Theoretical High Energy Physics in Latin America since 1990

- Science, physics and high energy physics (HEP) in Latin America (LA)
- Methodology: statistical data for theoretical HEP (HEPth)
- Records of 8 leading nations in LA, and intercontinental benchmark
  Publications, Impact Factor, citations; absolute and *per capita*
- Comparison to socio-economic indices:
  Gross Domestic Product (GDP),
  Human Development Index (HDI), Education Index (EI)
- Analysis and conclusions Appendix: World ranking

1990 – 2012: G. Urrutia Sánchez, lic. thesis 2015

G. Urrutia Sánchez, L. Prado and W.B., Scientometrics 116 (2018) 125-146

Historical background

Universities in LA exist since the 16th century, in (what is today)
Peru, Mexico, Bolivia, Dominican Republic, Colombia and Ecuador.
since 17th century in Argentina, Chile, Guatemala
since 18th century in Paraguay, Venezuela, Cuba, Panama

Devoted to higher education.
Only since the mid 20th century: also research centers; graduate programs in physics. Initially dependent on a few pioneers, like Marcos Moshinsky.

Groundbreaking early works in HEP

1933 Sandoval Vallarta (Mexico) and Lemaître (Belgium):
geomagnetic effect on cosmic rays

1958 Leite Lopes (Brazil): prediction of the Z-boson

1971 Bollini/Giambiagi (Argentina): dimensional regularization

[historic account by W.B./Prado, Physics Today, 2014]

1990s: New boost in experimental HEP worldwide

LA enters "Big Science": new style of research for LA

HEP in LA picks up momentum, including theoretical HEP (HEPth)
Mexico participates at CERN, DESY, SLAC, Fermilab, BNL
[Collazo-Reyes et al. '02, '04, '10]

Experimental papers are 4.5 times more quoted, but HEPth has longer "citation life", few cross-citations

E.g. Brazil, 2010-14: large collaborations yield just 8.3% of HEP papers, but 33.2% of citations. [Manganote et al. '16]

Hard to capture for national statistics $\rightarrow$ focus on theory, typically few authors, each one contributing significantly.

In our study: cutoff < 20 authors

Science community today: 8 millions of researchers
(UNESCO, all fields "professionals engaged in the conception and creation of new knowledge"), 0.1% of world population (7.7×10^9)

1 million of physicist (estimate by Day, 2015), 0.01% of humanity

LA in 2000: 500 millions of inhabitants, 10 000 active physicists (including Ph.D. students), 0.002% (5 times below world quota)
$\simeq 800$ in HEP, $\simeq 650$ in HEPth [Moran-Lopez '00, Masperini '00]

HEP Peculiarities: usually no immediate applications, direct motivation cultural and pedagogical, practical benefits conceivable on the long run.
[We skip fields like *condensed matter* and *optics*, which are closer to practical applications.]

"Luxury", explains dominance of wealthy countries (?)
However: HEPth is relatively *cheap* (and can hardly do any harm).

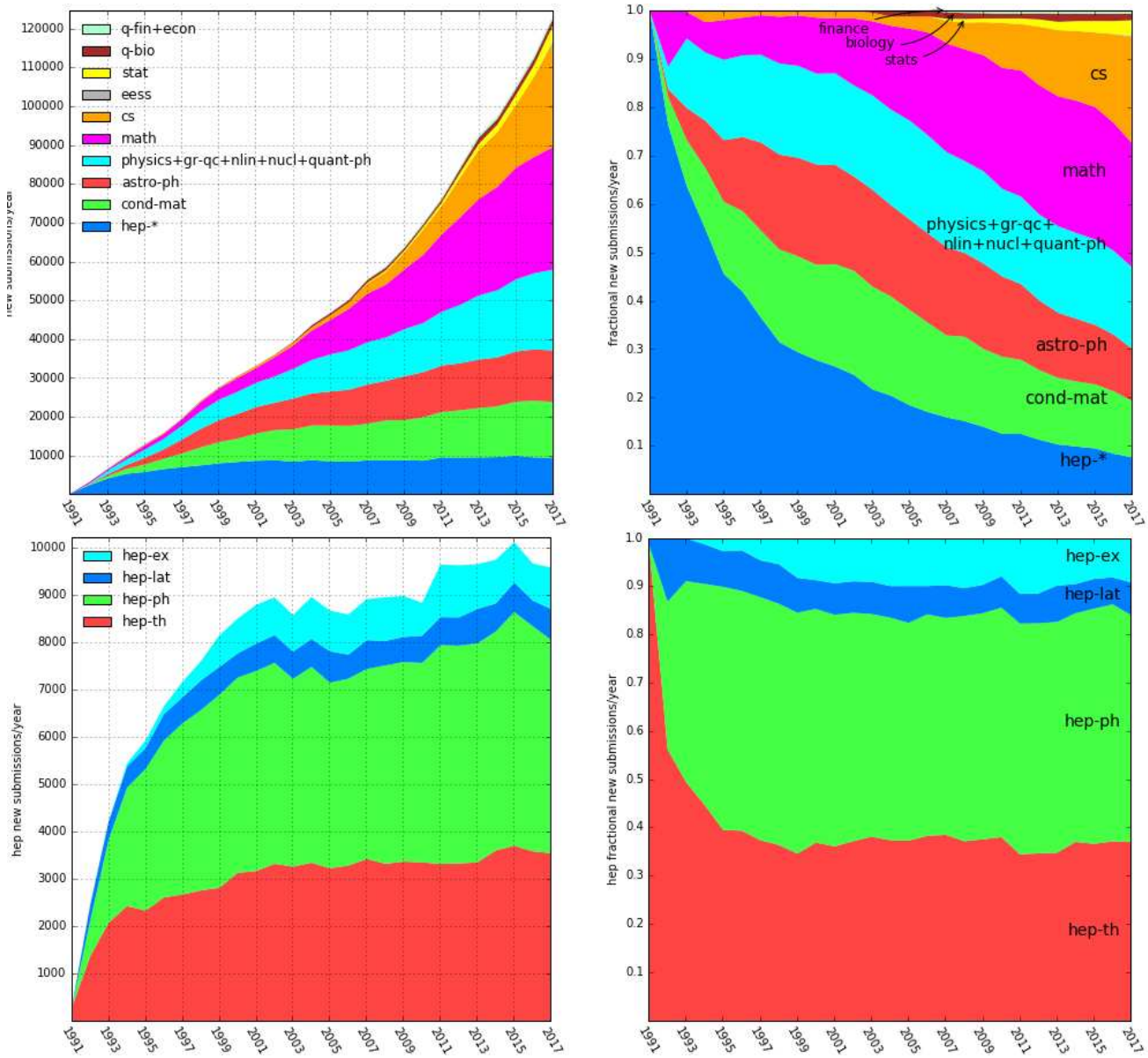
Methodology

HEPth in the period 1990-2012: we consider peer-reviewed papers, registered in Web of Science (WoS, formerly Web of Knowledge)

In scientific communication also proceedings and unpublished preprints play some rôle:
$E.g.$ 2015: 10 126 preprints arrived in the arXiv, 63 % were later published as regular papers.
We capture hep-ph, hep-th, hep-lat, gr-qc (subsets of astro-ph, quant-ph)

Papers enter a national record in our of statistics, if at least one author has a working address there (we don't care about citizenships, nor about the order of authors — in HEP-papers 3/4 alphabetic [Birnholtz '00])

One paper can count for several countries, but not frequent within LA (in HEP about 4 %, often Argentina-Brazil [Russell '07]).



Submission to arXiv, absolute and relative, 1991- 2017. Below: hep only

Journals

Journals specialized on HEP. Number of author $< 20 \Rightarrow$ restriction to HEPth in most cases, additional test by keywords and inspection.

We have to exclude interdisciplinary journals, like $Phys.\ Rev.\ Lett.$, $Nature$, $Science$ (despite their importance); selection of HEPth not feasible

Only *high-impact journals:* in 2012, 2-years Impact Factor (IF) > 1

IF of year Y: consider papers published in in a journal during $Y-1,\ Y-2$:

$\langle$ number of citations $\rangle$ during Y

We include 14 journals (5 founded after 1990)

Subjects: particle physics/quantum field theory, cosmology, gravity (usual terminology, although not always "high energy", all "luxury")

Citations count in all WoS entries until 2012.

