The Online Supplement to "International RD Spillovers and other Unobserved Common Spillovers and Shocks"

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Abstract

This document provides a review of the literature on International R&D Spillovers and includes unit root test results, the additional results of static and dynamic models, plots of all series, Stata routines, and tables of the data collection on Gross Expenditure on R&D (GERD) as a percentage of GDP, as found in the study by Ruge-Leiva (2015) "International R&D Spillovers and other Unobserved Common Spillovers and Shocks."

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1. Review of the Literature

The article by Coe and Helpman (1995) (hereafter CH) has been fundamental for several studies on international R&D spillovers at the aggregate level, which have analyzed three aspects of CH that have generated a considerable degree of debate: the weighting scheme used to construct a foreign R&D variable, the econometric implementation, and the inclusion of other regressors and weighted foreign R&D variables, which are defined according to other channels of knowledge diffusion.

1.1. Weighting scheme used for a foreign R&D variable

The CH weighting scheme, referred as the import-share-weighted average of the domestic R&D capital stock of trade partners, has been used to construct foreign R&D variables. However, this methodology has not been widely accepted in the literature on international R&D spillovers. Keller (1998), for example, casts doubt on the CH weighting scheme. In Keller's approach, which uses counterfactual estimates by Monte Carlo experiments, CH regressions are repeated by including foreign R&D variables which are computed with random bilateral import weights. Based on OLS models, similar results for true and counterfactual trade patterns are obtained; therefore, it is inferred that the pattern of trade might not be important to capture R&D spillovers. This is supported by larger spillovers obtained from a proposed foreign R&D variable constructed with the sum of the domestic R&D stocks of foreign partners.

However, Coe and Hoffmaister (1999) demonstrate that when alternative random weights are used, spillovers are small, when compared with the original weights from CH. Xu and Wang (1999) have shown that Keller's criticism does not apply when a spillover variable based on capital goods imports data is constructed because the inclusion of this variable improves the goodness of fit of the model, so that the weighted variables may yield information on knowledge spillovers. Moreover, Funk (2001) notices that Keller (1998) uses OLS on nonstationary panel data, so his estimates might be biased and provide inadequate information about the randomly weighted foreign R&D stocks. Employing new cointegration techniques, Funk (2001) finds that the choice of weights might yield information on R&D spillovers. In contrast, Edmond (2001) supports the findings by Keller (1998) when he allows for heterogeneous technology slopes, uses cointegration techniques and employs the CH sample.

Another major criticism of the CH weighing procedure is set forth by Lichtenberg and van Pottelsberghe de la Potterie (1998) (hereafter LP), who find that the CH weighted foreign R&D variable suffers from an aggregation and indexation biases. To deal with these problems, LP formulate a new weighted foreign R&D variable which is shown to outperform the CH spillover variable. However, Coe et al. (2009), by expanding the CH sample and without indexing the R&D variables, show that a CH spillover regressor and a LP weighted foreign R&D variable perform equally well when human capital or institutional variables are included. In fact, when a LP regressor and a CH variable are included in the same regression with the human capital, the CH variable performs better.

Other studies which have adopted the LP weighted foreign R&D variable, have found significant knowledge spillovers and that a LP variable does better than a CH spillover regressor. This is the case of Xu and Wang (1999), who employ capital and non-capital goods imports in a CH framework; Falvey et al. (2002), who use per capita GDP instead of TFP to analyze the impact of foreign R&D which can be a public or a private good in a donor country and in recipient developing countries; and Madsen (2007), who follows the CH specification and uses patent data and a panel for 16 OECD countries over 135 years to analyze knowledge spillovers and TFP convergence. Further, van Pottelsberghe de la Potterie and Lichtenberg (2001) use the LP procedure to study R&D spillovers embodied in imports and outward and inward FDI, and find that only inward FDI is not significant. Other studies, such as that by Guellec and van Pottelsberghe de la Potterie (2004), argue that a foreign R&D variable based on bilateral technology proximity should be preferred because technology may spread without an exchange of goods.

1.2. Econometric implementation

CH ‘s work sheds light on the proper use of cointegrating regressions without differentiating the data and in the presence of nonstationary covariates, which exhibit a time trend. However, Kao et al. (1999) states that since robust panel cointegration techniques were not available at the time of the CH study, CH could not address econometric issues, such as the characterization of the asymptotic distribution of the estimated cointegrating vector in a panel data model and the efficiency of estimates based on a small sample data set. Therefore, Kao et al. (1999) use dynamic OLS (DOLS) models and new cointegration tests to compare their results with those of CH. They show that the CH estimates are biased and foreign R&D spillovers are insignificant. However, Zhu and Jeon (2007) and Coe et al. (2009), show that it is possible to find significant and positive trade-related knowledge spillovers when Dynamic OLS models are employed.

Edmond (2001) uses panel cointegration tests in a CH setup which allows for cross-section heterogeneity. He shows that foreign R&D estimates become negative. Moreover, for a sample of 10 OECD countries from 1965-1999 and using multivariate VAR methods under a CH specification, Luintel and Kahn (2004) find heterogeneity in the R&D dynamics so that data cannot be pooled, and normalization of the relationship on TFP for some countries is not valid because there could be reverse causality. By contrast, Coe et al. (2009) show that when allowing for heterogeneity in slopes, the results do not differ from those of the DOLS models. In a more recent study, for a sample of 65 countries over a 40 year period and using Granger causality tests to address simultaneity problems, Bravo-Ortega and Garcia Marin (2011) show that with the inclusion of other covariates such as R&D expenditure, non-linear R&D, openness, scale economies, institutional and cyclical variables, R&D expenditure per capita is significant and that foreign R&D spillover variables are insignificant.

In the more recent years, some articles have highlighted the importance of studying the international knowledge spillover at the aggregate level, by taking into account the effect of unobserved common micro and macroeconomic spillovers and shocks across countries and years in a multifactor error structure. Two articles by Belitz and Molders (2013) and Ertur and Musolesi (2013) have analyzed the role of spillover variables at the aggregate level within a common factor framework (which take unobservables into account), by comparing their results with those of a CH approach, which does not account for unobserved common shocks (results from a spatial error model are also compared in Ertur and Musolesi (2013)).

