Growth accounting and regressions: New approach and results

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Motivation

Two workhorse tools of empirical growth, each with a known weakness

Growth accounting

- Splits growth into capital, labor and **total factor productivity** (TFP)
- Usually assumes **constant factor shares**, which "seems to be counterfactual" given recent evidence

Growth regressions

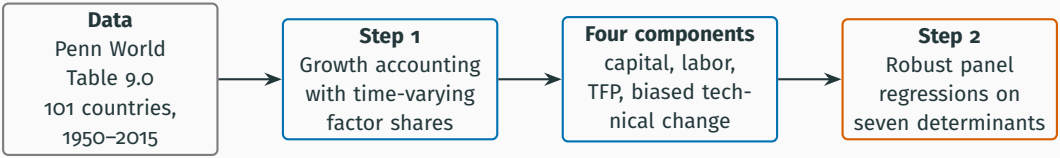
- Ask which determinants raise growth
- Criticised for endogeneity from omitted variables: **common shocks, heterogeneity, outliers**

Question

Why do some countries rely more on **factor accumulation** and others more on **technology** to grow? Which determinants move each source of growth?

Source: Introduction and Conclusion of the paper. The authors contrast this with the usual question, "why do some countries grow more than others?"

This paper: decompose growth first, then explain each component



- **Step 1**: factor shares may vary over time, which adds a **biased technical change** (BTC) component
- **Step 2**: regressions of each component on government spending, trade, human capital, instability and three time-invariant geographic and historical variables
- Inference accounts for **outliers, heterogeneity and cross-panel correlation**

Preview of results

- **Government current expenditure** (share of GDP) lowers the factor components and has **no effect on TFP**
- **Trade** lowers the capital component and raises the BTC component; it raises TFP at the 10% level in the baseline table
- **Human capital** lowers the TFP component and raises the BTC component
- **Deeper determinants** act differently across components: historical population density (BTC), temperature (TFP), ethnic diversity (capital, labor)
- Most baseline results **survive a wild cluster bootstrap**; some do not

Paper's summary table

Contribution

Contribution and closest literature

Growth accounting

- TFP as main source: Hall (1999), Easterly (2001)
- Constant shares as stylised fact: Kaldor (1961), Barro (1999)
- Varying shares: Zuleta (2008), Kahn (1998), Blanchard (1997), Sturgill (2014)
- Biased technical change: Acemoglu (2002)

Growth regressions

- Barro (1991) and followers
- Critiques: Sala-i-Martin (1997), Brock (2001), Durlauf (2005), Ley (2009)
- Extreme observations: Easterly (2005)
- Few panel studies cluster standard errors: Bertrand (2002)

Robust panel methods

- Clustering: Cameron (2008), Petersen (2009), Thompson (2011)
- Common effects: Eberhardt (2011), Nakamura (2017)
- Leverage weights: Cribari-Neto (2011)
- Software: Millo (2017)

Contribution (as stated by the authors)

(i) Explain the **sources** of growth (capital, TFP), not growth itself. (ii) Address the main criticisms of growth regressions with recent econometric tools. Closest paper: Zuleta (2015) uses a cross-section for one period; here a panel, with corrections for persistent and common shocks.

Method and data

Step 1: growth accounting with a time-varying capital share

$$Y_t = A_t\, F(\theta_k K_t,\ \theta_l L_t), \qquad g_y = g_a + \alpha_t\, g_k + (1 - \alpha_t)\, g_l + \Delta\alpha_t \ln\left(\frac{\theta_k K_t}{\theta_l L_t}\right)$$

- Y_t output, K_t capital stock, L_t persons engaged; A_t technology
- θ_k, θ_l efficiency of capital and labor
- g_y, g_k, g_l: annual compound growth rates of Y, K, L
- α_t output elasticity of capital (time-varying); $1 - \alpha_t$ that of labor
- $\Delta\alpha_t$ change in α_t
- g_a TFP growth

With a constant share, $\Delta\alpha_t = 0$ and the biased technical change term vanishes

Notes: Shares vary over time and countries following Zuleta (2012); competitive factor markets and labor-augmenting technology are assumed.