	1990–94	1995–9	2000–04	2005–09	2012
J. Cosmol. Astropart. Phys.	—	—	7.914	6.374	6.036
J. High Energy Phys.	—	—	6.454	5.678	5.618
J. Phys. G	2.178	1.277	1.348	2.966	5.326
Eur. Phys. J. C	—	—	4.766	3.453	5.247
Astropart. Phys.	—	—	3.924	3.783	4.777
Phys. Rev. D	2.734	3.702	4.462	4.883	4.691
Phys. Lett. B	3.174	3.723	4.314	4.291	4.569
Nucl. Phys. B	4.578	3.311	5.395	4.771	4.327
Class. Quantum Gravity	1.492	1.790	2.262	2.924	3.562
Adv. High Energy Phys.	—	—	—	—	3.500
Prog. Part. Nucl. Phys.	2.060	2.119	2.354	3.699	2.257
Int. J. Mod. Phys. A	1.411	1.400	1.198	1.014	1.127
Mod. Phys. Lett. A	1.306	1.070	1.251	1.335	1.110
Int. J. Theor. Phys.	0.370	0.438	0.556	0.530	1.086

Journals and IF, before 2010 averaged over 5-years periods; in 2012 IF > 1.

Empty slots for *J. Cosmol. Astropart. Phys.* (since 2003), *J. High Energy Phys.* (since 1997), *Eur. Phys. J. C* (since 1998), *Astropart. Phys.* (since 1992) and *Adv. High Energy Phys.* (since 2010)

Ranking by Nations

Total number of publications $\Rightarrow$

Leading group in LA:
Brazil (BRA), Mexico (MEX), Argentina (ARG), Chile (CHL)

Sub-leading group:
Colombia (COL), Venezuela (VEN), Uruguay (URY), Cuba (CUB)

Rest: < 2 papers/year, performance below one individual

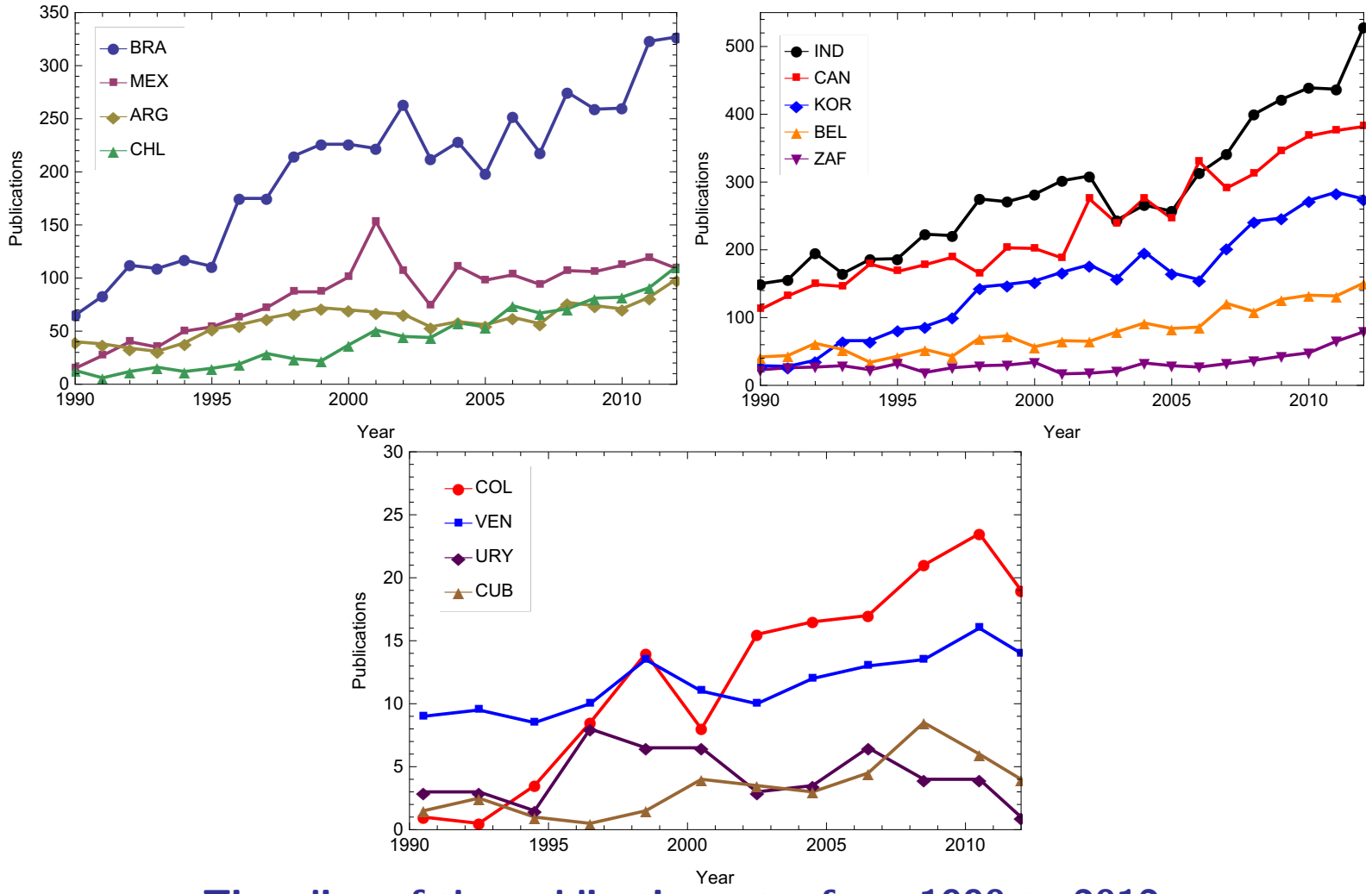
[Morán-Lopez '00] LA in 4 groups, counting Ph.Ds in physics, and their "overall scientific output":
1. BRA, MEX, ARG 2. CUB, CHL, VEN, COL
3. 11 countries, including URY (for us, CHL, URY move one level up)

		publi-cations	rwf				publi-cations	rwf
Brazil	BRA	4650	3.68		India	IND	6570	3.39
Mexico	MEX	1924	3.33		Canada	CAN	5452	4.03
Argentina	ARG	1387	3.73		South Korea	KOR	3491	4.23
Chile	CHL	1034	4.23		Belgium	BEL	1819	4.08
					South Africa	ZAF	747	3.51
Colombia	COL	277	3.88					
Venezuela	VEN	266	3.48					
Uruguay	URY	100	3.63					
Cuba	CUB	77	3.72					

"rwf": average re-weighting factor by the journal IF

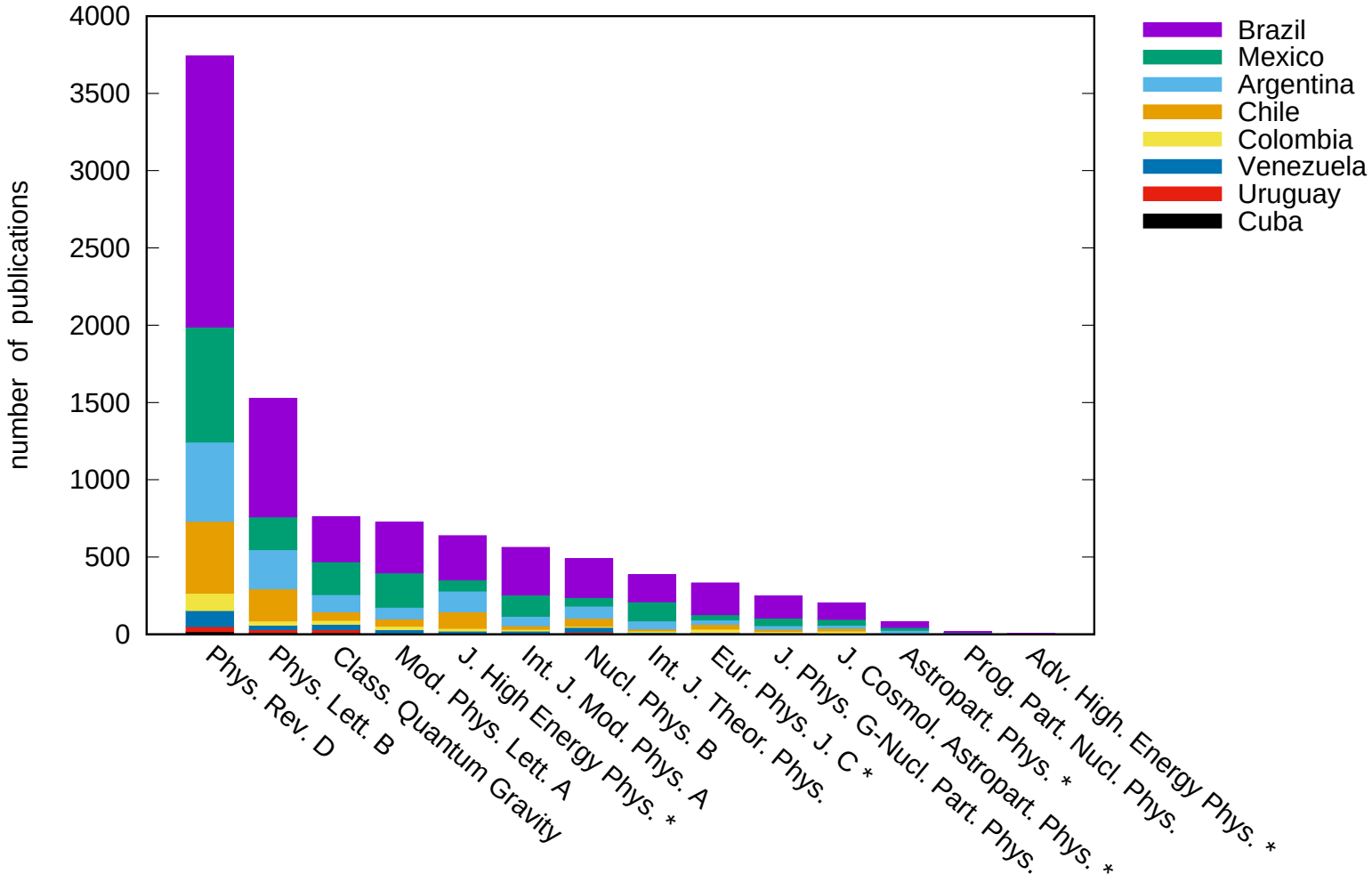
Intercontinental benchmark: India (IND), Canada (CAN), South Korea (KOR), Belgium (BEL), South Africa (ZAF); comparable to leading group in LA

