Seminar in International Economics
17 September 2018

Human Capital, Technology Diffusion and Total Factor Productivity Growth in Regions

Anja Kukuvec
Vienna University of Economics and Business (WU)

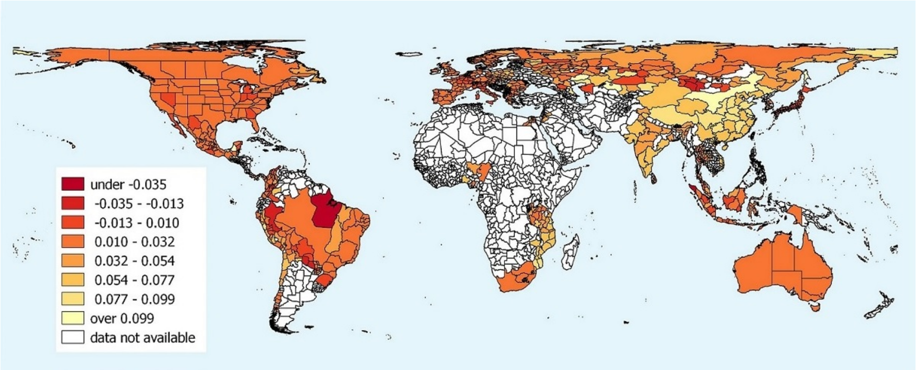
This seminar series is an activity in the framework of FIW ('Forschungsschwerpunkt Internationale Wirtschaft'), which is a project designed to build a center of excellence in research on International Economics, funded by the Austrian Ministry for Digital and Economic Affairs (BMDW).

Human Capital, Technology Diffusion and Total Factor Productivity Growth in Regions

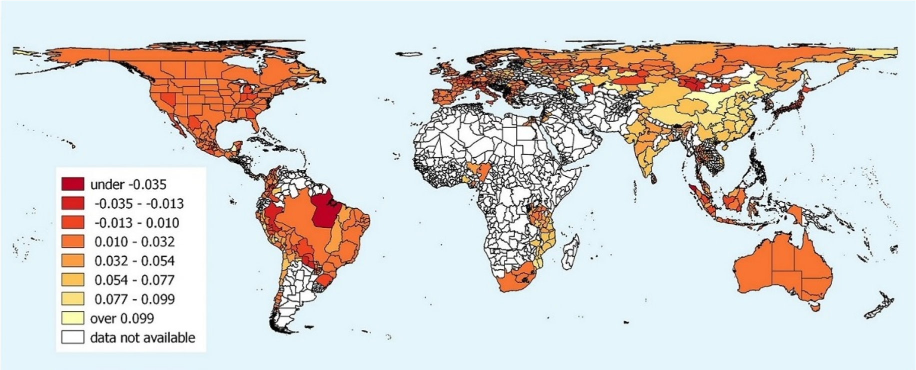
Anja Kukuvec
Vienna University of Economics and Business
Institute for International Economics
anja.kukuvec@wu.ac.at

FIW-wiiw Seminars in International Economics
Vienna, September 17th 2018

Regional Growth 1995-2010

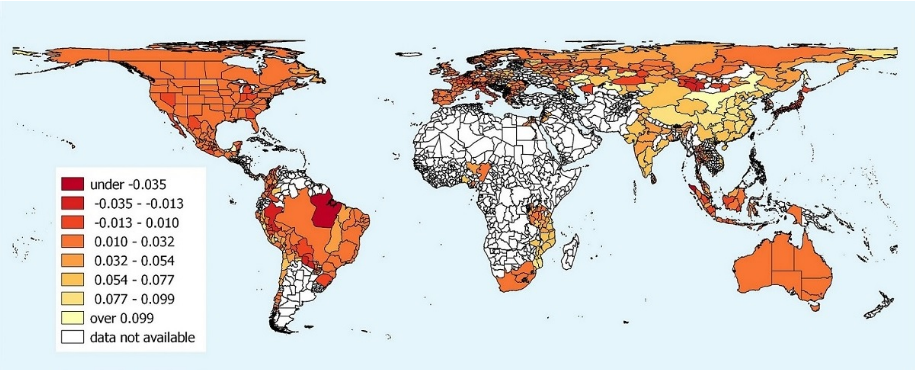


Regional Growth 1995-2010



- Substantial disparities of GDP pc growth between regions

Regional Growth 1995-2010



- Substantial disparities of GDP pc growth between regions
- Spatial dependence of regions