Belitz and Molders (2013) use LP weighted foreign R&D variables and data on the number of patent applications for 77 countries from 1990-2008 to study the knowledge transfer via trade, FDI, internationalization of business R&D, imports of high tech goods and R&D of foreign owned companies; whereas Ertur and Musolesi (2013), using the CH dataset, study the international knowledge transfer as a decreasing function of geographical distance from foreign economies. Both papers have provided evidence of significant foreign R&D estimates in common factor models, so that the authors claim that international knowledge flows determine TFP in accordance with the findings of the literature on international R&D spillovers.

1.3. Inclusion of other determinants of productivity and weighted foreign R&D variables defined according to other channels of knowledge diffusion

Other studies have shown that the significance and/or the magnitude of international R&D spillovers captured by a CH foreign R&D variable weighted by bilateral imports may vary across countries when other determinants of TFP and weighted foreign R&D variables defined according to other channels of knowledge diffusion are regarded. Coe et al. (1997) implement the CH framework (although without including a domestic R&D variable) to study the effect of the foreign R&D, openness and human capital stock on productivity across 77 developing countries between 1971 and 1990. They find that these variables determine the TFP of developing countries so long as foreign R&D is interacted with openness. Another finding is that North-South spillovers are important even though their magnitude might differ across countries. Engelbrecht (1997) broadens the CH study by including a human capital variable, and subsequently adds an interaction between a human capital variable and a catch-up regressor. His findings show that while the fact that coefficients of domestic and foreign R&D remain statistically significant, overall estimates shrink when human capital is incorporated. Funk (2001), employing the CH framework and data, cointegration techniques and dynamic OLS panel data models, shows that the international R&D spillovers captured by a CH foreign R&D variable weighted by bilateral exports are statistically significant while spillovers diffused by bilateral imports are statistically insignificant.[1]

Another study by Park (2004) who follows the basic CH specification and weighting scheme, and employs cointegration techniques, shows that domestic R&D and knowledge spillovers through student migration are significant, whereas knowledge flows through trade are insignificant. Lee (2006), who follows the CH framework and uses dynamic OLS for a panel of 16 OECD countries from 1981-2000, shows that knowledge spillovers embodied in inward FDI and disembodied in patent citation and technological proximity are significant, while those embodied in outward FDI, and imports through a CH weighted foreign R&D variable based on imports of intermediate goods are insignificant.

More recently, Zhu and Jeon (2007) basing themselves on the CH framework, weighting scheme and sample from 1981-1998, and using OLS and DOLS models, demonstrate that international trade, inward and outward stock-based FDI and information technology are significant and positive channels of knowledge diffusion when they interact with their respective measure of openness (except outward FDI in DOLS models), but trade-related spillovers shrink. Coe et al. (2009) show that when the human capital is accounted for, R&D spillovers shrink. However, when

[1] However, Falvey et al. (2004), using weighting schemes similar to those of CH and LP, find that spillovers through imports are significant (either as a public or a private good) while the evidence of spillovers through exports (which is more likely to be a public good) was less convincing.

openness and foreign R&D are interacted, they rise. Also, when institutional variables are added (without human capital), the spillovers tend to increase; conversely, they fall when patent protection and human capital are incorporated.

2. Unit Root Tests Results

<<INSERT TABLE A HERE>>

3. Additional Results of Static Econometric Models

Table B reports results for models which include foreign R&D variables based on alternative weighting schemes. As can be seen, specifications (i) to (iv), which include LP foreign R&D variables that allow for knowledge dissemination from all OECD countries plus BRICs and from 23 OECD countries plus BRICs, are characterized by stationarity and low degrees of cross-section dependence of the residuals and yield significant foreign and domestic R&D estimates. This also applies only to the specifications with a CH weighted foreign R&D variable, which allows for knowledge dissemination from 23 OECD countries plus BRICs, such as (v), and from all OECD countries plus BRICs, such as (vii), both without a time trend. In contrast, four specifications that include a foreign R&D variable based on CH weights (in Table B, models (vi) and (viii) to (x)) are misspecified, due to strong cross-section dependence of the residuals, despite the fact that all domestic and foreign R&D coefficients are positive and significant at the 1% level. This suggests that these specifications are characterized by seriously biased and inconsistent estimates, even when unobserved common shocks have been regarded. According to these findings, we can conclude that the estimates of the R&D variables embody a mixture of the direct effects of the R&D variables and unobservables because they are subject to residual cross-section dependence. Therefore, trade-related R&D spillovers cannot be identified. In fact, this problem is more pervasive for the estimates where a CH foreign R&D variable has been included, because the coefficient of a spillover variable is subject to a high degree of residual cross-section dependence, which also yields drastic changes in the domestic R&D estimates compared to the estimates of other models.

<<INSERT TABLE B HERE>>

4. Additional Results of Dynamic Models That Account For Error Cross-Section Dependence

Tables C1 to C5 present results for dynamic models that include LP and CH foreign R&D variables weighted by different schemes and that account for unobservables. Tables C1 and C2 contain results from dynamic models that include LP weighted foreign R&D variables which allow for knowledge dissemination from 23 OECD countries plus BRICs and from all OECD countries plus BRICs respectively. They show that there is complementarity between the results of the CS-ARDL and CS-DLMG models since at least one of the former which include three lagged cross-section averages of the variables, two of the former which incorporate two lagged cross-section averages, and all the CS-DLMG models, yield positive and significant estimates of the domestic and foreign R&D. Moreover, these models are not misspecified since there are low degrees of residual cross-section dependence and cointegration in the long-run is achieved at the 1% level for the CS-ARDL models. In Tables C3 and C4, it seems that when the models include a CH foreign R&D variable, the coefficient of this variable is larger than that obtained from models which include LP foreign R&D variables and that have been reported in Tables C1, C2 and Table 5 of the main article. Further, the coefficient of the domestic R&D is significant in most cases, long-run cointegration is significant at the 1% level for CS-ARDL models, and at least three CS-ARDL and all CS-DLMG models yield low degrees of the cross-section dependence of residuals and significant and positive domestic and foreign R&D coefficients.

