

Coe, D., E. Helpman and A. Hoffmaister (2009), 'International R&D Spillovers and Institutions', *European Economic Review*, **53**(7): 723–741.

Cohen, W., R. Nelson and J. Walsh (2002), 'Links and Impacts: The Influence of Public Research on Industrial R&D', *Management Science*, **48**(1): 1–23.

Dasgupta, P. and P. David (1994), 'Toward a New Economics of Science', *Research Policy*, **23**(5): 487–521.

Dean, J. and V. Geloso (2022), 'Economic Freedom Improves Income Mobility: Evidence from Canadian Provinces, 1982–2018', *Journal of Institutional Economics*, **18**(5): 807–826.

Égert, B. (2016), 'Regulation, Institutions, and Productivity: New Macroeconomic Evidence from OECD Countries', *The American Economic Review*, **106**(5): 109–113.

Engelbrecht, H. (1997), 'International R&D Spillovers, Human Capital and Productivity in OECD Economies: An Empirical Investigation', *European Economic Review*, **41**(8): 1479–1488.

Faulkner, W. and J. Senker (1994), 'Making Sense of Diversity: Public-Private Sector Research Linkage in Three Technologies', *Research Policy*, **23**(6): 673–695.

Gittelman, M. and B. Kogut (2003), 'Does Good Science Lead to Valuable Knowledge? Biotechnology Firms and the Evolutionary Logic of Citation Patterns', *Management Science*, **49**(4): 366–382.

Graafland, J. (2020), 'Contingencies in the Relationship between Economic Freedom and Human Development: The Role of Generalized Trust', *Journal of Institutional Economics*, **16**(3): 271–286.

Grossman, G. and E. Helpman (1991), *Innovation and Growth in the Global Economy*, London, UK: MIT Press.
Guellec, D. and B. van Pottelsberghe de la Potterie (2004), 'From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter?', *Oxford Bulletin of Economics and Statistics*, **66**(3): 353–378.
Hadri, K. (2000), 'Testing for Stationarity in Heterogeneous Panel Data', *Econometric Journal*, **3**(2): 148–161.
Hall, R. and C. Jones (1999), 'Why Do Some Countries Produce So Much More Output Per Worker Than Others?', *The Quarterly Journal of Economics*, **114**(1): 83–116.
Hall, B., J. Mairesse and P. Mohnen (2010), 'Measuring the Returns to R&D', in B. Hall, and N. Rosenberg (eds), *Handbook of the Economics of Innovation* (Vol. **2**), Chapter 24. Amsterdam: Elsevier B. V, pp. 1033–1082.
Hanushek, E. and L. Woessmann (2008), 'The Role of Cognitive Skills in Economic Development', *Journal of Economic Literature*, **46**(3): 607–668.
Hanushek, E., G. Schwerdt, S. Wiederhold and L. Woessmann (2015), 'Returns to Skills around the World: Evidence from PIAAC', *European Economic Review*, **73**: 103–130.
Hou, B., J. Hong, S. Wang, X. Shi and C. Zhu (2021), 'University-Industry Linkages, Regional Entrepreneurship and Economic Growth: Evidence from China', *Post-Communist Economies*, **33**(5): 637–659.
Im, K., M. Pesaran and Y. Shin (2003), 'Testing for Unit Roots in Heterogeneous Panels', *Journal of Econometrics*, **115**(1): 53–74.
Jaffe, A. (1989), 'Real Effects of Academic Research', *The American Economic Review*, **79**(5): 957–970.
Jaffe, A., M. Trajtenberg and R. Henderson (1993), 'Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations', *The Quarterly Journal of Economics*, **108**(3): 577–598.
Jaumotte, F. and N. Pain (2005a), From Ideas to Development: The Determinants of R&D and Patenting. *OECD Economics Department Working Paper*, No. 457.
Jaumotte, F. and N. Pain (2005b), 'Innovation in the Business Sector', OECD Economics Department Working Paper: No. 459.
Jensen, R. and M. Thursby (2001), 'Proofs and Prototypes for Sale: The Licensing of University Inventions', *The American Economic Review*, **91**(1): 240–259.
Jones, J. and G. de Zubielqui (2017), 'Doing Well by Doing Good: A Study of University-Industry Interactions, Innovationess and Firm Performance in Sustainability-Oriented Australian SMEs', *Technological Forecasting and Social Change*, **123**: 262–270.
Kao, C. and M. Chiang (2000), 'On the Estimation and Inference of a Cointegrated Regression in Panel Data', in B. Baltagi (ed), *Nonstationary Panels, Panel Cointegration, and Dynamic Panels (Advances in Econometrics)*, Amsterdam: JAI Press, pp. 161–178.
Kao, C., M. Chiang and B. Chen (1999), 'International R&D Spillovers: An Application of Estimation and Inference in Panel Cointegration', *Oxford Bulletin of Economics and Statistics*, **61**(S1): 691–709.
Kerr, W. (2010), 'Breakthrough Inventions and Migrating Clusters of Innovation', *Journal of Urban Economics*, **67**(1): 46–60.
Krammer, S. (2015), 'Do Good Institutions Enhance the Effect of Technological Spillovers on Productivity? Comparative Evidence from Developed and Transition Economies', *Technological Forecasting & Social Change*, **94**: 133–154.
Kufenko, V. and V. Geloso (2021), 'Who are the Champions? Inequality, Economic Freedom and the Olympics', *Journal of Institutional Economics*, **17(3)**: 411–427.
Lai, W. H. (2011), 'Willingness-to-Engage in Technology Transfer in Industry–University Collaborations', *Journal of Business Research*, **64**(11): 1218–1223.
La Porta, R., F. Lopez-de-Silanes, A. Shleifer and R. Vishny (1999), 'The Quality of Government', *Journal of Law, Economics and Organization*, **15**(1): 222–279.
Le, T. (2008), '"Brain Drain" or "Brain Circulation": Evidence from OECD's International Migration and R&D Spillovers', *Scottish Journal of Political Economy*, **55**(5): 618–636.
Le, T. (2010), 'Are Student Flows a Significant Channel of R&D Spillovers from the North to the South?', *Economics Letters*, **107**(3): 315–317.
Le, T. (2012), 'R&D Spillovers through Student Flows, Institutions, and Economic Growth: What Can We Learn from African Countries?', *Scottish Journal of Political Economy*, **59**(1): 115–130.
Le, T. (2022), 'Out of Sight but Not Out of Mind: On the North-South Academic Knowledge Spillovers and Human Capital Nexus', *Studies in Higher Education*, **47**(11): 2224–2238.
Le, T. and P. Bodman (2011), 'Remittances or Technological Diffusion: Which Drives Domestic Gains from Brain Drain?', *Applied Economics*, **43**(18): 2277–2285.
Le, T. and K. K. Tang (2015), 'Impacts of Academic R&D on High-Tech Manufacturing Products: Tentative Evidence from Supercomputer Data', *Studies in Higher Education*, **40**(6): 957–971.
Le, T., H. Pham, S. Mai and N. Vu (2022), 'Frontier Academic Research, Industrial R&D and Technological Progress: The Case of OECD Countries', *Technovation*, **114**: 102436.
Lundberg, J. (2017), 'Does Academic Research Affect Local Growth? Empirical Evidence Based on Swedish Data', *Regional Studies*, **51**(4): 586–601.
Mansfield, E. (1991), 'Academic Research and Industrial Innovation', *Research Policy*, **20**(1): 1–12.