Motivation

- Drivers of regional per capita growth
  - Standard neoclassical growth theory: physical and human capital accumulation and technological progress (Solow, 1956; Mankiw, Romer & Weil, 1992)
    $\Rightarrow$ Long-term per capita growth is only determined by the **exogenous** growth rate of technology (TFP growth)

Motivation

- Drivers of regional per capita growth
  - Standard neoclassical growth theory: physical and human capital accumulation and technological progress (Solow, 1956; Mankiw, Romer & Weil, 1992)
    ⇒ Long-term per capita growth is only determined by the **exogenous** growth rate of technology (TFP growth)
  - Benhabib & Spiegel (1994): technological progress is **not exogenous** but dependent on the stock level of **human capital** and its **interaction with backwardness**
    ⇒ Presumption that an educated labor force is better at creating, implementing and adopting new technologies from abroad

Motivation

- Drivers of regional per capita growth
  - Standard neoclassical growth theory: physical and human capital accumulation and technological progress (Solow, 1956; Mankiw, Romer & Weil, 1992)
    ⇒ Long-term per capita growth is only determined by the **exogenous** growth rate of technology (TFP growth)
  - Benhabib & Spiegel (1994): technological progress is **not exogenous** but dependent on the stock level of **human capital** and its **interaction with backwardness**
    ⇒ Presumption that an educated labor force is better at creating, implementing and adopting new technologies from abroad
- Spatial dependence
  - **Spatial externalities of technology** (e.g. Ertur & Koch, 2007; Fischer, 2011)
    ⇒ Technology diffusion is influenced by geographical distance

Research Question

- Do **human capital** and **technology diffusion** play a role in explaining regional differences in **technological progress**?

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS

Research Question

- Do **human capital** and **technology diffusion** play a role in explaining regional differences in **technological progress**?
- ***How*** does regional technology diffuse across regions?

Technology diffusion by Benhabib & Spiegel (1994)

$$\frac{\dot{A}_i(t)}{A_i(t)} = g(H_i(t)) + c(H_i(t))\frac{A_m(t) - A_i(t)}{A_i(t)}, \quad i = 1, ..., N \tag{1}$$

where $A_i(t)$ is the level of technology in region i at time t, $H_i(t)$ is its exogenous stock of human capital, $A_m(t)$ is the level of technology in the region with highest level of technology (technology leader) at time t

- Technological progress depends on stock of human capital and technology adoption from abroad
- $g(H_i(t))$ is the endogenous region specific growth rate driven by human capital $\rightarrow$ domestic innovation
- $c(H_i(t))$ is the speed of technological "catch-up" of region i to the leading region m
- $g(H_i(t))$ and $c(H_i(t))$ are non-decreasing functions of H_i

Implications

- The Benhabib & Spiegel (B&S) model (1994) implicitly presumes that a region only adopts technology from the technology leader
- Supposing a region can also benefit from technology spillovers of other regions
  $\Rightarrow$ Impose a spatial econometric model setting on the B&S model

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS

Spatial Durbin Model (SDM)

$$\boldsymbol{y} = \alpha \boldsymbol{\iota}_N + \rho \boldsymbol{W} \boldsymbol{y} + \boldsymbol{X} \boldsymbol{\beta} + \boldsymbol{W} \boldsymbol{X} \boldsymbol{\theta} + \boldsymbol{\epsilon}, \qquad \boldsymbol{\epsilon} \sim \mathcal{N}(0, \sigma^2 \boldsymbol{I}_N) \tag{2}$$