<<INSERT TABLES C1 TO C4 HERE>>

A different situation is presented in Table C5 where a CH weighted foreign R&D variable with information on knowledge transmission from all countries of the sample has been incorporated. Although all CS-DLMG models have low degrees of the cross-section dependence of the residuals, positive and significant estimates for the domestic and foreign R&D variables, and large foreign R&D estimates, only one of the five CS-ARDL models is characterized by all these features. The other four CS-ARDL models manage to have many of these features, but, strangely, none of their domestic R&D coefficients are significant and all are very small compared to the estimates from Tables C3 and C4. This unusual change does not happen when a LP weighted foreign R&D variable is introduced under any of the three knowledge diffusion configurations stated in Tables C1, C2 or Table 5 of the main article. As a result, the CS-ARDL and CS-DLMG models from Table C5 are not as complementary as the models in Tables C3 and C4. This might indicate that results of dynamic models which account for feedback effects and unobserved common effects are sensitive to the inclusion of a CH weighted foreign R&D regressor which incorporates the global dissemination of knowledge from all countries of the sample (including most of the emerging economies of the sample). Therefore, this evidence indicates that the inclusion of this sort of weighted knowledge variable could affect estimates of the domestic R&D regressor. Moreover, these findings indicate that LP and CH spillover variables cannot successfully separate R&D spillovers from unobservables. In fact, their coefficients might be capturing other data cross-section dependencies rather than genuine R&D spillovers.

<<INSERT TABLE C5 HERE>>

5. Plots of All Series

Data for 7 countries are illustrated in Figures 1 to 3. Figure 1 shows that the Chinese TFP registered the largest growth between 1970 and 2011 (3% on average), with a shift in 1980. In contrast, the Brazilian TFP registered a negative growth, at an average rate of 0.5% and coincided with Latin America’s “lost decade” in the 1980’s. Thailand, the US, the UK and India show a similar TFP growth rate (0.7%) and increase at an identical rate over time. Although the Russian TFP also grows by 0.7% on average over time, its dynamic is different from that of the other six countries. It falls in the 90s due to a structural change of its political and economic regime, but then it rises steadily from 1999. Moreover, the TFP falls for all countries (except China) in 2008, and later TFP recovers.

Figure 2 displays a positive trend for the domestic R&D capital stock, except for Russia which exhibits a slight U shape evolution. Chinese domestic R&D grows quickly from 2000, while the growth of Brazilian and the Indian domestic R&D accelerate from the mid 1980's (with an average growth of 4% from 1970 to 2011). Conversely, the UK domestic R&D registers the smallest growth rate (2%) after Russia, whose growth rate is negative (-0.4%). As seen in Figure 3, foreign R&D capital stock presents a monotonic upward trend, falls for all countries in 2008 and is more volatile across countries than the domestic R&D capital stock and the TFP. The foreign R&D for China, Russia, Thailand and India grow faster than the other countries (15.6%, 13.5%, 9.8% and 7.2% in average respectively). Meanwhile, the UK and the US register the lowest growth rates (which rose about 4%).

<<INSERT FIGURES 1 TO 3 HERE>>

6. Stata Routines

We carried out our empirical study in Stata 13 by using the following econometric routines[2]:

i) Multipurt of Eberhardt (2011a) and Xtfisher of Merryman (2005). I employ these routines to examine residual nonstationarity according to the Pesaran (2007) panel unit root test.

ii) Xtcd of Eberhardt (2011b) which we use according to the Pesaran (2015) CD test for weak cross-section dependence, and which is based on the CD test of Pesaran (2004).

iii) Xtmg of Eberhardt (2012) updated by Eberhardt (2013). I use this command to carry out all regressions where I allow for heterogeneity in technology parameters.

7. Data collection on Gross Expenditure on R&D (GERD) as a percentage of GDP

<<INSERT TABLES D1 AND D2 HERE>>

[2] Stata Do-files with full routines are available upon request.

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TABLE A

Panel 1: Logarithmic Variables in Levels						
Pesaran (2007) CIPS test (Including a Constant)						
Lags	*TFP*		*Rd*		*Rf*	
	Chi sq	*p-value*	*Chi sq*	*p-value*	*Chi sq*	*p-value*
0	4.666	1.000	9.486	1.000	-0.669	0.252
1	2.164	0.985	-1.369	0.085	1.787	0.963
2	3.556	1.000	1.335	0.909	4.514	1.000
3	3.777	1.000	2.860	0.998	4.076	1.000
Pesaran (2007) CIPS test (Including a Constant and a Time Trend)						
Lags	*TFP*		*Rd*		*Rf*	
	Chi sq	*p-value*	*Chi sq*	*p-value*	*Chi sq*	*p-value*
0	2.272	0.988	3.296	1.000	-2.317	0.010
1	-0.820	0.206	-3.239	0.001	-0.291	0.386
2	0.274	0.608	0.319	0.625	1.729	0.958
3	1.278	0.899	1.986	0.976	0.933	0.825
Panel 2: Logarithmic Variables in First Differences						
Pesaran (2007) CIPS test (Including a Drift)						
Lags	*Δ TFP*		*Δ Rd*		*Δ Rf*	
	Chi sq	*p-value*	*Chi sq*	*p-value*	*Chi sq*	*p-value*
0	-20.802	0.000	-3.462	0.000	-26.145	0.000
1	-14.246	0.000	-3.954	0.000	-17.144	0.000
2	-9.186	0.000	-2.829	0.002	-10.203	0.000
3	-6.377	0.000	-1.734	0.041	-7.710	0.000

Notes: The Pesaran (2007) test presents a standardized Z-tbar statistic and its respective p-value. The null hypotheses refer to all series which are nonstationary at the 5% level of significance. Zero to three lags augmentation in the performed Dickey Fuller regressions are included. Panel 1 displays the Dickey Fuller regression for logarithmic variables in levels, including a constant, on the one hand, and, on the other, a constant and a trend. Panel 2 contains the variables in first differences including a drift (constant).