Separating TFP from biased technical change

The traditional Solow residual mixes TFP and BTC:

$$S_t = g_y - \alpha_t g_k - (1-\alpha_t) g_l = g_a + \Delta\alpha_t \ln\left(\frac{\theta_k K_t}{\theta_l L_t}\right)$$

Netting out $\Delta\alpha_t \ln(K_t/L_t)$:

$$\tilde{S}_t = S_t - \Delta\alpha_t \ln\left(\frac{K_t}{L_t}\right) = g_a + \Delta\alpha_t C_1$$

Regress $\tilde{S}_t = C_0 + C_1 \Delta\alpha_t + \eta_t$, so that

$$g_a = C_0 + \eta_t, \qquad C_1 = \ln\left(\frac{\theta_k}{\theta_l}\right)$$

Four components of g_y (paper's eq. 3.6)

Name	Label	Term
Capital	*k_comp*	$\alpha_t g_k$
Labor	*l_comp*	$(1-\alpha_t) g_l$
TFP	*a_comp*	g_a
BTC	*btc_comp*	$\Delta\alpha_t C_1$

C_1: the higher the productivity of capital relative to labor, the more the technical change is biased towards capital

Notes: S_t: Solow residual; $\tilde{S}_t$: residual net of the capital-labor ratio term; C_0, C_1: coefficients; η_t: error. The paper calls the four components "shares".

Data: Penn World Table panel, five-year periods

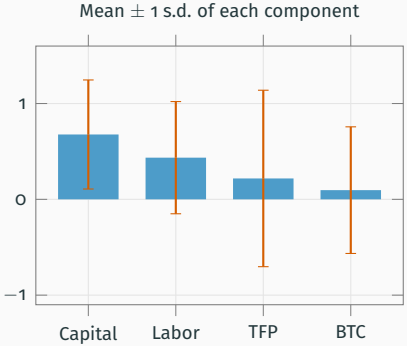
- **Growth accounting sample**: 101 countries, 1950–2015, from Penn World Table 9.0 (Feenstra 2015). Only criterion: data availability for the longest period
- Variables are **quinquennial** to avoid short-run (business cycle) oscillations. With n indexing five-year periods,

$$g_y = \left(\frac{rgdpo_n}{rgdpo_{n-1}}\right)^{1/5} - 1, \quad g_k = \left(\frac{ck_n}{ck_{n-1}}\right)^{1/5} - 1, \quad g_l = \left(\frac{emp_n}{emp_{n-1}}\right)^{1/5} - 1$$

- *rgdpo*: output-side real GDP at current PPPs; *ck*: capital stock at current PPPs (both in millions of 2011 US$); *emp*: persons engaged (millions)
- **Regression sample**: 719 observations, 71 countries, unbalanced panel (13 five-year periods at most, average 10.1 per country)

Descriptive statistics

What the four components look like



Notes: Table 1 of the paper: 719 country-period observations. Means are 0.677, 0.435, 0.218, 0.096. Units as in the paper.

Figure 1 of the paper (bar charts for low- and high-income countries; see paper):

- **Lower-income** countries: growth gains from productivity growth and capital accumulation; a harmful BTC component, which "may be explained" by brain drain to rich countries
- **Rich** countries: a meager TFP contribution (possibly the productivity slowdown), gains from labor and capital, and a positive BTC contribution

Averages hide wide dispersion: the standard deviation of each component exceeds its mean, except for capital.