$\boldsymbol{y}$	dependent variable (TFP growth rate) $(N \times 1)$
α	scalar of the intercept
$\boldsymbol{\iota}$	vector of ones $(N \times 1)$
ρ	spatial autoregressive coefficient where $-1 < \rho < 1$
$\boldsymbol{W}$	spatial weight matrix, row standardized $(N \times N)$
$\boldsymbol{X}$	matrix of explanatory variables $(N \times K)$
$\boldsymbol{\beta}$	vector of coefficients of explanatory variables $(K \times 1)$
$\boldsymbol{\theta}$	coefficient of spatially lagged explanatory variables $(K \times 1)$
$\boldsymbol{\epsilon}$	error term $(N \times 1)$
N	number of observations (regions)
K	number of explanatory variables

- $\boldsymbol{X} = [\boldsymbol{h} \quad \boldsymbol{a} \quad \boldsymbol{h} \circ \boldsymbol{a} \quad \boldsymbol{Z}]$, where $\boldsymbol{h}$ is a vector of human capital stocks, $\boldsymbol{a}$ is a vector of technology gaps with $a_i = \frac{A_m}{A_i}$, and $\boldsymbol{Z}$ is a matrix of further control variables
  $\Rightarrow$ Definition of $\boldsymbol{X}$ based on B&S model when assuming that c and g are linear functions of H_i

Technology Diffusion

- The model specification allows for technology spillovers via three channels

  1. **Technological distance** to the technology leader
  2. **Human capital**, which determines the speed of technology adoption
  3. **Geographical distance** $\Rightarrow$ Regions have better access to technology resources of neighbours than of non-neighbours

- Global technology spillovers

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS

Data

- Cross-section of 569 regions in 30 countries (15 non-OECD countries)
- Average annual growth rate in period 1980-2005
- Regions at the most disaggregated administrative or statistical division of countries where data was available (often provinces)
  - Europe: NUTS-2 (except for DEU, GBR: NUTS-1)
- Main source: Gennaioli et al. (2014)
  - In some cases needed to aggregate regions to higher statistical unit $\Rightarrow$ Eurostat Regional Database for population weights

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS

Data

- Construct measure for **total factor productivity** consistent with Benhabib & Spiegel (2005):

$$lnA_{it} = lnY_{it} - \frac{1}{3}lnK_{it} - \frac{2}{3}lnL_{it} \quad (3)$$

where A_{it} is TFP, Y_{it} is GDP, K_{it} is physical capital and L_{it} is population of region i at time t respectively

  - GDP in current purchasing power US$ values
  - Derive estimates for regional stocks of physical capital: national physical capital stock $\times$ share of each region in national GDP
    (estimates for country physical capital stocks from PWT 8.0)

- Measure for **human capital stocks**: average years of schooling
  - Methodology by Barro & Lee (2013)
  - Initial levels (year 1980)