TABLE B

Other results for static CCEMG models

	(i)	*(ii)*	*(iii)*	*(iv)*	*(v)*	*(vi)*	*(vii)*	*(viii)*	*(ix)*	*(x)*
TFP dependent variable										
Independent variables										
Rd	0.056**	0.090***	0.056**	0.094***	0.061***	0.063***	0.066***	0.062***	0.068***	0.065***
std errors	(0.022)	(0.022)	(0.023)	(0.021)	(0.018)	(0.024)	(0.020)	(0.021)	(0.018)	(0.021)
Rf	0.055***	0.060***	0.057***	0.060***	0.048***	0.057***	0.045***	0.057***	0.043***	0.051***
std errors	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.015)
CD-test	0.06	-0.39	-0.29	-0.64	1.77	2.06†	1.78	2.11†	2.12†	2.44†
Order of Integration	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
RMSE	0.034	0.031	0.035	0.032	0.034	0.036	0.035	0.029	0.035	0.029
NXT	1871	1871	1871	1871	1871	1871	1871	1871	1871	1871
N	50	50	50	50	50	50	50	50	50	50
Time Trend	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES

Notes: log total factor productivity (TFP) is the dependent variable. log domestic R&D (Rd) and log foreign R&D (Rf) are the independent variables. A constant term is included but not reported. Estimator: CMG, Common Correlated Effects MG Pesaran (2006) augmented with cross-section averages is employed in ten different setups: (i) and (ii) include a Rf variable defined by Lichtenberg and van Pottelsberghe de la Potterie (1998) (henceforth LP) which allows for knowledge transmission from 23 OECD countries plus BRICs, (iii) and (iv) incorporate a LP-Rf variable allowing for knowledge diffusion from all OECD countries of the sample plus BRICs, (v) and (vi) include a Rf variable defined by Coe and Helpman (1995) (henceforth CH) which allows for knowledge flows from 23 OECD countries plus BRICs, (vii) and (viii) incorporate a CH-Rf variable allowing for knowledge dissemination from all OECD countries plus BRICs, (ix) and (x) include a CH-Rf variable allowing for knowledge diffusion from all the countries of the sample. White heteroskedasticity-robust standard errors are reported in parentheses. Levels of significance are represented by * 10%, ** 5% and *** 1%. Diagnostics: (evaluated at the 5% level of significance, full results of the next tests are available on request): 1) CD test: The Pesaran (2015) test which is based on Pesaran (2004), for which Ho: Cross-section weak dependence of the residuals. 2) CIPS test: The Pesaran (2007) test evaluates the order of integration of the residuals where I(0): stationary, I(1): nonstationary. Root mean squared error (RMSE), NXT number of country-time observations and N number of countries are also included. † indicates that the null hypothesis of weak cross-section dependence of the residuals at the 5% level is rejected.

TABLE C1

Dynamic panel data models in a ECM representation accounting for cross-section dependence of errors and LP knowledge diffusion from 23 OECD countries plus BRICS

Estimators	*CS-ARDL (ECM)*					*CS-DLMG*		
	(i)			*(ii)*				
	1 lag	*2 lags*	*3 lags*	*1 lag*	*2 lags*	*1 lag*	*2 lags*	*3 lags*
TFP dependent variable								
Independent variables								
Rd	0.035	0.067**	0.064*	0.075**	0.086**	0.077***	0.102***	0.115***
std errors	(0.029)	(0.031)	(0.035)	(0.035)	(0.033)	(0.017)	(0.027)	(0.037)
Rf	0.083***	0.064**	0.073*	0.073**	0.059*	0.050**	0.062**	0.082***
std errors	(0.030)	(0.029)	(0.039)	(0.033)	(0.034)	(0.021)	(0.025)	(0.030)
Cointegration coefficients	-0.433***	-0.526***	-0.623***	-0.394***	-0.469***			
std errors	(0.040)	(0.055)	(0.075)	(0.034)	(0.047)			
CD-test	-1.75	-0.06	-0.04	-1.31	0.02	-1.60	-1.04	-0.16
RMSE	0.013	0.011	0.014	0.015	0.013	0.026	0.018	0.017
NXT	1720	1640	1579	1791	1735	1758	1741	1687
N	48	45	43	50	48	50	50	48

Notes: log total factor productivity (TFP) is the dependent variable. log domestic R&D capital stock (Rd) and log foreign R&D capital stock defined by Lichtenberg and van Pottelsberghe de la Potterie (1998) (Rf) (allowing for R&D transmission from 23 OECD countries of the sample) are the independent variables. A constant term is included but not reported. Long run estimates and cointegration coefficients are reported. Estimators for autoregressive distributed lagged (ARDL) panel data specifications, which are represented by a Error Correction Model (ECM), are the following: 1) Dynamic cross-sectional ARDL Chudik and Pesaran (2013) (CS-ARDL-i) (augmented with three lags of the cross-sectional averages of the dependent and independent variables). 2) Dynamic cross-sectional ARDL (CS-ARDL-ii) (augmented with two lags of the cross-sectional averages of the dependent and independent variables). 3) Cross-sectional DL Chudik et al. (2013) Mean Group: CS-DLMG (augmented with three lags of the cross-sectional averages of the independent variables). White heteroskedasticity-robust standard errors are reported in parentheses. All models include a time trend. CS-ARDL (i) models are augmented with p=1, 2 and 3 lagged dependent and independent variables. CS-ARDL (ii) models are augmented with p=1 and 2 lags. CS-DLMG models are augmented with p=1, 2 and 3 lagged independent variables. Levels of significance are represented by * 10%, ** 5% and *** 1%. Diagnostics: See Table B, except for the CIPS test.