Step 2: seven determinants and their link to growth in the literature

Determinant	Label	Source	Link to growth in the literature
Government current expenditure (share of GDP)	*csh_g*	PWT 9.0	Negative: lower government consumption enhances growth (Barro 1997)
Openness (exports plus imports)	*trade*	PWT 9.0	Positive (Yanikkaya 2003)
Human capital per person	*hc*	PWT 9.0	Positive in recent literature (Sunde 2015; Teixeira 2016)
Guerrilla warfare (instability)	*gwar*	CNTS, Banks (2019)	Instability lowers growth (Alesina 1996)
Population density in 1 CE	*pd1*	G-Econ, Nordhaus (2006)	Development effects in long-lived countries (Ashraf 2012)
Average temperature	*temp*	G-Econ	Lower growth, mainly in emerging countries (Dell 2012)
Ethnic diversity	*ethnic*	G-Econ	Lower growth, via unstable regimes (Easterly 1997; Alesina 2003)

Notes: pd1, *temp* and *ethnic* are time-invariant. The dependent variables are the four components of Step 1.

Regression model: country effects and persistent common shocks

$$y_{it} = X'_{it}\beta + \varepsilon_{it}, \qquad \varepsilon_{it} = \bar{\varepsilon}_i + \phi_i \varsigma_t + \omega_{it}, \qquad \zeta_{it} = \bar{\zeta}_i + \delta_i \varkappa_t + \xi_{it}$$

- y_{it}: component (capital, labor, TFP or BTC) of country i in period t
- X_{it}: constant and the regressors ζ_{it}; β coefficients; $E(\varepsilon_{it} \mid \zeta_{it}) = 0$
- $\bar{\varepsilon}_i$, $\bar{\zeta}_i$: country-specific effects
- ς_t, $\varkappa_t$: common factors following an AR(1)
- ϕ_i, δ_i: country-specific sensitivities to them, with distribution $\mathcal{N}(0, 1)$
- ω_{it}, ξ_{it}: idiosyncratic errors

Uncorrelated ς_t: time effects. Persistent ς_t: time effects plus persistent common shocks

Error structure follows Eberhardt (2011). Random effects for labor, pooled for the other three (Lagrange multiplier test).

Diagnostics decide which standard errors to use, component by component

- Tests on standardised residuals: **heteroskedasticity, non-normality**, cross-sectional dependence and serial correlation (by component), and **high-leverage outliers**
- No sign of omitted variables (RESET) or multicollinearity (mean VIF 1.36), reported for the capital equation

Component	Standard errors need to be robust against	Estimator used
Capital	overleverage, heteroskedasticity, within-panel and cross-panel autocorrelation	Thompson (2011) two-way cluster, kernel-robust
Labor	overleverage, heteroskedasticity, contemporaneous cross-panel correlation	Petersen (2009) two-way cluster
TFP	as capital	Thompson (2011)
BTC	overleverage, heteroskedasticity	Arellano (1987) one-way (country) cluster

Notes: Table 6 of the paper and the standard-error note of the baseline table.

Test statistics

Robust variance: double clustering, a kernel, and leverage weights

$$\hat{V}_{Double} = \hat{V}_{Country} + \hat{V}_{Period} - \hat{V}_{White}, \qquad w_i = (1 - h_i)^{-\tau_i/2}, \quad \tau_i = \min\left(4,\ h_i/\bar{h}\right)$$

- $\hat{V}_{Country}$: variance clustered by country (within-country autocorrelation)
- $\hat{V}_{Period}$: clustered by period (common shocks)
- $\hat{V}_{White}$: OLS variance robust to arbitrary heteroskedasticity

- h_i: leverage of observation i (diagonal of the hat matrix); $\bar{h}$: its mean
- w_i: weight limiting the effect of high-leverage points (HC4, Cribari-Neto 2011); τ_i: discount exponent, truncated at 4 (written δ_i in the paper)

- **Persistent shocks**: Thompson (2011) adds a kernel over L lags with linearly decaying weights; with T periods the lag rule is $m(T) = \lfloor 4\,(T/100)^{2/9} \rfloor$, and the tables use **2 lags**