Mansfield, E. (1998), 'Academic Research and Industrial Innovation: An Update of Empirical Findings', *Research Policy*, **26**(7–8): 773–776.
Miller, S. and M. Upadhyay (2000), 'The Effects of Openness, Trade Orientation, and Human Capital on Total Factor Productivity', *Journal of Development Economics*, **63**: 399–423.
Moellman, N. and D. Tarabar (2022), 'Economic Freedom Reform: Does Culture Matter?', *Journal of Institutional Economics*, **18**(S1): 139–157.
OECD. (2021), *Main Science and Technology Indicators*. https://www.oecd.org/sti/msti.htm.
Partha, D. and P. David (1994), 'Toward a New Economics of Science', *Research Policy*, **23**(5): 487–521.
Pedroni, P. (1999), 'Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors', *Oxford Bulletin of Economics and Statistics*, **61**(4): 653–670.
Psacharopoulos, G. (1994), 'Return to Investment in Education: A Global Update', *World Development*, **22**(9): 1325–1343.
Qian, Y. (2007), 'Do Additional Patent Laws Stimulate Domestic Innovation in a Global Patenting Environment?', *Review of Economic Studies*, **89**(3): 436–453.
Qiu, L. and H. Yu (2010), 'Does the Protection of Foreign Intellectual Property Rights Stimulate Innovation in the US?', *Review of International Economics*, **18**(5): 882–895.
Rodrik, D., A. Subramanian and F. Trebbi (2004), 'Institutions Rule: The Primacy of Institutions Over Geography and Integration in Economic Development', *Journal of Economic Growth*, **9**(2): 131–165.
Romer, P. (1990), 'Endogenous Technological Change', *Journal of Political Economy*, **98**(5, Part 2): S71–S102.
Rosenberg, N. and R. Nelson (1994), 'American Universities and Technical Advance in Industry', *Research Policy*, **23**(3): 323–348.
Sharma, A., C. Sousa and R. Woodward (2022), 'Determinants of Innovation Outcomes: The Role of Institutional Quality', *Technovation*, **118**: 102562.
Soete, L., B. Verspagen and T. Ziesemer (2020a), The Economic Impact of Public R&D: An International Perspective. *UNU-MERIT Working Paper Series*.
Soete, L., B. Verspagen and T. Ziesemer (2020b), 'The Productivity Effect of Public R&D in the Netherlands', *Economics of Innovation and New Technology*, **29**(1): 31–47.
Tebaldi, E. and B. Elmslie (2013), 'Does Institutional Quality Impact Innovation? Evidence from Cross-Country Patent Grant Data', *Applied Economics*, **45**(7): 887–900.
Thursby, J. and S. Kemp (2002), 'Growth and Productive Efficiency of University Intellectual Property Licensing', *Research Policy*, **31**(1): 109–124.
Tsionas, M. (2019), *Panel Data Econometrics Theory*, London, UK: Academic Press: An Imprint of Elsevier.
Wirsich, A., A. Kock, C. Strumann and C. Schultz (2016), 'Effects of University–Industry Collaboration on Technological Newness of Firms', *Journal of Product Innovation Management*, **33**(6): 708–725.
Zucker, L., M. Darby and M. Brewer (1998), 'Intellectual Human Capital and the Birth of US Biotechnology Enterprises', *The American Economic Review*, **88**(1): 290–306.
Zucker, L., M. Darby and M. Tolero (2002), 'Labor Mobility from Academe to Commerce', *Journal of Labor Economics*, **20**(3): 629–660.

Cite this article: Le T, Vu Bich N, Mai S (2023). Frontier academic research in OECD countries: the role of institutional factors. *Journal of Institutional Economics* **19**, 526–547. https://doi.org/10.1017/S1744137422000509