Fraction of HEP papers worldwide in 2005/6: CAN 2.8%, BRA 2.7 %, IND 2.7%, KOR 1.8%, MEX 0.8%, BEL 0.7%, ARG 0.6%, CHL 0.6 % [Mele '09]



Time-line of the publication rate, from 1990 to 2012.

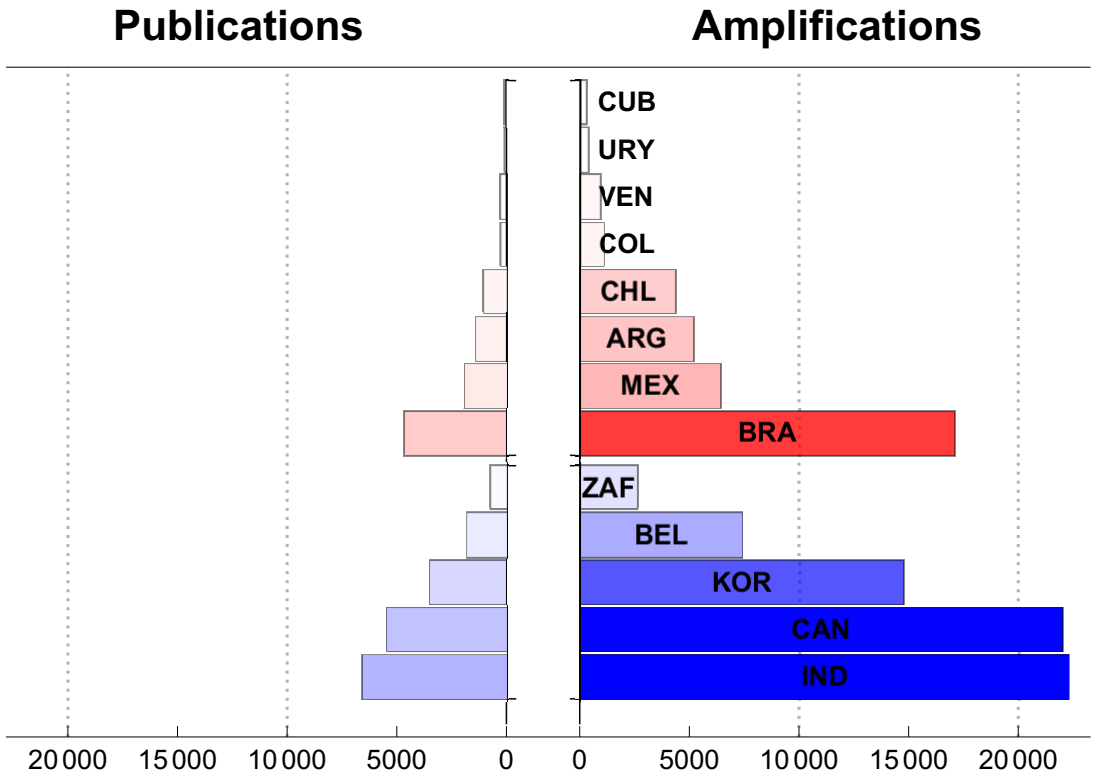
Below: 2-years averages, to smoothen large relative fluctuations.



Histogram for the LA publications in the journals of our list

Phys. Rev. D **dominates in all countries, mostly followed by** *Phys. Lett. B* (exceptions are MEX: *Mod. Phys. Lett. A*, VEN: *Class. Quantum Grav.*). 5 journals (marked by *) did not exist over the full period.

IFs vary from 0.370 to 7.914 in this period. Re-weighting of the papers by journal IF:



Hierarchy in LA unchanged, BRA dominates even more.

However: considering the mean re-weighting factor *alone* changes the picture:
CHL, KOR, BEL, CAN publish in the "best" journals; lower end: ZAF, VEN, IND, MEX

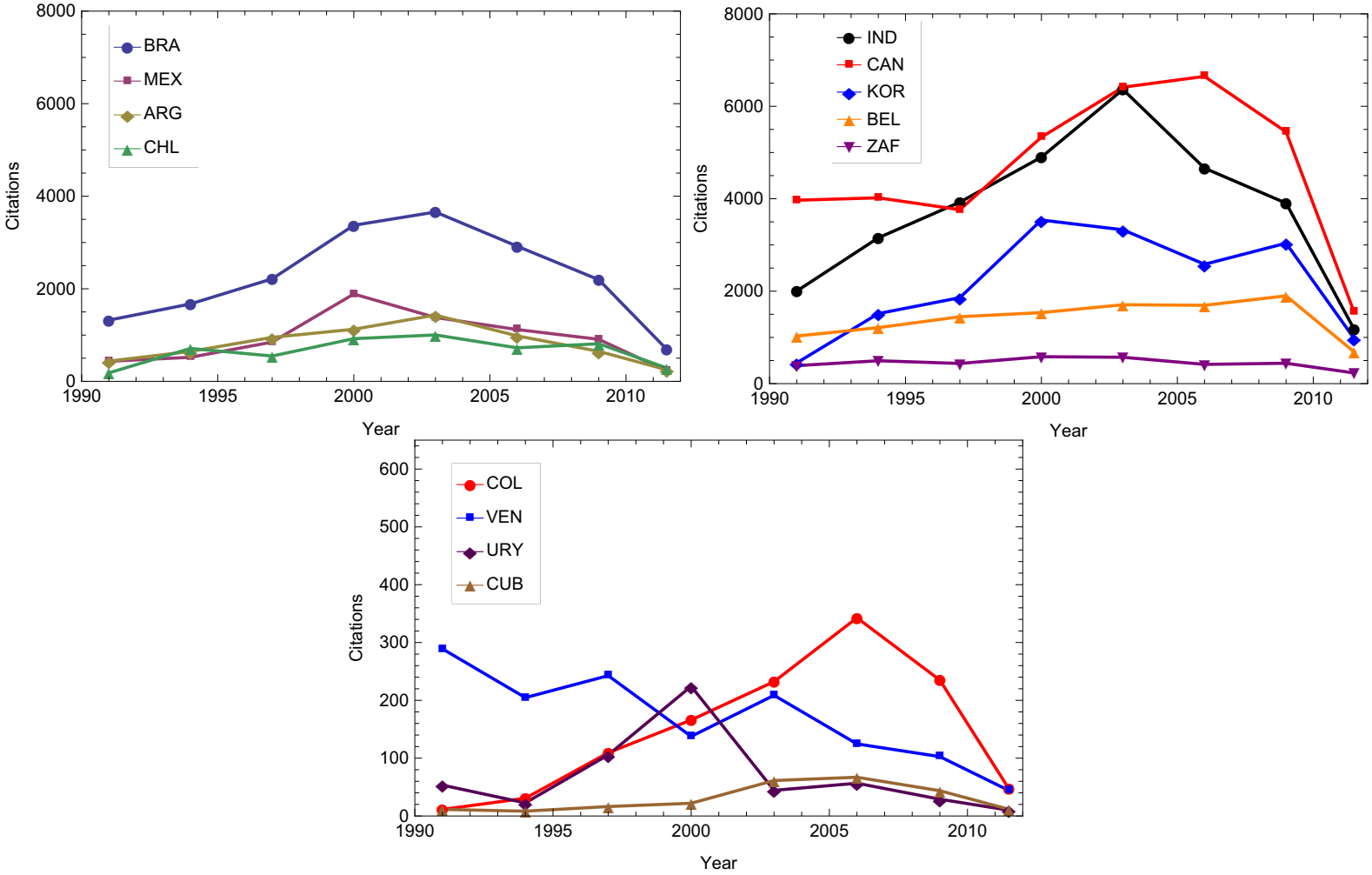
Yet another approach: re-weight each article with its own citations ⇒ statistics of all citations:

	cita-tions	citations per article			cita-tions	citations per article
				Canada	105189	19.3
				India	89100	13.6
Brazil	53452	11.5		South Korea	50894	14.6
Mexico	21797	11.3		Belgium	32951	18.1
Argentina	19164	13.8				
Chile	15284	14.8				
				South Africa	10455	14.0
Venezuela	4018	15.1				
Colombia	3476	12.5				
Uruguay	1628	16.3				
Cuba	713	9.3				

Total number of citations until 2012. Hierarchy in LA changes little, VEN supersedes COL.
Ratio BRA/MEX in publications: 2.42, in citations: 2.45. Very similar, but ARG, CHL move closer to MEX.