Kernel-robust variance

Results

Government and trade lower capital; human capital shifts TFP and BTC

	Capital	Labor	TFP	BTC
csh_g	-0.841^{***} (0.211)	-0.799^{*} (0.248)	-0.26 (0.366)	0.321 (0.283)
trade	-0.45^{***} (0.061)	-0.225 (0.151)	0.413^{*} (0.245)	0.51^{***} (0.181)
hc	0.05 (0.067)	0.008 (0.054)	-0.224^{**} (0.102)	0.116^{***} (0.042)
gwar	-0.002 (0.074)	-0.004 (0.028)	0.024 (0.137)	-0.011 (0.108)
pd1	-0.001 (0.003)	0.01 (0.006)	-0.002 (0.006)	0.017^{***} (0.005)
temp	0.001 (0.005)	0.005 (0.003)	-0.016^{***} (0.006)	0.0017 (0.003)
ethnic	-0.201^{***} (0.071)	0.296^{**} (0.091)	-0.182 (0.11)	0.124 (0.112)
Wald $F(7, 711)$	3.349^{***}	2.028^{**}	2.68^{***}	3.097^{***}
Method	Pooled	Random	Pooled	Pooled

Notes: Table A.5 of the paper; 719 observations. Standard errors in parentheses: Thompson (2011) for capital and TFP, Petersen (2009) for labor, Arellano (1987) for BTC; HC4 weights and a 2-lag kernel. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ (the paper's note prints "$>$"). The constant is not shown.

Government spending lowers capital and labor components, not TFP

csh_g on	Coefficient	(SE)
Capital	−0.841***	(0.211)
Labor	−0.799*	(0.248)
TFP	−0.26	(0.366)
BTC	0.321	(0.283)

Notes: Baseline results (Table A.5).

- The usual negative sign of government spending in growth regressions **may come from the physical capital source** of growth
- The authors read this as a **potentially strong long-run crowding-out**, possibly linked to intertemporal Ricardian effects on investment (and on labor/leisure decisions) if agents expect higher taxes
- Across estimation methods, the negative effect on the factor components is one of the **most robust** results

Bootstrap table

Trade and human capital act on TFP and BTC, with opposite signs for TFP

	on	Coefficient	(SE)
trade	Capital	-0.45^{***}	(0.061)
	TFP	0.413^{*}	(0.245)
	BTC	0.51^{***}	(0.181)
hc	TFP	-0.224^{**}	(0.102)
	BTC	0.116^{***}	(0.042)

Notes: Baseline results (Table A.5). Trade on labor and human capital on capital and labor are not significant.

- **Trade**: the negative capital effect may reflect an *infant industry* argument, and may help explain why openness is not always significant in growth regressions. It is consistent with Madsen (2009): openness matters for growth when technology is taken into account
- **Human capital**, TFP: the negative effect is "somewhat unexpected"; the authors suggest duplication effects (Jones 1995) or complexity effects (Sequeira 2016)
- **Human capital**, BTC: expected, as skilled labor is more adapted to new investment and higher wages for the qualified may raise the capital-labor ratio (Acemoglu 2002)

Deeper determinants work through different components

	on	Coefficient	(SE)
pd1	BTC	0.017^{***}	(0.005)
temp	TFP	-0.016^{***}	(0.006)
ethnic	Capital	-0.201^{***}	(0.071)
	Labor	0.296^{**}	(0.091)

Notes: Baseline results (Table A.5). *gwar* is not significant in any component.

- **Historical population density**: raises BTC. Historically more developed regions tend to favour physical capital today, a channel for the **historical persistence of development** (Dalgaard 2018)
- **Temperature**: lowers TFP, suggesting a channel through which temperature (and climate change) may affect growth (Dell 2012)
- **Ethnic diversity**: lowers capital, consistent with Easterly (1997) and Alesina (2003); raises labor, and the authors suggest the negative growth effect may come from investment rather than from the labor market