TABLE C2

Dynamic panel data models in a ECM representation accounting for cross-section dependence of errors and LP knowledge diffusion from all OECD countries plus BRICS

Estimators	*CS-ARDL (ECM)*					*CS-DLMG*		
		(i)		*(ii)*				
	1 lag	*2 lags*	*3 lags*	*1 lag*	*2 lags*	*1 lag*	*2 lags*	*3 lags*
TFP dependent variable								
Independent variables								
Rd	0.041	0.063**	0.057	0.059*	0.092**	0.077***	0.096***	0.112***
std errors	(0.030)	(0.031)	(0.037)	(0.033)	(0.037)	(0.018)	(0.025)	(0.034)
Rf	0.084***	0.065**	0.054	0.076**	0.067**	0.057***	0.063**	0.084***
std errors	(0.030)	(0.029)	(0.036)	(0.032)	(0.031)	(0.020)	(0.024)	(0.028)
Cointegration coefficients	-0.441***	-0.538***	-0.632***	-0.402***	-0.471***			
std errors	(0.040)	(0.056)	(0.079)	(0.034)	(0.048)			
CD-test	-1.95	0.03	-0.11	-1.51	0.09	-1.88	-1.29	-0.41
RMSE	0.013	0.011	0.013	0.015	0.013	0.025	0.018	0.017
NXT	1720	1640	1579	1791	1735	1758	1741	1687
N	48	45	43	50	48	50	50	48

Notes: log total factor productivity (TFP) is the dependent variable. log domestic R&D capital stock (Rd) and log foreign R&D capital stock defined by Lichtenberg and van Pottelsberghe de la Potterie (1998) (Rf) (allowing for R&D transmission from all OECD countries of the sample) are the independent variables. See also the notes to Table C1.

TABLE C3

Dynamic panel data models in a ECM representation accounting for cross-section dependence of errors and CH knowledge diffusion from 23 OECD countries plus BRICS

Estimators	*CS-ARDL (ECM)*					*CS-DLMG*		
	(i)			*(ii)*				
	1 lag	*2 lags*	*3 lags*	*1 lag*	*2 lags*	*1 lag*	*2 lags*	*3 lags*
TFP dependent variable								
Independent variables								
Rd	0.072**	0.072*	0.084**	0.067*	0.092**	0.124***	0.110***	0.082***
std errors	(0.033)	(0.041)	(0.040)	(0.037)	(0.038)	(0.024)	(0.023)	(0.023)
Rf	0.094***	0.066***	0.057**	0.110***	0.082***	0.067***	0.073***	0.091***
std errors	(0.028)	(0.024)	(0.027)	(0.030)	(0.028)	(0.021)	(0.024)	(0.028)
Cointegration coefficients	-0.537***	-0.701***	-0.820***	-0.490***	-0.602***			
std errors	(0.052)	(0.066)	(0.084)	(0.036)	(0.051)			
CD-test	-2.42†	-0.32	-1.15	-0.65	2.08†	-1.16	-1.08	-1.12
RMSE	0.013	0.018	0.009	0.015	0.013	0.019	0.017	0.015
NXT	1720	1640	1579	1791	1735	1758	1741	1687
N	48	45	43	50	48	50	50	48

Notes: log total factor productivity (TFP) is the dependent variable. log domestic R&D capital stock (Rd) and log foreign R&D capital stock defined by Coe and Helpman (1995) (Rf) (allowing for R&D transmission from 23 OECD countries of the sample) are the independent variables. See also the notes to Table C1.

TABLE C4

Dynamic panel data models in a ECM representation accounting for cross-section dependence of errors and CH knowledge diffusion from all OECD countries plus BRICS

Estimators	*CS-ARDL (ECM)*					*CS-DLMG*		
	(i)			*(ii)*				
	1 lag	*2 lags*	*3 lags*	*1 lag*	*2 lags*	*1 lag*	*2 lags*	*3 lags*
TFP dependent variable								
Independent variables								
Rd	0.094**	0.056	0.068*	0.075*	0.071*	0.108***	0.092***	0.086***
std errors	(0.044)	(0.042)	(0.039)	(0.039)	(0.039)	(0.030)	(0.030)	(0.032)
Rf	0.099***	0.087***	0.092***	0.128***	0.104***	0.067***	0.086***	0.096***
std errors	(0.029)	(0.022)	(0.028)	(0.033)	(0.028)	(0.021)	(0.030)	(0.031)
Cointegration coefficients	-0.573***	-0.736***	-0.885***	-0.507***	-0.633***			
std errors	(0.051)	(0.060)	(0.090)	(0.035)	(0.051)			
CD-test	-1.59	0.19	-0.66	-0.44	1.98†	-0.8	-0.12	-0.75
RMSE	0.013	0.011	0.009	0.015	0.013	0.019	0.017	0.015
NXT	1720	1640	1579	1791	1735	1758	1741	1687
N	48	45	43	50	48	50	50	48

Notes: log total factor productivity (TFP) is the dependent variable. log domestic R&D capital stock (Rd) and log foreign R&D capital stock defined by Coe and Helpman (1995) (Rf) (allowing for R&D transmission from all OECD countries of the sample) are the independent variables. See also the notes to Table C1.

TABLE C5

Dynamic panel data models in a ECM representation accounting for cross-section dependence of errors and CH knowledge diffusion from all countries

Estimators	*CS-ARDL (ECM)*					*CS-DLMG*		
	(i)			*(ii)*				
	1 lag	*2 lags*	*3 lags*	*1 lag*	*2 lags*	*1 lag*	*2 lags*	*3 lags*
TFP dependent variable								
Independent variables								
Rd	0.082*	0.026	0.031	0.059	0.037	0.108***	0.070**	0.061*
std errors	(0.046)	(0.041)	(0.043)	(0.042)	(0.035)	(0.036)	(0.033)	(0.032)
Rf	0.092***	0.083***	0.087***	0.107***	0.091***	0.068***	0.081***	0.102***
std errors	(0.029)	(0.026)	(0.029)	(0.032)	(0.028)	(0.024)	(0.031)	(0.033)
Cointegration coefficients	-0.587***	-0.751***	-0.899***	-0.523***	-0.666***			
std errors	(0.051)	(0.069)	(0.083)	(0.035)	(0.052)			
CD-test	-1.71	0.38	-0.62	-0.34	1.55	-0.67	-0.15	-0.53
RMSE	0.013	0.019	0.009	0.015	0.012	0.019	0.017	0.015
NXT	1720	1640	1579	1791	1735	1758	1741	1687
N	48	45	43	50	48	50	50	48

Notes: log total factor productivity (TFP) is the dependent variable. log domestic R&D capital stock (Rd) and log foreign R&D capital stock defined by Coe and Helpman (1995) (Rf) (allowing for R&D transmission from all countries of the sample) are the independent variables. See also the notes to Table C1.