- **Geographical data** on the location of each region: Natural Earth Database

Data - Estimates for TFP growth rates 1980-2005

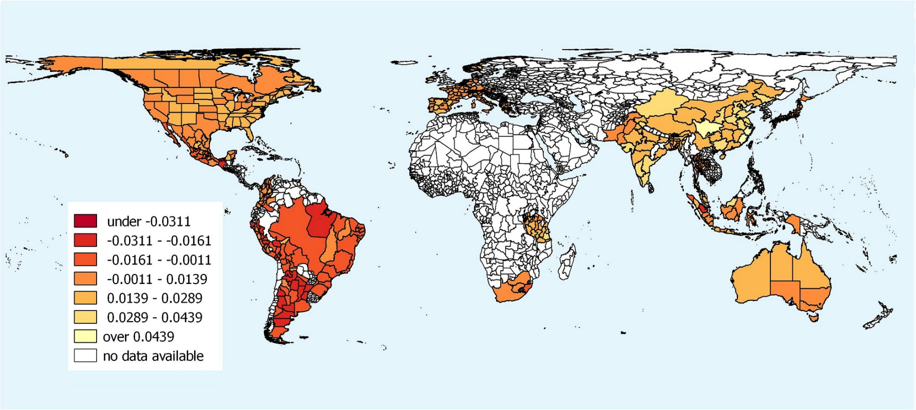


Table: *Estimation results*

Specification	(I)	(II)	(III)	(IV)	(V)	(VI)
$\boldsymbol{h}$	0.111^{***}	0.019	0.011	0.012	0.013	0.011
	(0.021)	(0.050)	(0.035)	(0.048)	(0.036)	(0.058)
$\boldsymbol{a}$	0.055^{***}	0.026^{*}	0.053^{***}	0.050^{***}	0.056^{***}	0.025^{***}
	(0.010)	(0.014)	(0.013)	(0.014)	(0.013)	(0.005)
$\boldsymbol{h} \circ \boldsymbol{a}$	0.022^{***}	0.025^{***}	0.026^{***}	0.021^{***}	0.026^{***}	0.006^{***}
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.002)
$\boldsymbol{W h}$			0.028	-0.071^{*}	-0.008	-0.065^{*}
			(0.037)	(0.041)	(0.040)	(0.038)
$\boldsymbol{W a}$			-0.035^{***}	-0.100^{***}	-0.034^{**}	-0.031^{***}
			(0.015)	(0.019)	(0.015)	(0.005)
$\boldsymbol{W h} \circ \boldsymbol{a}$			-0.020^{***}	0.012^{*}	-0.017^{***}	0.006^{***}
			(0.005)	(0.007)	(0.006)	(0.002)
ρ			0.704^{***}	0.095	0.634^{***}	0.036
			(0.031)	(0.060)	(0.037)	(0.060)
Country FE	NO	YES	NO	YES	NO	YES
Add. controls	NO	NO	NO	NO	YES	YES
R^2	0.260	0.720	0.265	0.736	0.490	0.748
adj. R^2	0.256	0.704	0.257	0.720	0.473	0.727
log L	1725	2005	2097	2218	2122	2229
N	569	569	569	569	569	569

Notes Additional controls: lnoilgas, lnpopden, capcity, invcoast, malaria, latitude. W is a k-nearest neighbour matrix with $k = 5$. Constant not reported in table. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Interpretation of Effects

Taking the non-linearity of the interaction term into consideration (consistent with Balli & Sorensen (2013))

- Linear regression model:

$$\frac{\partial \boldsymbol{y}}{\partial \boldsymbol{h}'} = \boldsymbol{I}_N \beta_1 + \mathsf{diag}(\boldsymbol{a})\beta_3 \tag{4}$$

- Spatial Durbin Model (Piribauer & Wanzenböck, 2016):

$$\frac{\partial \boldsymbol{y}}{\partial \boldsymbol{h}'} = (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1}(\boldsymbol{I}_N \beta_1 + \mathsf{diag}(\boldsymbol{a})\beta_3 + \boldsymbol{W}\theta_1 + \boldsymbol{W}\mathsf{diag}(\boldsymbol{a})\theta_3) \tag{5}$$

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS

Interpretation of Effects

- When the matrix of partial derivatives is summarized as in LeSage & Pace (2009), the effect of a main term is conditional on the *average* level of the other main term

Table: *Impact estimates, without country fixed effects (Spec. (III))*

Variables	Lower 0.01	Mean	Upper 0.99
		Average direct impact	
Human capital $\boldsymbol{h}$	0.186	0.286	0.388
Technology gap $\boldsymbol{a}$	0.179	0.244	0.310
		Average indirect impact	
Human capital $\boldsymbol{h}$	−0.354	−0.241	−0.134
Technology gap $\boldsymbol{a}$	−0.288	−0.217	−0.149
		Average total impact	
Human capital $\boldsymbol{h}$	0.017	0.045	0.077
Technology gap $\boldsymbol{a}$	0.010	0.027	0.045