[Leading group consistent with HEP citation study 1983-93 by Osrah/Wilson '97.]

Intercontinentals are now superior, in particular CAN and IND.
Papers from LA are less quoted: 12.3 on average, vs. 16.0 for the intercontinental five.



Time-line of the citation rate, from 1990 to 2012.

Matches trend of increasing citation numbers worldwide.

(Dip at the end because newer papers had less time to be quoted before 2013.)

Website "Journal & Country Rank"

Nuclear Physics and HEP, since 1996 based on Hirsch Index:

Almost same hierarchy, but ARG $>$ MEX

In annual rankings, sometimes Ecuador, Peru and Puerto Rico appear in the sub-leading group.

8 most cited papers in our statistics:

> 250 citations ("famous" in INSPIRE terminology)

all authors are distinct

5 times co-authors of 1st world, no co-authors of 3rd world

Dominance by BRA, CHL, ARG, URY

[1] M. Banados, M. Henneaux, C. Teitelboim and J. Zanelli, "Geometry of the (2+1) black hole", Phys. Rev. D48 (1993) 1506 [Chile, Belgium, USA] 799 citations.

[2] R. Gambini and J. Pullin, "Nonstandard optics from quantum space-time", Phys. Rev. D59 (1999) 124021 [Uruguay, USA] 413 citations.

[3] F. Pisano and V. Pleitez, "An SU(3) x U(1) model for electroweak interactions", Phys. Rev. D46 (1992) 410 [Brazil] 371 citations.

[4] J. Frenkel and J.C. Taylor, "High Temperature Limit of Thermal QCD", Nucl. Phys. B334 (1990) 199 [Brazil, UK] 370 citations.

[5] N. Berkovits, "Super-Poincaré covariant quantization of the superstring", J. High Energy Phys. 0004 (2000) 018 [Brazil] 299 citations.

[6] L.P. Chimento, A.S. Jakubi, D. Pavon and W. Zimdahl, "Interacting quintessence solution to the coincidence problem", Phys. Rev. D67 (2003) 083513 [Argentina, Germany, Spain] 263 citations.

[7] P.B. Arnold and O. Espinosa, "Effective potential and first order phase transitions: Beyond leading-order", Phys. Rev. D47 (1993) 3546 [Chile, USA] 258 citations.

[8] G. Aldazabal, L.E. Ibáñez, F. Quevedo and A.M. Uranga, "D-branes at singularities: A bottom-up approach to the string embedding of the standard model", J. High Energy Phys. 0008 (2000) 002 [Argentina, Switzerland, Spain, UK] 254 citations.

Addition:

New study of period 2013–2018 with data from INSPIRE, *e.g.*

`find tc p and cc mexico and date 2013→2018 and ac 1→19 and primarch hep-th`

Specifies regular publications, country, period, less than 20 authors

We sum the contributions submitted to **hep-th, hep-ph, hep-lat** and **gr-qc**

We count all citations that INSPIRE reports

For Appendix: in case of Switzerland: `... and not aff cern`

	papers	citations			papers	citations
				IND	3452	44423
BRA	2717	33226		CAN	2428	56535
CHL	1113	17084		KOR	1809	28808
MEX	832	8466		BEL	1161	32726
ARG	546	7583		ZAF	532	6733
COL	204	2505				
URY	69	1180				
VEN	56	923				
Costa Rica	23	873				
CUB	18	190				
Ecuador	12	225				
Peru	10	102				

Costa Rica, Ecuador (and Peru) join. (Costa Rica: G. Téramond: 19 paps, 849 cits)

In citation record, some positions swap: Ecuador $\leftrightarrow$ CUB, CAN $\leftrightarrow$ IND, BEL $\leftrightarrow$ KOR.

CHL moves up!

Publications *per capita*

Populations of these 8 LA countries differs strongly.
Millions of inhabitants:

	1990	2012	increase
BRA	149	198	33 %
MEX	83	115	39 %
COL	34	47	38 %
ARG	32	41	28 %
VEN	19	30	58 %
CHL	13	17	31 %
CUB	10.6	11.3	7 %
URY	3.1	3.4	10 %

We now consider publications and citation *per million of inhabitants* ("intensive" vs. previous "extensive" quantities).

Total number of publications, and citations, divided by millions of inhabitants:

	publications per million inhabitants	citations per million inhabitants		publications per million inhabitants	citations per million inhabitants
			Belgium	173.50	2969.9
			Canada	172.19	3020.3
Chile	63.90	878.2	South Korea	72.91	1017.7
Argentina	37.60	467.1			
Uruguay	30.54	481.5			
Brazil	25.89	269.5			
Mexico	18.93	189.8	South Africa	16.49	204.2
Venezuela	10.80	136.1			
Cuba	6.88	63.3			
Colombia	6.49	74.6	India	6.18	72.8

Now the hierarchy changes: CHL, ARG, URY (and BEL, CAN) move to the top.

BRA, MEX lose 3 positions, COL (or IND) last (referring to publications).

CHL's leading position matches study by [Gonzalez-Brambila et al. '16] of entire physics.

Their explanation: excellent collaborations with Europe, such as the European Southern Observatory (ESO) located in northern Chile (operating since 1966), now 16 European member states.

However: we observed the same trend solely in HEPth
$\Rightarrow$ requires additional explanation

Here 1st world dominates (CAN, BEL), as expected in a field without quick applications.

This takes us to the consideration of socio-economic conditions.

	papers	citations			papers	citations
				BEL	103.3	2912
CHL	63.7	962		CAN	67.8	1578
URY	20.1	344		KOR	35.5	565
BRA	13.2	161				
ARG	12.6	175				
				ZAF	9.6	122
MEX	6.6	67.2				
Costa Rica	4.8	182				
COL	4.2	51.9				
VEN	1.8	29.6		IND	2.6	34
CUB	1.6	16.6				
Ecuador	0.7	13.9				
Peru	0.3	3.2				

INSPIRE analysis for the period 2013-2018, divided by millions of inhabitants in 2015.

URY second. Based on citations: CHL, URY, Costa Rica, ARG, BRA, MEX

Correlation with socio-economic indices

Gross Domestic Product (GDP, Producto interno bruto)

Measure of economic performance: monetary value — in US $, but converted to purchasing power parity — of *all goods produced and services provided in one year.*

Purely economic, does not account for wealth distribution, quality of health care and education, environment-friendliness of production, . . .