TABLE D1

Data collection of Gross Expenditure on R&D (GERD) as a percentage of GDP, part 1

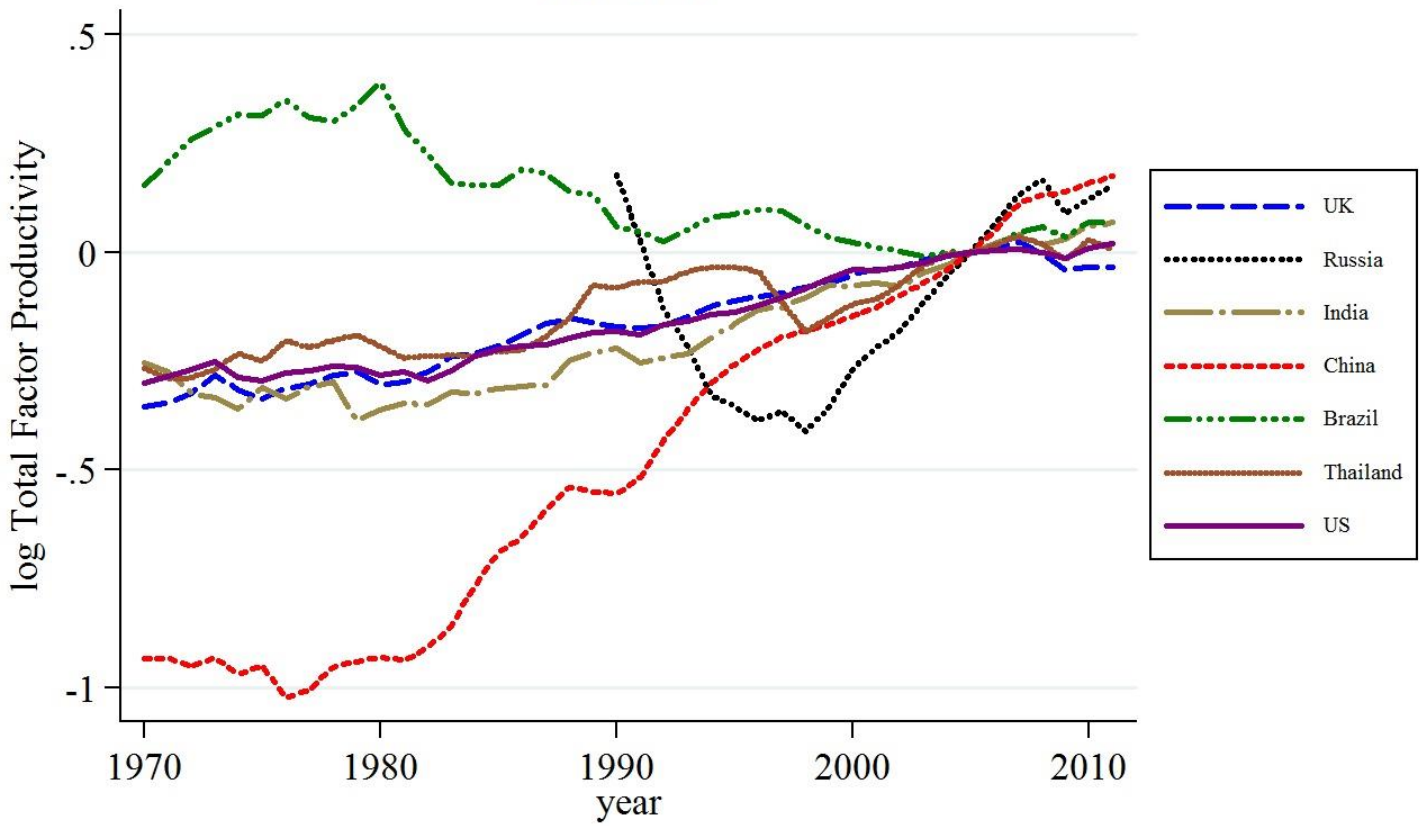
Country	*UNESCO Institute for Statistics on Science*	*UNESCO 1999 Statistical Yearbook*
Argentina	1996-2010	1995
Australia	1996-2010 (even years)	1981, 1984-1988, 1990, 1992, 1994
Austria	1996-2011	1981-1995
Brazil	2000-2010	1994-1996
Bulgaria	1996-2011	1992-1994
Canada	1996-2011	1981-1995
Chile	2007-2010	1993-1996
China	1996-2011	1988-1995
Colombia	1996-1997, 2000-2011	1982
Costa Rica	1996-2000, 2003-2004, 2006-2011	1989-1991
Cyprus	1998-2011	1991-1992
Denmark	1996-1999, 2001-2011	1981-1993, 1995
Ecuador	1996-1998, 2001-2003, 2006-2008	1993-1995
Egypt	1996-2000, 2004-2011	1992-1995
Estonia	1998-2011	1993-1997
Finland	1996-2011	1984-1995
France	1996-2011	1981-1995
Germany	1996-2011	1991-1995
Greece	1997, 1999, 2001, 2003-2007	1981, 1986, 1988-1989, 1991, 1993
Hungary	1996-2011	1981-1995
Iceland	1996-2003, 2005-2008	1981, 1983-1987, 1989-1996
India	1996-2007	1980-1994
Indonesia	2000, 2001, 2009	1980-1988, 1994
Ireland	1996-2011	1981-1995
Israel	1996-2011	1989-1995 (except 1991)
Italy	1996-2011	1980-1995
Japan	1996-2010	1980-1995 (except 1992)
Korea	1996-2010	1980-1995 (except 1987-1988)
Malaysia	1996-2008 (even years), 2009-2011	1992, 1994
Mexico	1996-2011	1984-1995 (except 1989-1992)
Netherlands	1996-2011	1980-1995
New Zealand	1997-2009 (odd years)	1989-1995 (except 1994)
Norway	1997, 1999, 2001-2011	1980-1987, 1989-1995 (odd years)
Panama	1996-2010	1986
Peru	1997-2004	1981-1984
Philippines	2002, 2003, 2005, 2007	1981-1984 (except 1982), 1992
Poland	1996-2011	1985-1995 (except 1987, 1993)
Portugal	1996-2011	1980-1992 (even years), 1995
Romania	1996-2011	1991, 1995
Russia	1996-2011	1994, 1995
Singapore	1996-2010	1981, 1984, 1987, 1990, 1995
Spain	1996-2011	1981-1995
Sweden	1997, 1999, 2001, 2003-2011	1981-1995 (even years)
Switzerland	1996, 2000, 2004, 2008	1981, 1983, 1992
Thailand	1996, 1997, 1999-2007, 2009	1980, 1982-1985, 1987, 1989-1991, 1993, 1995
Turkey	1996-2010	1984-1985, 1990-1995
United Kindom	1996-2011	1981, 1983, 1985-1995
United States	1996-2011	1980-1995
Uruguay	1996-2000, 2002, 2006-2010	-
Venezuela	-	1980-1992