- In order to demonstrate the impact of the non-linearity $\Rightarrow$ also compute the effect when **the other main term is evaluated at different deciles of its distribtuion**

Figure: *Average impacts of* ***human capital*** *at different quantiles of the tfp gap (Spec. (III))*

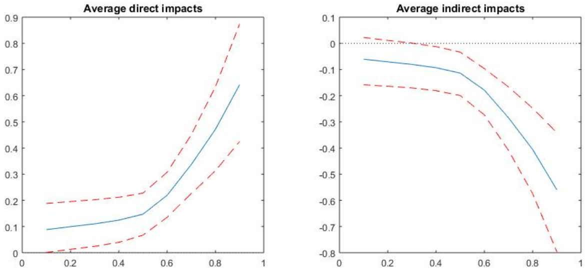


Figure: *Average impacts of* ***tfp gap*** *at different quantiles of human capital (Spec. (III))*

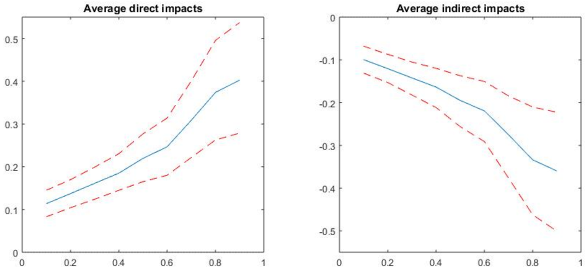


Table: *Impact estimates, with country fixed effects (Spec. (IV))*

Variables	Lower 0.01	Mean	Upper 0.99
		Average direct impact	
Human capital $\boldsymbol{h}$	0.104	0.222	0.342
Technology gap $\boldsymbol{a}$	0.140	0.196	0.252
		Average indirect impact	
Human capital $\boldsymbol{h}$	-0.215	-0.107	0.002
Technology gap $\boldsymbol{a}$	-0.182	-0.128	-0.067
		Average total impact	
Human capital $\boldsymbol{h}$	0.049	0.115	0.185
Technology gap $\boldsymbol{a}$	0.029	0.068	0.106

Figure: *Average impacts of* ***human capital*** *at different quantiles of the tfp gap (Spec. (IV))*

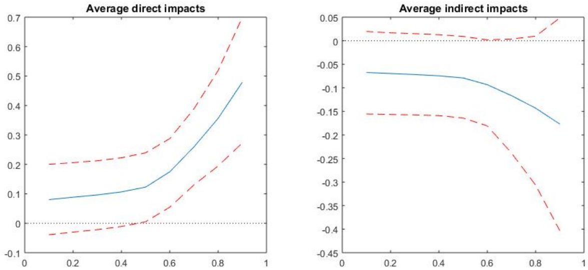


Figure: *Average impacts of* ***tfp gap*** *at different quantiles of human capital (Spec. (IV))*

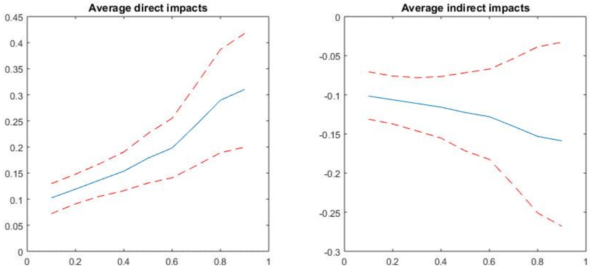


Table: *Average impact estimates including further controls, without country FE (Spec. (V))*