2002-7: GDP in LA increases by 50.8 %, **GERD** (Gross Domestic Expenditure for Research and Development) by 56.5 %

$8\,\% \longrightarrow 8.5\,\%$ of GDP worldwide
$2.8\,\% \longrightarrow 3.5\,\%$ of GERD worldwide

R&D investments in business, universities, gov. non-profit [Chinchilla-Rodríguez et al. '15]
(we have no data solely for HEP, or HEPth)

[Gonzalez-Brambila et al. '16]

World fraction of GERD and citations in science and technology:

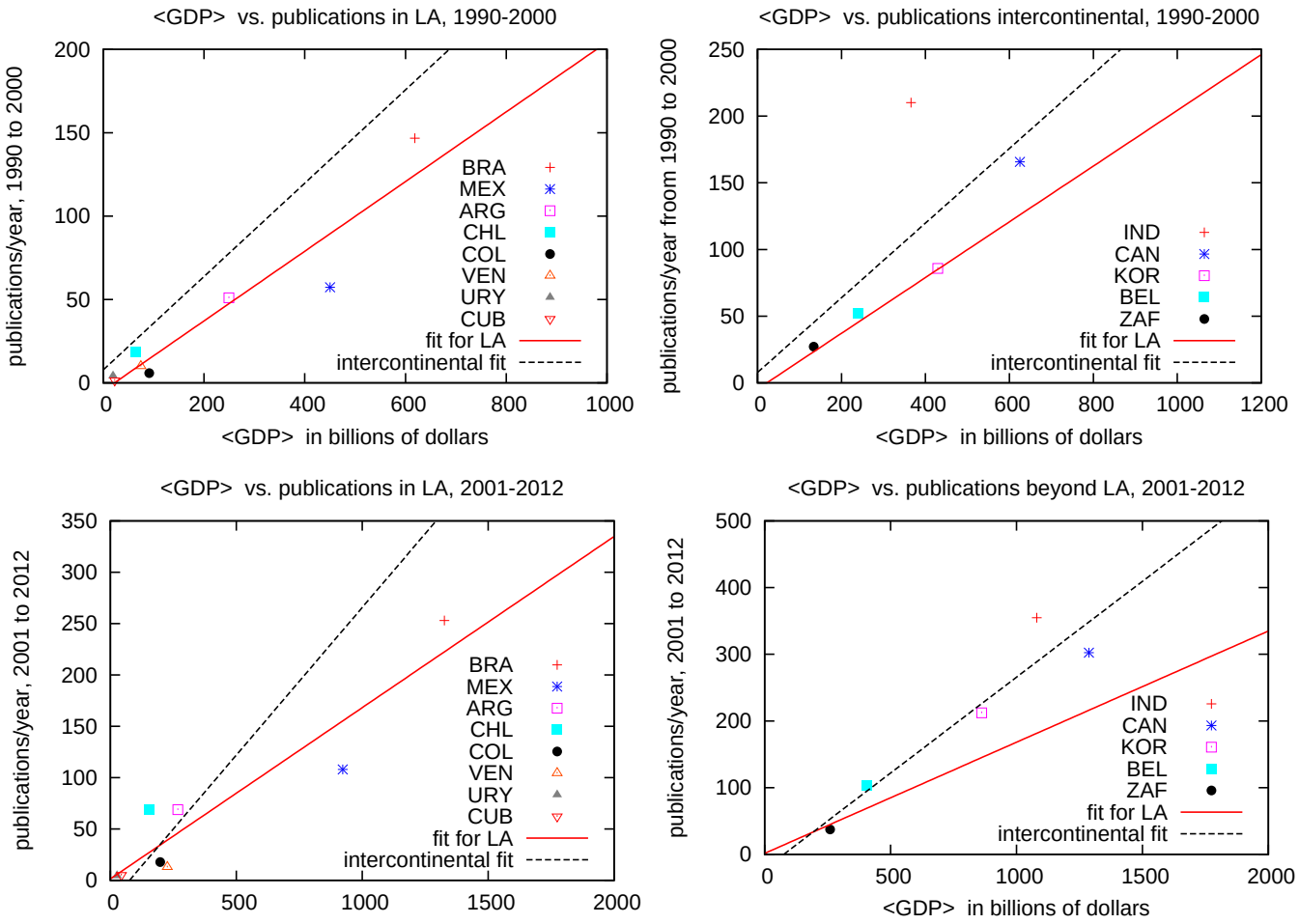
1993: CHL balanced, 0.1 %

ARG, BRA, MEX, IND, ZAF: citations stay behind

2009: CHL: 0.1 % of GERD, but 0.2 % of citations

ARG balanced (0.3 %), rest still behind

We consider: publications/year vs. GDP,
mean values over periods 1990-2000, and 2001-2012,
in LA and beyond:



Only sensible fit: linear (despite some strong deviations, *e.g.* for IND). In both periods:

stronger slope for (selected) intercontinentals: 0.28 vs. 0.21 (2st period), 0.17 vs. 0.29 (2nd period).

Extrapolation above LA data $\Rightarrow$ **backlog of LA not only due to lower economic level.**

Effect driven by IND. In LA: BRA, CHL high HEP productivity relative to GDP; opposite: MEX.

Human Development Index (HDI) and Education Index (EI)

"Well-being", "happiness" etc. are hard to parameterize, but:

Index oriented towards quality of human life (unlike GDP) could shift priorities of decision-makers from purely economic to more social aspects.

Motivation for M. ul Haq (Pakistan) and A. Sen (India) to elaborate the HDI, since the 1990s.

Components: health, income, education. Definition until 2010:

$$\text{HDI} = (\text{LEI} \times \text{II} \times \text{EI})^{1/3}$$

geometric mean (below arithmetic mean the more the 3 components differ)

- Life Expectancy Index $\text{LEI} = (\text{LE} - 25)/60$

  (1 for Life Expectancy of 85 years)

- Income Index II $= \dfrac{\ln\left(\text{GDPpc}/100\right)}{\ln 400}$

  (1 for GDPpc $= 40\,000$, exceed by most wealthy countries)

- Education Index EI $= (2 \times \text{ALI} + \text{GEI})/3$

  ALI : Adult Literacy Index

  GEI : Gross Enrollment Index (in schools)

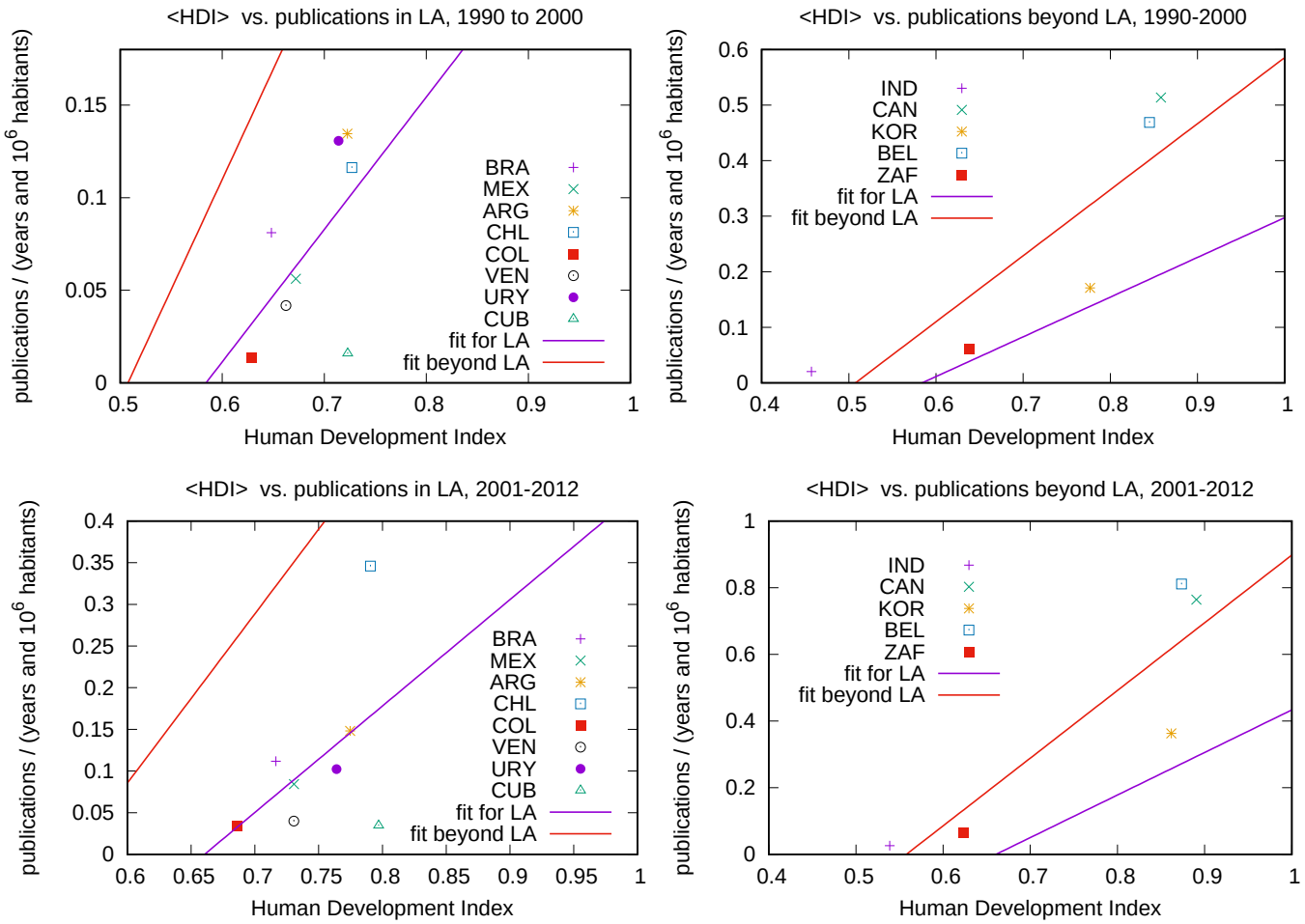
  Since 2010: II and EI are modified:

