The Developmental Trinity: Institutions, Infrastructure, and Technology

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Understanding differences in country incomes

- Results of Lucas (1990) and Caselli and Feyrer (2007): Country income differences arise primarily from **technology**
- Three questions
  1. Can countries converge, technologically?
  2. If so, how?
  3. And is technological convergence sufficient for economic convergence?
- The paper develops a novel measure of technological prowess using the patent data
- It shows the existence of technological convergence in the wild ("inventive" imitation $\rightarrow$ innovation)—studies the examples of China, India, Korea, and Taiwan
- It argues economic convergence requires successful institutions and infrastructure to complement technological prowess

Simple neoclassical theory of Lucas (1990)

Consider simple neoclassical production function $y = Ak^{\beta}$. Marginal product of capital is:

$$MPK = \beta A k^{\beta-1} = \beta A^{\frac{1}{\beta}} y^{\frac{\beta-1}{\beta}}$$

Consider the example of two countries with differences in per capita income, y:

$$\frac{y_i}{y_j} = \left(\frac{MPK_i}{MPK_j}\right)^{\frac{\beta}{\beta-1}} \left(\frac{A_i}{A_j}\right)^{\frac{1}{1-\beta}}$$

Pure accounting:

- Caselli and Feyrer (2007) tell us $\frac{MPK_i}{MPK_j}$ is roughly 1 for all countries i, j
- But, we know $\frac{y_i}{y_j}$ is far from 1 for many countries i, j
- So, $\frac{A_i}{A_j}$ must not be the same across countries i, j

Endogenous growth theory on $\frac{A_i}{A_j} \neq 1$

- Why were institutions like the World Bank founded? *"The central idea of virtually all postwar development policies is to stimulate transfers of capital goods from rich to poor countries"* (Lucas, 1990)

- For a long time the debate was on whether $\frac{A_i}{A_j} \neq 1$ or whether international capital markets were imperfect (and ignoring massive arbitrage opportunities)
  - Perhaps it has been obvious for some time. *"It is by now incontrovertible that increases in per capita income cannot be explained simply by increases in the capital-labor ratio"* (Arrow, 1962)
  - To me: it is clear that the literature settled on $\frac{A_i}{A_j} \neq 1$ as the dominant explanation
  - How should the World Bank's mission adapt?

- **Innovation**, **Imitation/Adoption**, and **Human capital development**

Outline of results

1. The paper uses patent data to construct a direct measure of technological prowess
2. It studies the evolution of per capita income and technological prowess in four case studies: China, India, Korea, and Taiwan
3. We show economic convergence in Korea and Taiwan and economic stagnation in China and India (relative to their technological peers)
4. We provide evidence that complementary institutions and infrastructure are required to translate raw technical knowledge into gains in material prosperity

Technology

Goals

Measure how close countries are to the technological frontier

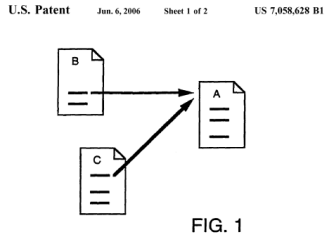
- A country near the frontier should generate many inventions (relative to their size) and high quality inventions—**quantity** and **quality**
- For **quantity**, we use a simple measure of patent families per capita (unique inventions, normalized by country population)
  - Ideas are the cornerstone of modern economic growth (Romer, 1990)
  - All ideas come from people (for now)
  - This captures how efficiently a country utilizes its most vital resource, people, to generate ideas as embodied in patent documents
- For **quality**, we use a measure of innovation centrality
  - How central is a given country's innovations to generating follow-on innovations in the RoW
  - Generate this using cross-country citation data