TABLE D2

Data collection of Gross Expenditure on R&D (GERD) as a percentage of GDP, part 2

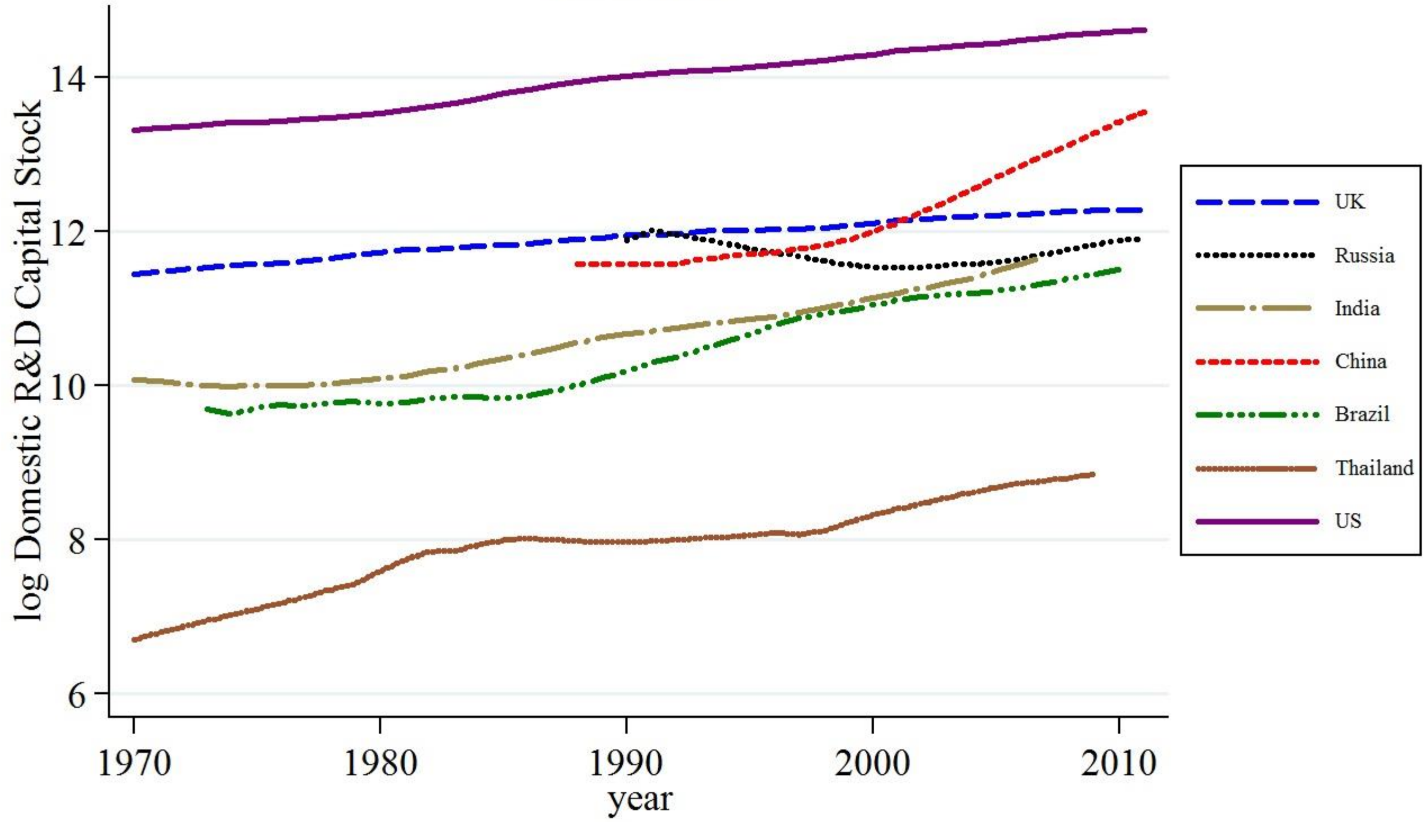
Country	*OECD Main Science and Technology*	*Lederman and Saenz (2005)*
Argentina	2011	1970-1980 (even years), 1981-1982, 1988, 1990-1994
Australia	-	1973, 1976, 1978
Austria	-	1970, 1972, 1975, 1978
Brazil	-	1973-1978, 1980, 1982, 1985, 1990-1993, 1999
Bulgaria	-	1980-1981, 1989-1991, 1995
Canada	-	1970-1980
Chile	-	1979-2004 (except 1981-1982, 1993-1996)
China	-	-
Colombia	-	1971, 1978, 1995, 1998-1999
Costa Rica	-	1974-1979, 1983, 1985-1986, 1988
Cyprus	-	1980-1984
Denmark	-	1973, 1976-1977, 1979
Ecuador	-	1970, 1973, 1976, 1979, 1990
Egypt	-	1973, 1976, 1982, 1990
Estonia	-	1992
Finland	1981, 1983	1971-1979 (even years) (interpolation 1969-1971 to cover 1970)
France	-	1970-1980
Germany	1981-1990	1971, 1974-1975, 1977, 1979-1980
Greece	1995	1976, 1979-1980, 1982-1983 (interpolation 1969-1976 to cover 1970-1975)
Hungary	-	1970-1971, 1974-1980
Iceland	2009	1971-1979 (even years) (interpolation 1966-1971 to cover 1970)
India	-	1970-1978 (except 1973), 1995
Indonesia	-	1972-1979, 1995
Ireland	-	1971, 1974-1975, 1977, 1979 (interpolation 1969-1971 to cover 1970)
Israel	1991	1970-1978, 1981-1983, 1985-1986
Italy	-	1970-1979
Japan	1992, 2011	1970-1979
Korea	2011	1970-1971, 1974-1979, 1988
Malaysia	-	1988-1989
Mexico	-	1970-1974 (except 1972), 1989
Netherlands	-	1970-1979
New Zealand	1981, 1983, 2011	1972-1979 (except 1973, 1978)
Norway	-	1970-1979 (except 1973, 1975-1976)
Panama	-	1990-1995
Peru	-	1971, 1973, 1976, 1985, 1987-1989, 1993-1996
Philippines	-	1970-1975, 1979-1980, 1982, 1989-1991
Poland	1993	-
Portugal	1983-1993 (odd years), 1994	1971-1972, 1976, 1978 (interpolation 1967-1971 to cover 1970)
Romania	1992-1994	1989
Russia	1989-1993	-
Singapore	1994, 2011	1978 (interpolation 1965-1978 to cover 1970-1977)
Spain	-	1970-1976 (except 1975)
Sweden	-	1971-1979 (odd years) (interpolation 1969-1971 to cover 1970)
Switzerland	1986, 1989	1970-1979
Thailand	-	1979 (interpolation 1968-1979 to cover 1970-1978)
Turkey	2011	1970-1972, 1975, 1977-1980, 1983
United Kindom	-	1972, 1975, 1978 (interpolation 1961-1972 to cover 1970-1971)
United States	-	1970-1979
Uruguay	-	1971-1972, 1990-1995 (interpolation 1967-1971 to cover 1970)
Venezuela	-	1970, 1973, 1977, 1993-2000