  $\text{EI} = (\text{MYSI} + \text{EYSI})/2$

  MYSI : (schooling years of population over 24)/15

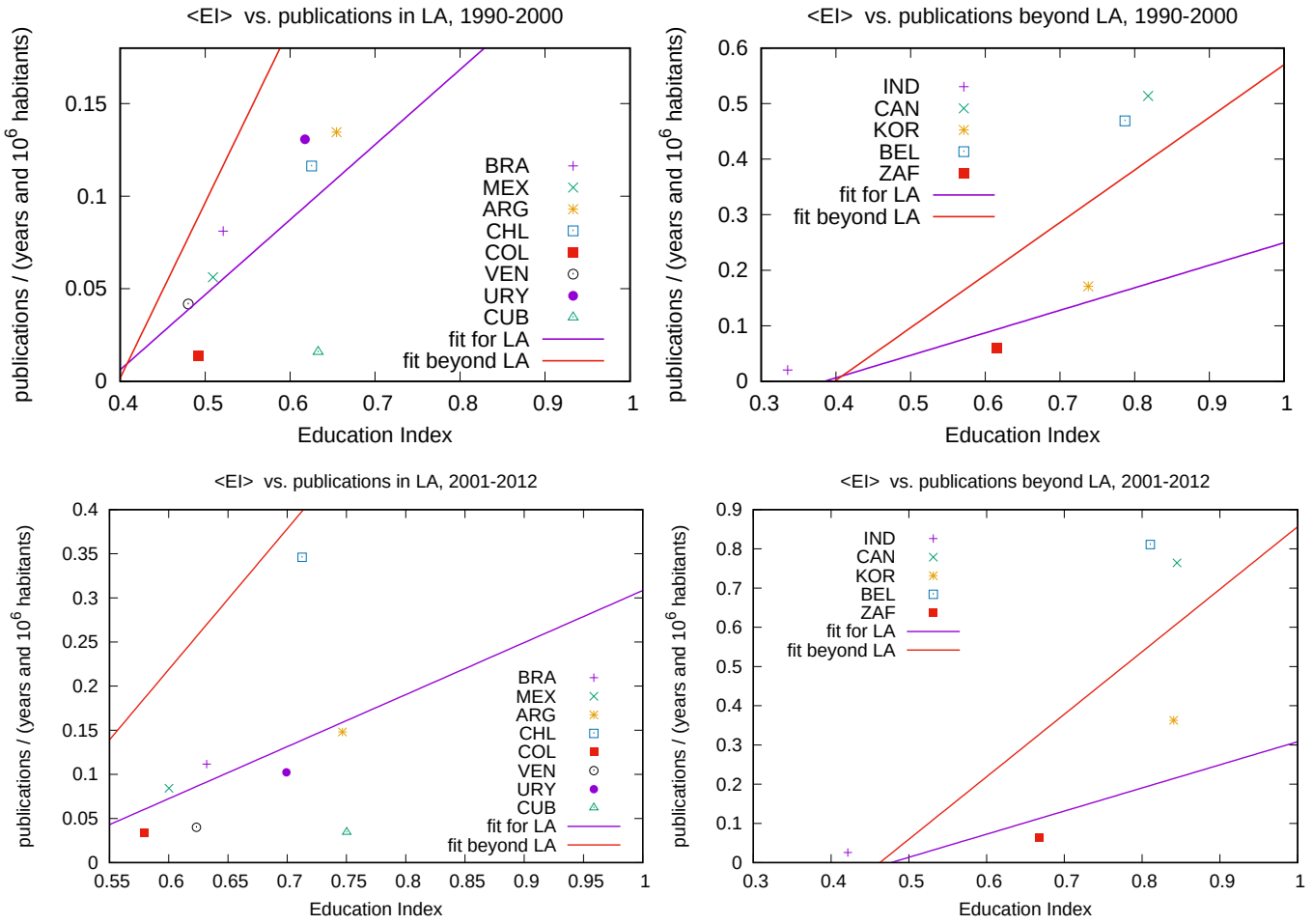
  EYSI : (expected schooling years of a 5-year old child)/18

  (1 for Master degree)



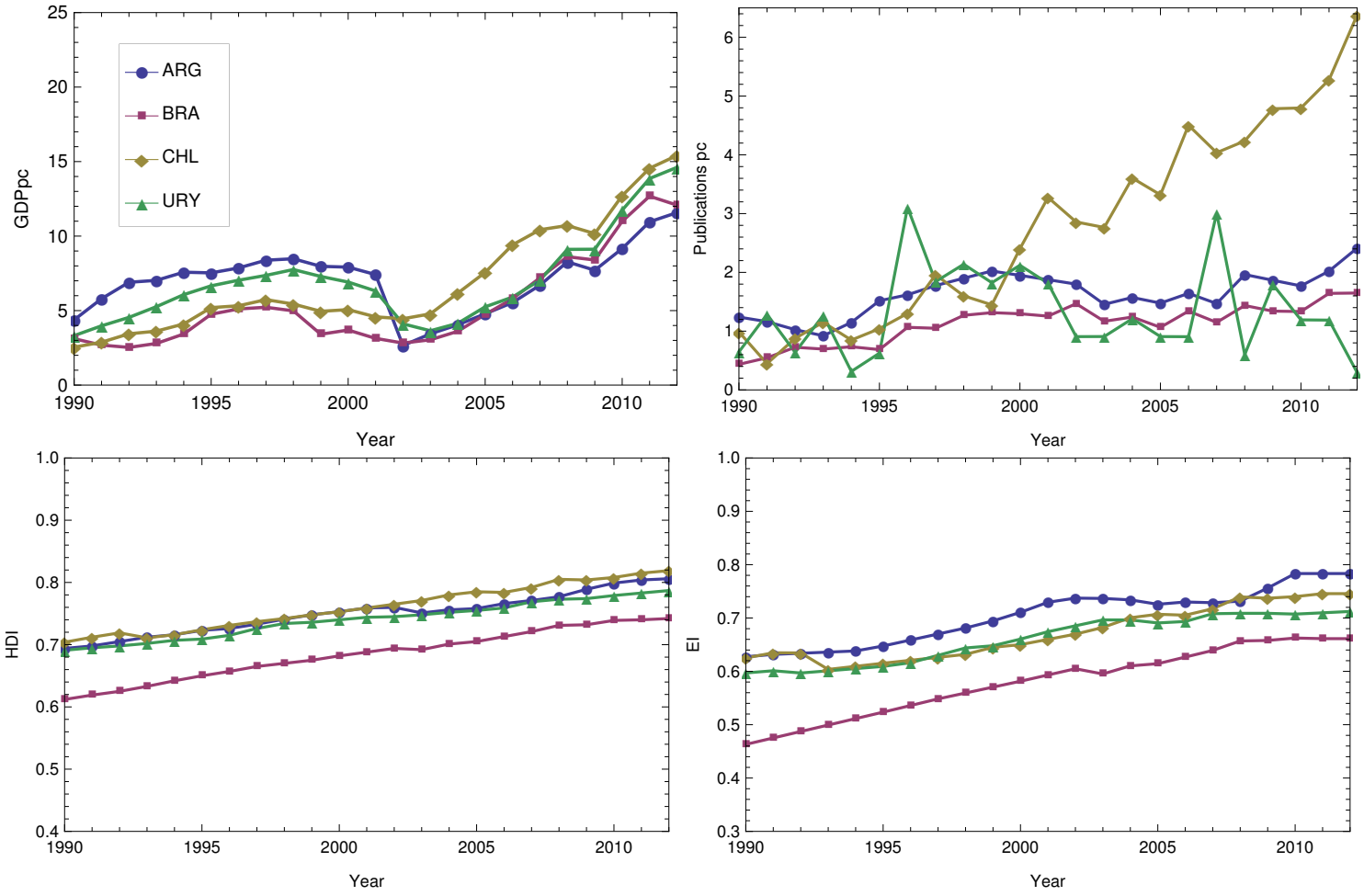
Focus on intensive quantities: HDI vs. publications / (year and 10^6 inhabitants). Again no alternative to **linear fits** (despite poor quality). **LA has weaker slope:** 0.72 vs. 1.19 (1st period) 1.28 vs. 2.03 (2nd period), due to CAN, BEL, IND (KOR, ZAF similar to LA).

In LA: BRA and CHL have high productivity relative to HDI, opposite for CUB.