Robustness: a wild cluster bootstrap keeps most results

	Capital	Labor	TFP	BTC
csh_g	$-^{***}$ / $-^{***}$	$-^{*}$ / $-^{**}$	ns / ns	ns / $+^{***}$
trade	$-^{***}$ / $-^{**}$	ns / ns	$+^{*}$ / ns	$+^{***}$ / $+^{***}$
hc	ns / ns	ns / ns	$-^{**}$ / $-^{***}$	$+^{***}$ / $+^{***}$
gwar	ns / ns	ns / ns	ns / $+^{*}$	ns / ns
pd1	ns / ns	ns / $-^{**}$	ns / ns	$+^{***}$ / $+^{**}$
temp	ns / ns	ns / ns	$-^{***}$ / $-^{***}$	ns / ns
ethnic	$-^{***}$ / ns	$+^{**}$ / $+^{**}$	ns / ns	ns / $+^{*}$

Notes: Sign and stars: baseline (Table A.5) / wild cluster bootstrap (Table A.6, 999 replications); ns = not significant at 10%.

- **Maintained**: government and trade on capital, trade on BTC, human capital, temperature
- **Changes**: ethnic diversity no longer significant for capital, marginal for BTC; trade loses significance for TFP
- **New**: government spending raises BTC (the authors cite Cozzi 2010); population density lowers labor

Bootstrap table

Conclusion

Different determinants drive different sources of growth

- **Approach**: growth accounting with time-varying factor shares, then growth regressions on each component, with inference robust to common shocks, heterogeneity and outliers
- **Government spending** lowers the factor components with no effect on TFP; **trade** lowers capital and raises BTC; **human capital** lowers TFP and raises BTC
- Different determinants explain different sources of growth, so growth regressions "may be misleading" when seeking to explain **overall growth**

Caveats stated in the paper

Interpretations are tentative ("may", "suggest"). Some results depend on the method: ethnic diversity on capital and trade on TFP weaken under the bootstrap. TFP is a residual and cannot be fully read as technological progress.

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Paper's summary table

Backup

Backup: descriptive statistics

	AR(1)	CSD	Mean	S.D.	Min	Max
K_share	3.47*	31.29***	0.677	0.5692	−3.599	2.272
L_share	8.77***	7.81***	0.435	0.5856	−2.736	2.338
A_share	3.86*	2.98***	0.218	0.9210	−3.242	4.111
BTC_share	0.21	1.26	0.096	0.6609	−3.377	3.239
csh_g	169.3***	34.9***	0.179	0.0840	0.0324	0.6342
trade	99.46***	8.56***	−0.034	0.0989	−0.5745	0.3612
hc	6121.83***	110.22***	2.269	0.7158	1.009	3.719
gwar	3.49***	1.74	0.402	2.663	0	60.2
pd1			3.176	4.403	0.011	23.80
temp			16.60	8.764	−7.929	28.64
ethnic			0.418	0.2490	0.012	0.887

Notes: Table 1 of the paper: 719 observations, 71 countries, average of 10.127 periods. AR(1): Wooldridge test; CSD: Pesaran cross-sectional dependence test. *** $p < 0.01$, * $p < 0.1$.

‹ Back

Backup: diagnostic test statistics as reported

Pesaran and Wooldridge tests

	Cross-sect. dep.	Serial corr.
Capital	11.347***	2.915*
Labor	1.237	8.746***
TFP	3.592***	3.843*
BTC	−0.553	0.217

Capital equation only

Test	Statistic
Breusch-Pagan, homoskedasticity	$F(1, 749) = 901.72^{***}$
Doornik-Hansen, normality	$\chi^2(2) = 1014.98^{***}$
RESET, omitted variables	$F(3, 740) = 0.66$
Link test, redundant variables	$\mathcal{N}(0, 1) = 0.13$
Multicollinearity	mean VIF $= 1.36$

Lagrange multiplier test (country variance = 0)

	Capital	Labor	TFP	BTC
Statistic	$\chi^2(1) = 0.00$	$\chi^2(1) = 9.28^{***}$	$\chi^2(1) = 0.69$	$\chi^2(4) = 0.00$

Notes: Tables 2–5 of the paper. Pesaran statistic $\mathcal{N}(0, 1)$ (null: errors cross-sectionally independent); Wooldridge statistic $F(1, 70)$ (null: no AR(1) in the errors). *** $p < 0.01$, * $p < 0.1$.