Figure 1: Total Factor Productivity
1970-2011



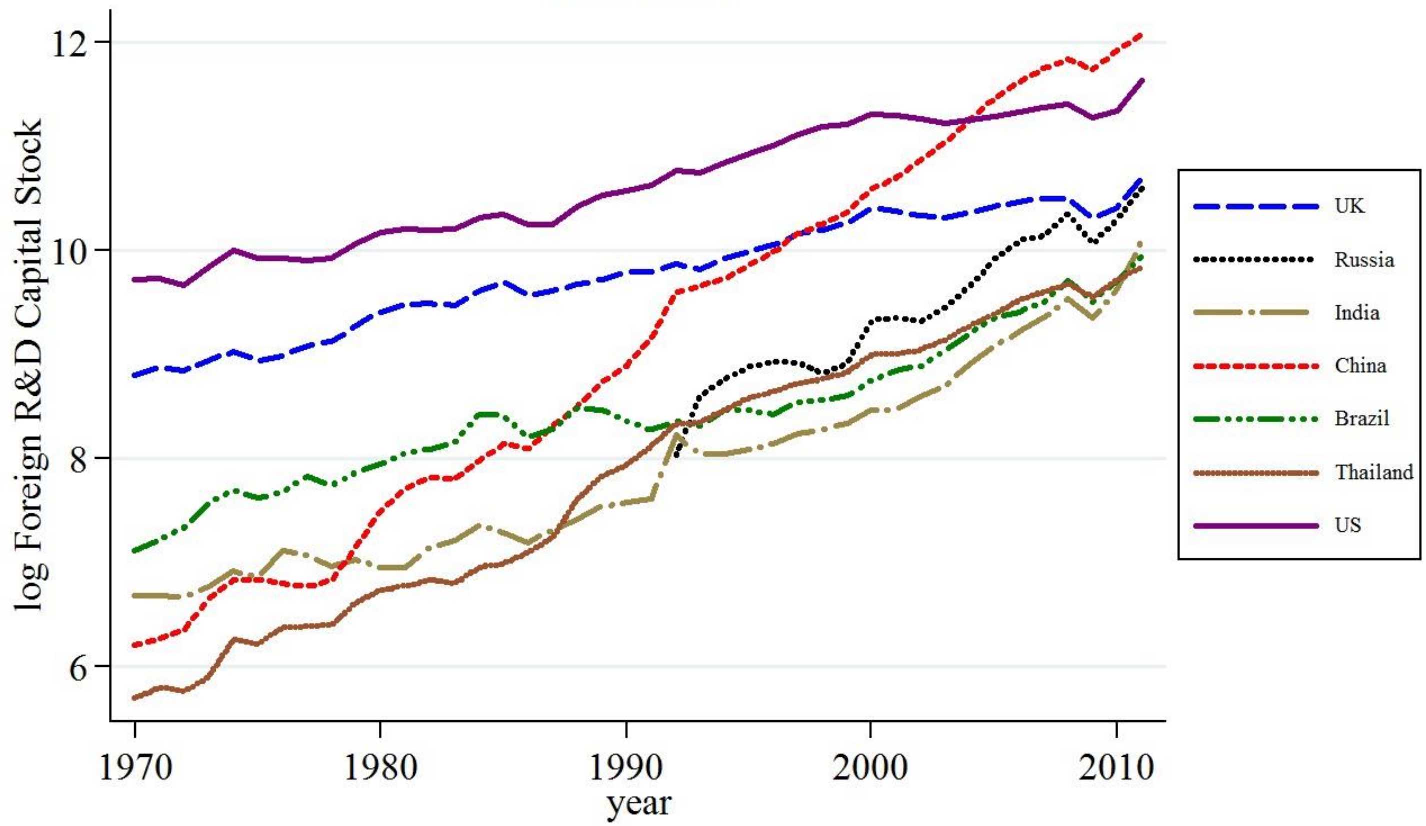
Total Factor Productivity (TFP) derived from national accounts variables (2005=1).
Source: Penn World Table 8.0.

Figure 2: Domestic R&D Capital Stock (Rd)
1970-2011



Rd is defined in terms of constant 2005 million dollars based on purchasing power parity (PPP).
For information about the construction of Domestic R&D Capital Stock refer to the article.

Figure 3: Foreign R&D Capital Stock (Rf)
1970-2011



Rf in constant 2005 million dollars at PPP is based on Litchtenberg and van Pottelsberghe de la Potterie (1998) bilateral import weights. For more information refer to the article.