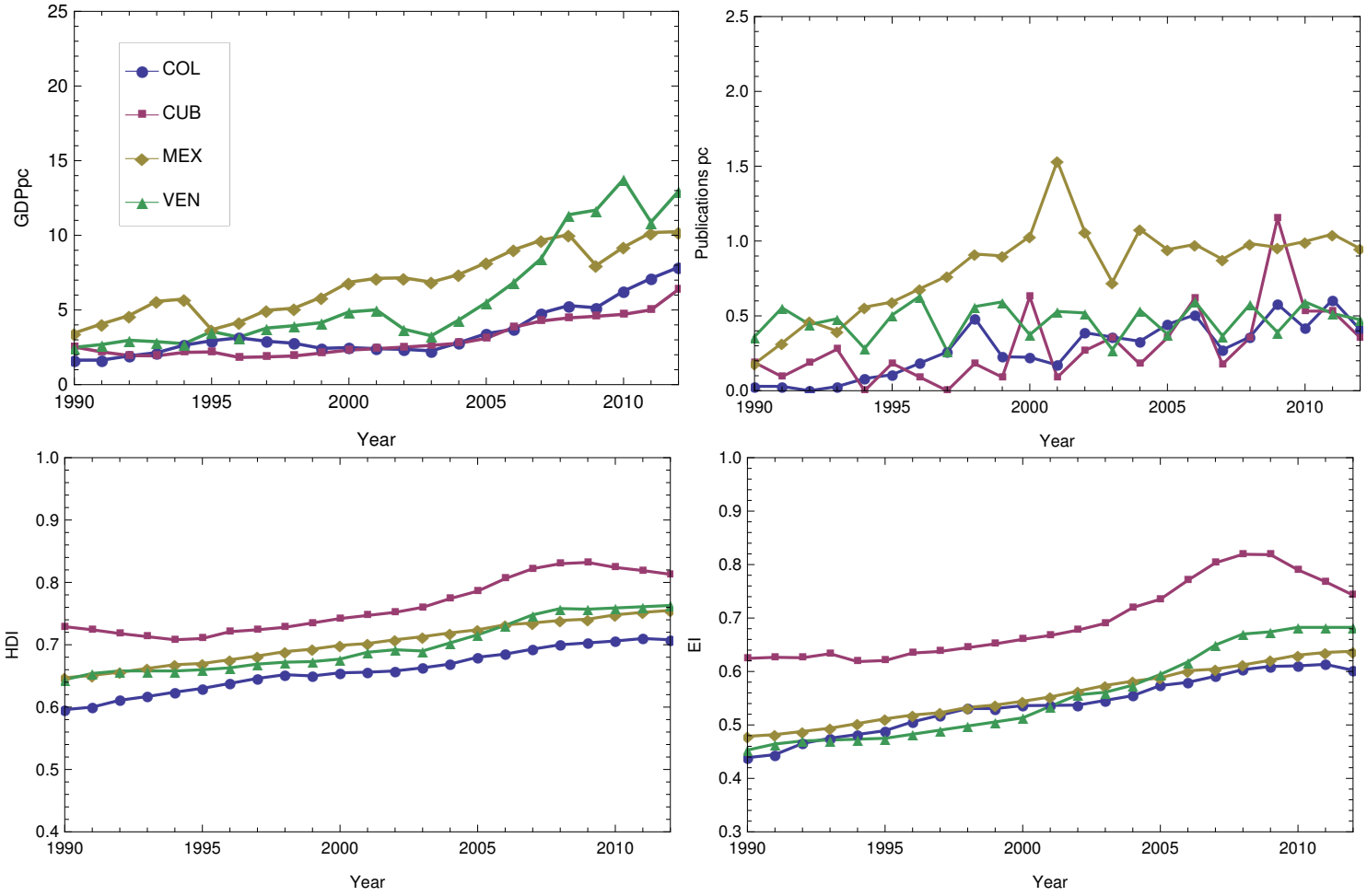


EI vs. publications / (year and 10^6 inhabitants). Again linear fits for LA are below intercontinentals, slope 0.41 vs. 0.95 (1st period), 0.59 vs. 1.59 (2nd period). Picture similar to HDI (involves EI).

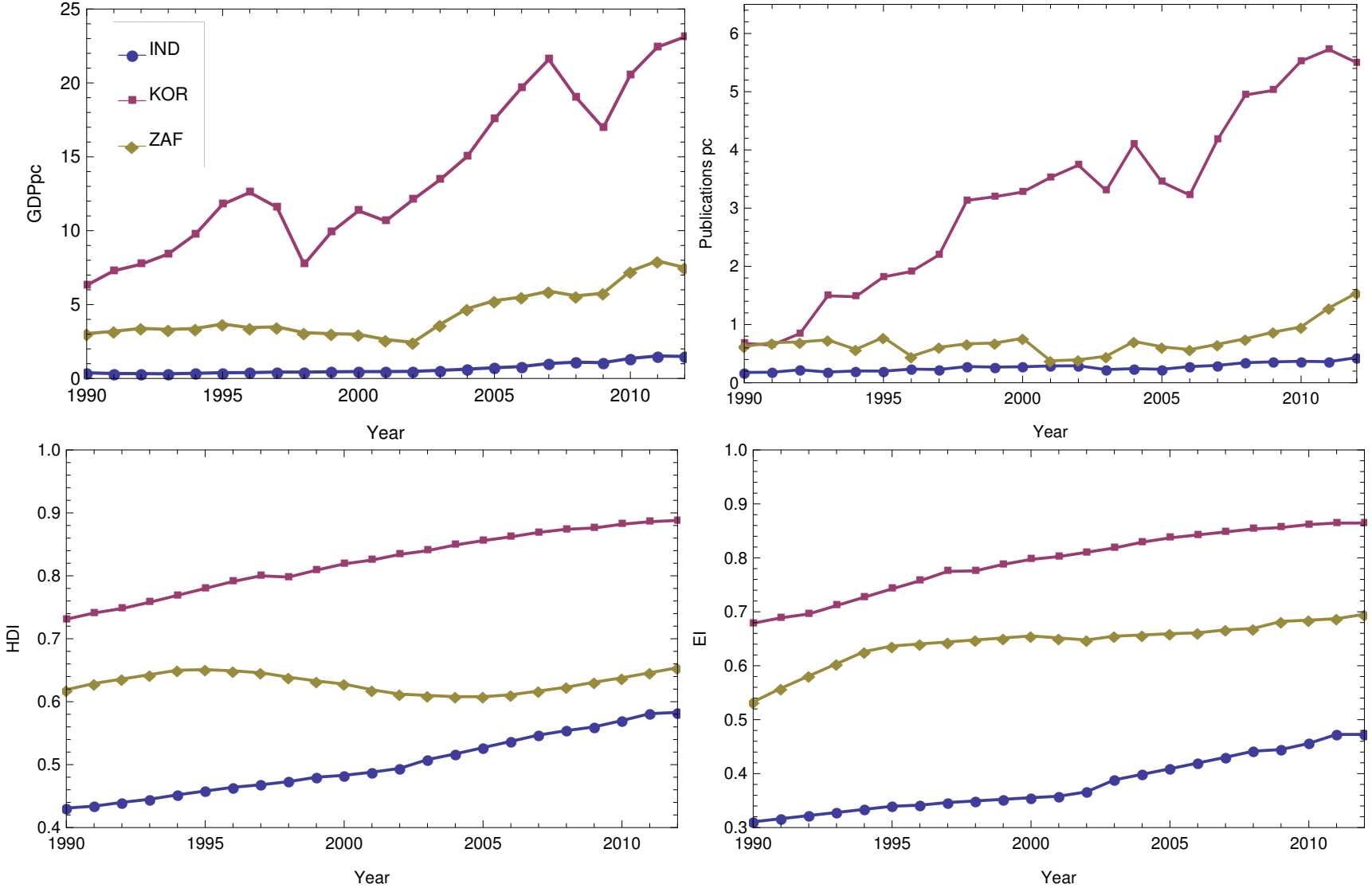
HEPth in LA stays behind its potential, given (extrapolated) HDI and EI conditions, in particular compared to first world (BEL, CAN). **Search for correlations in the time-evolution:**



We stay with <u>intensive</u> quantities: **GDPpc (in units of 1000 $), publication rate per million of inhabitants, HDI, EI.** Leading group in LA in the period 1990-2012. Economic recession in 2002/3, followed by significant growth. ARG: GDPpc collapsed by 64 %, followed by 5 years of stagnation in HDI and EI, and recession of publication rate.



Same for sub-leading group in LA. Correlated trends are not obvious (except for HDI and EI).



Same for 3 intercontinental countries. Correlations are not obvious, perhaps ZAF.