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Backup: kernel-robust double-clustered variance

$$\hat{V}_{Double,L} = \hat{V}_{Country} + \hat{V}_{Period} + \sum_{\ell=1}^{L} \left(\hat{V}_{Period,\ell} + \hat{V}'_{Period,\ell} \right) - \hat{V}_{White} - \sum_{\ell=1}^{L} \left(\hat{V}_{White,\ell} + \hat{V}'_{White,\ell} \right)$$

- $\hat{V}_{Period,0}$: variance clustered by period; $\hat{V}_{White}$: OLS variance robust to arbitrary heteroskedasticity
- $\hat{V}_{Period,\ell}$, $\hat{V}_{White,\ell}$: lag-ℓ versions, correcting for persistent common shocks across panels that disappear after L periods (business-cycle shocks; Thompson 2011)
- Assumptions: country effects (correlation across periods), time effects (correlation across countries), persistent common shocks

	Capital	Labor	TFP	BTC
Country effects	X	X	X	X
Time effects	X	X	X	
Persistent common shocks	X		X	

Notes: Table 7 of the paper (components only). Multi-way clustering: Petersen (2009); Cameron (2011).

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Backup: wild cluster bootstrap standard errors

	Capital	Labor	TFP	BTC
csh_g	−0.841*** (0.224)	−0.799** (0.341)	−0.263 (0.458)	0.321*** (0.121)
trade	−0.45** (0.035)	−0.224 (0.169)	0.413 (0.302)	0.512*** (0.05)
hc	0.05 (0.042)	0.008 (0.054)	−0.224*** (0.068)	0.116*** (0.028)
gwar	−0.002 (0.011)	−0.004 (0.005)	0.024* (0.013)	−0.011 (0.021)
pd1	−0.001 (0.007)	−0.011** (0.005)	−0.002 (0.007)	0.017** (0.006)
temp	0.001 (0.003)	0.004 (0.005)	−0.016*** (0.004)	0.0017 (0.002)
ethnic	−0.201 (0.123)	0.279** (0.127)	−0.182 (0.138)	0.124* (0.086)

Notes: Table A.6 of the paper: wild bootstrapped multi-way clustered standard errors (Cameron 2008), 999 replications, as printed. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ (the paper's note prints ">"). Constant not shown.

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Backup: the paper's own summary of the results

Determinant	*k*	*l*	*a*	*btc*
csh_g	−	−		+
trade	−			+
hc			−	+
gwar				
pd1		−		+
temp			−	
ethnic		+		+

Notes: Table A.3 of the paper, as printed. It combines the baseline and bootstrap tables: for example, the effect of government spending on BTC and of population density on labor appear only in the bootstrap table. Use the tables for exact significance.

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References (works named on the slides)

Author-year labels follow the manuscript's citation keys (first author and year); full bibliographic details are in the paper.

Acemoglu (2002); Alesina (1996); Alesina (2003); Arellano (1987); Ashraf (2012); Banks (2019); Barro (1991); Barro (1997); Barro (1999); Bertrand (2002); Blanchard (1997); Brock (2001); Cameron (2008); Cameron (2011); Cozzi (2010)

Cribari-Neto (2011); Dalgaard (2018); Dell (2012); Durlauf (2005); Easterly (1997); Easterly (2001); Easterly (2005); Eberhardt (2011); Feenstra (2015); Hall (1999); Jones (1995); Kahn (1998); Kaldor (1961); Ley (2009); Madsen (2009)

Millo (2017); Nakamura (2017); Nordhaus (2006); Petersen (2009); Sala-i-Martin (1997); Sequeira (2016); Sturgill (2014); Sunde (2015); Teixeira (2016); Thompson (2011); Yanikkaya (2003); Zuleta (2008); Zuleta (2012); Zuleta (2015)