Variables	Lower 0.01	Mean	Upper 0.99
	Average direct impact		
Human capital $\boldsymbol{h}$	0.160	0.289	0.403
Technology gap $\boldsymbol{a}$	0.180	0.243	0.304
Lnoilgas	−17.483	−1.999	13.109
Lnpopden	−0.170	−0.072	0.030
Capcity	−0.116	0.352	0.835
Invcoast	−1.730	0.555	2.771
Malaria	−0.094	−0.021	0.044
Latitude	−0.026	−0.003	0.022
	Average indirect impact		
Human capital $\boldsymbol{h}$	−0.364	−0.248	−0.114
Technology gap $\boldsymbol{a}$	−0.274	−0.206	−0.140
Lnoilgas	−11.136	10.506	32.061
Lnpopden	−0.002	0.097	0.203
Capcity	−0.770	−0.271	0.273
Invcoast	−1.690	0.941	3.679
Malaria	−0.040	0.030	0.105
Latitude	−0.017	0.010	0.035
	Average total impact		
Human capital $\boldsymbol{h}$	0.007	0.041	0.076
Technology gap $\boldsymbol{a}$	0.018	0.037	0.056
Lnoilgas	−5.953	8.507	21.021
Lnpopden	−0.010	0.025	0.060
Capcity	−0.389	0.080	0.558
Invcoast	−0.009	1.496	3.056
Malaria	−0.012	0.010	0.029
Latitude	0.003	0.007	0.011

Table: *Average impact estimates including further controls, with country FE (Spec. (VI))*

Variables	Lower 0.01	Mean	Upper 0.99
	Average direct impact		
Human capital $\boldsymbol{h}$	0.047	0.178	0.302
Technology gap $\boldsymbol{a}$	0.138	0.194	0.248
Lnoilgas	−15.253	−2.232	11.103
Lnpopden	−0.100	0.003	0.084
Capcity	−0.176	0.250	0.709
Invcoast	−1.938	0.233	2.288
Malaria	−0.040	0.026	0.089
Latitude	−0.021	0.000	0.021
	Average indirect impact		
Human capital $\boldsymbol{h}$	−0.200	−0.089	0.024
Technology gap $\boldsymbol{a}$	−0.187	−0.130	−0.070
Lnoilgas	−10.634	8.582	27.038
Lnpopden	−0.075	0.024	0.147
Capcity	−1.024	−0.426	0.104
Invcoast	−2.020	0.674	3.120
Malaria	−0.066	0.000	0.074
Latitude	−0.020	0.002	0.025
	Average total impact		
Human capital $\boldsymbol{h}$	0.017	0.089	0.170
Technology gap $\boldsymbol{a}$	0.022	0.064	0.101
Lnoilgas	−7.211	6.350	18.077
Lnpopden	−0.023	0.027	0.076
Capcity	−0.753	−0.177	0.361
Invcoast	−0.879	0.906	2.523
Malaria	0.003	0.026	0.051
Latitude	−0.010	0.002	0.012

Figure: *Average impacts of* ***human capital*** *at different quantiles of the tfp gap (Spec. (VI))*

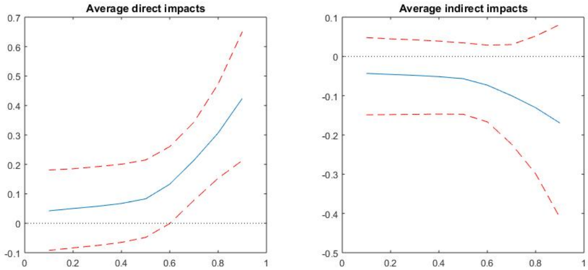
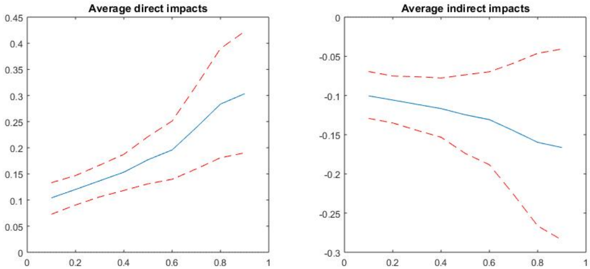