Analysis

PUPpc := Publications per capita

The economic crisis of 2002, followed by substantial growth, is visible in **ARG**, URY, VEN, and the growth after 2003 is also manifest in BRA, CHL, COL; ZAF, KOR.

- URY: EI stagnates after 2002, but trend in PUBpc not clear (depends on few persons $\rightarrow$ strong fluctuations, same for CUB, CHL).
- VEN: HDI and EI well improved in early 21st century, but PUBpc rather stable.
- COL: HDI, EI also improved (though at low level), PUBpc as well. Consistent, but no correlated fluctuations.
- BRA and CHL: powerful economic growth after 2003; HDI and EI increased as well
  - CHL: boost in PUBpc, take lead in LA, although EI is below ARG and CUB
  - BRA: PUBpc increased marginally, not reflecting the economic boom
- MEX: smooth economic growth (except 1995 and 2009) same for HDI, EI and PUBpc (except 2001 and 2003, why?). Consistent, but no detailed correlation.
- CUB: Stagnation, followed by economic progress since late 1990s. Boost in HDI and EI (decrease after 2009, but at high level). PUBpc fluctuates with long-term trend up.

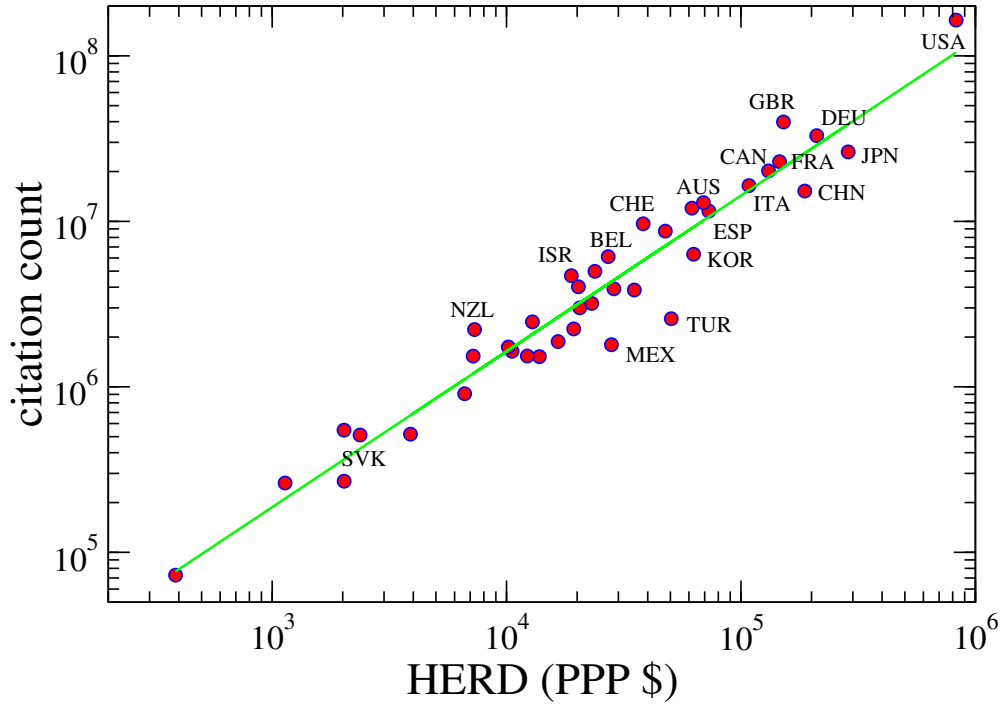
Beyond LA

- KOR: economic boom (though discontinuous), clear trend up in all 4 parameters, in particular PUBpc
- IND: qualitatively similar to KOR, but at much lower level, and progress in PUBpc is modest
- ZAF: GDPpc grows after 2003 (as in most of LA), PUBpc as well, but HDI stagnates

Summary:

As a consistent pattern, there is a long-term trend up in all 4 parameters (though for PUBpc this is least clear), but a detailed correlations between PUBpc and socio-economic indices is only obvious for ARG, and plausible in CHL, KOR and ZAF.

We did not analysis correlations with investment (no data for HEP). Large-scale study by [Cimini et al., PLoS '14] of Higher Education expenditure on Research and Development (HERD) vs. citations to scientific articles for period 1996-2012:



Green curve: fit to cx^{γ}, with $\gamma = 0.94(2)$. BEL, CAN above; KOR, MEX below

HERD$_{\rm MEX}$ $\simeq$HERD$_{\rm BEL}$, but BEL has $\gtrsim 3$ times more citations !

Conclusions

Statistical study of HEPth, in period 1990-2012:

8 dominant countries in LA, plus 5 from other regions as a benchmark.

Number of publications and citations:

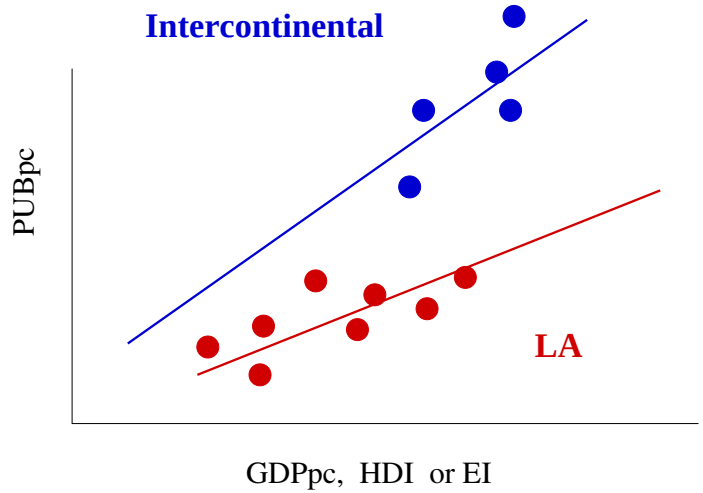
BRA, MEX, ARG, CHL

per capita: CHL, ARG, URY, BRA

Evolution: productivity increases, along with GDP, HDI and EI, but no simple pattern. HEPth depends on priorities within a country, and even within science ($e.g.$ CUB: priority on medicine).

In time-line: detailed correlations are rarely obvious (exceptions: ARG, perhaps CHL)

However, linear fits for PUBpc vs. GDPpc, HDI and EI do exhibit a generic pattern:



Intercontinental line above LA line

To explain why HEPth productivity is superior in (parts of) Asia, Europe, North America, it is not *sufficient to refer to economic power, nor to HDI or EI.*

LA does not fully exploit its scientific potential !

Appendix: World ranking based on INSPIRE data for 2013–2018

Extensive table: total number of papers and citations MEX: 832 paps, 8466 cits (Switzerland *with CERN:* 2791 paps, 106400 cits). Cits: Europe moves up

	papers			citations
1. USA	12888		1. USA	340953
2. Germany	7387		2. Germany	194856
3. China	5543		3. France	142256
4. UK	5257		4. UK	136356
5. France	4580		5. Italy	97769
6. Japan	4437		6. China	86238
7. Italy	4250		7. Spain	76023
8. IND	3452		8. Japan	74955
9. Russia	3195		9. CAN	56535
10. Spain	3055		10. IND	44423
11. BRA	2717		11. Russia	42347
12. CAN	2428		12. Switzerland	35422
13. KOR	1809		13. BRA	33226
14. Iran	1446		14. BEL	32726
15. Poland	1220		15. KOR	28808
16. BEL	1161		16. Netherlands	27901
17. Netherlands	1155		17. Sweden	20837
18. Switzerland	1132		18. Poland	20582
19. CHL	1113		19. Taiwan	19442
20. Portugal	1022		20. Portugal	18831

Intensive table: number of paps and cits per millions (> 1) of inhabitants (in 2015)
CHL: 962 cits, MEX: 6.6 paps, 67 cits. (Switzerland with CERN: 339 paps, 12916 cits)

	papers			citations
1. Switzerland	137		1. Switzerland	4300
2. Denmark	106		2. Estonia	3051
3. BEL	103		3. Denmark	3077
4. Israel	100		4. BEL	2912
5. Portugal	99		5. Slovenia	2566
6. Estonia	97		6. Germany	2371
7. Germany	90		7. Sweden	2138
8. Sweden	88		8. France	2136
9. Cyprus	86		9. UK	2093
10. UK	81		10. Israel	1902
11. Italy	70		11. Cyprus	1877
12. France	69		12. Portugal	1816
13. Netherlands	68		13. Netherlands	1651
14. Greece	68		14. Spain	1637
15. CAN	68		15. Italy	1608
16. Austria	67		16. CAN	1578
17. Slovenia	67		17. Finland	1311
18. Spain	66		18. Austria	1246
19. Finland	64		19. Greece	1221
20. CHL	63		20. Ireland	1140