Figure: *Average impacts of* ***tfp gap*** *at different quantiles of human capital (Spec. (VI))*



Robustness Checks

- Exclude observations where TFP growth is is either below the 5th percentile or above the 95th percentile
- Variations in $\boldsymbol{W}$ Matrix $\rightarrow$ choose $\boldsymbol{W}$ where RSS is minimized
- Average human capital instead of initial human capital

Concluding remarks

- Investigate the nature of technology diffusion and the impact of human capital on TFP growth for an extensive amount of regions
- Findings
  - **Technological catch-up** and **human capital** are **important drivers** of technological progress in regions
  - Human capital effects are higher for less developed regions than for more developed regions
    $\Rightarrow$ **Regions with a higher human capital stock show a higher speed of technological catch-up**
  - A negative indirect impact of the technology gap is observed
    $\Rightarrow$ Interpreted as **positive spatial spillovers of technology *levels***
  - In contrast, spatial autocorrelation of technology *growth* is not robust to adding further controls when including country fixed effects

Thank you for your attention.

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS

References

Balli, H. & Sorensen, B. (2013). Interaction effects in econometrics. *Empirical Economics*, *45*(1), 583–603.

Barro, R. & Lee, J.-W. (2013). A new data set of educational attainment in the world, 1950-2010. *Journal of Development Economics*, *104*(C), 184–198.

Benhabib, J. & Spiegel, M. (1994). The role of human capital in economic development. Evidence from aggregate cross-country data. *Journal of Monetary Economics*, *34*(2), 143–173.

Benhabib, J. & Spiegel, M. (2005). Human capital and technology diffusion. In P. Aghion & S. Durlauf (Eds.), *Handbook of Economic Growth* (1 ed.)., volume 1, Part A chapter 13, (pp. 935–966). Elsevier.

Ertur, C. & Koch, W. (2007). Growth, technological interdependence and spatial externalities: theory and evidence. *Journal of Applied Econometrics*, *22*(6), 1033–1062.

Fischer, M. (2011). A spatial Mankiw Romer Weil model: theory and evidence. *The Annals of Regional Science*, *47*(2), 419–436.

Gennaioli, N., La Porta, R., López-de Silanes, F., & Shleifer, A. (2014). Growth in regions. *Journal of Economic Growth*, *19*(3), 259–309.

LeSage, J. P. & Pace, R. K. (2009). *Introduction to Spatial Econometrics*. Statistics: A Series of Textbooks and Monographs. CRC Press.

Mankiw, N. G., Romer, D., & Weil, D. N. (1992). A contribution to the empirics of economic growth. *The Quarterly Journal of Economics*, *107*(2), 407–437.

Piribauer, P. & Wanzenböck, I. (2016). R&D networks and regional knowledge production in Europe: Evidence from a space-time model. *Papers in Regional Science*.

Solow, R. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, *70*(1), 65–94.

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS

Country	Numer of regions
Argentina	24
Australia	8
Austria	9
Bangladesh	7
Bolivia	9
Brazil	20
Canada	11
Switzerland	23
China	27
Colombia	24
Germany	9
Denmark	1
Spain	17
France	20
Greece	7
Indonesia	26
India	27
Ireland	1
Italy	19
Japan	46
Mexico	32
Malaysia	10
Norway	19
Pakistan	4
Peru	23
Portugal	5
Thailand	66
United Republic of Tanzania	20
United States of America	51
South Africa	4

Descriptive Statistics

Table: *Descriptive statistics*

Variable	Min.	Mean	Median	Max.	St.dev.
Ln(TFP) (1980)	3.32	5.52	5.84	7.31	0.83
Average annual growth of TFP (1980-2005)	-4.61	0.91	0.96	5.89	1.36
Average years of schooling (1980)	0.50	5.71	4.94	13.07	3.49