Centrality in the global citation network

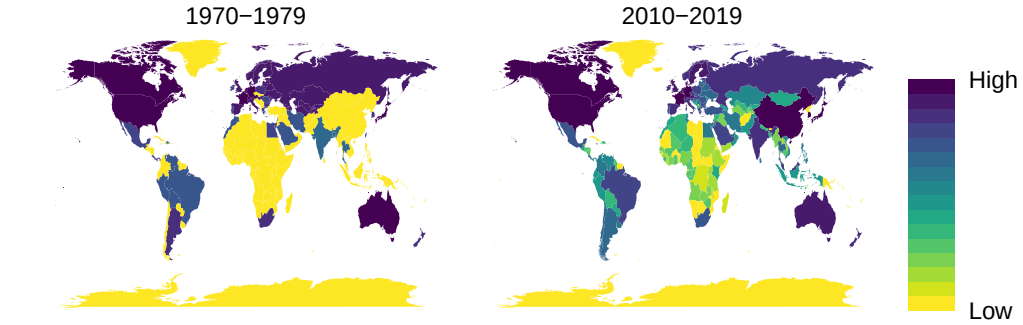
Innovation centrality
Following Acemoglu et al. (2016) and Liu and Ma (2021), for each period t, we construct a matrix $\mathbf{M}_t$ such that:

$$\mathbf{M}_{ij,t} = \frac{\text{Citations}_{i \to j,t}}{\sum_{j'} \text{Citations}_{i \to j',t}} = \Pr\{i \text{ cites } j \text{ in } t\}$$

- Centrality is the first dominant eigenvector of $\mathbf{M}'_t$
- Countries score highly when
  - They receive many citations from RoW
  - They receive many citations from other countries that are themselves central in the network
  - Google uses a similar method in their PageRank algorithm, which was itself patented—US7058628B1



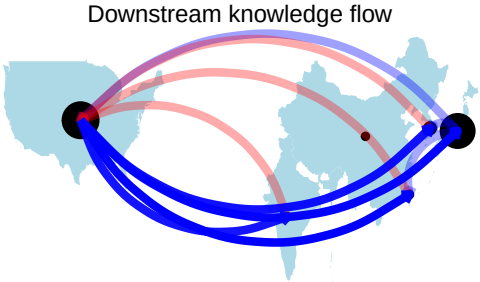
A measure of technological prowess



- Use Google Patents data to characterize world frontier of knowledge
- Our measure is the product of normalized
  1. Patent per capita
  2. Innovation centrality (uses patent citations) ▸ Details

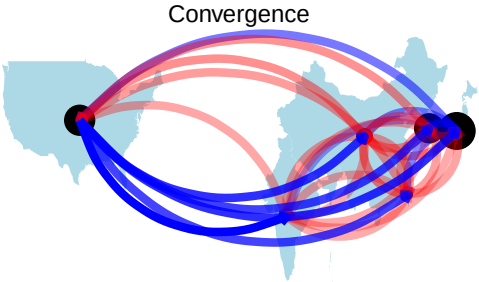
- Shift in technological frontier toward Asia (China, India, Korea, and Taiwan)
- Diffusion in global patenting activity

Learning from the frontier



(a) 1970-1979

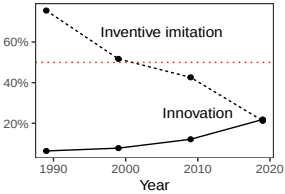
- 1970-1979: China, India, Korea, and Taiwan imitate and learn from the frontier (the United States and Japan)



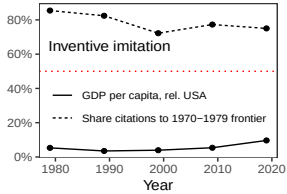
(b) 2010-2019

- In 2010-2019: these countries are learning from each other
  - Citations flow both directions
  - Citations flow *between* the formerly laggard countries

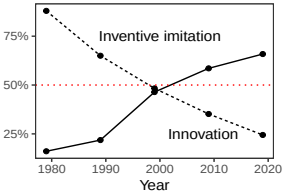
Technological convergence begets economic convergence—sometimes



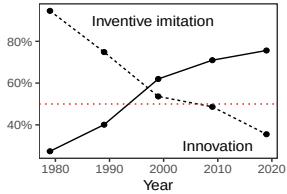
(a) China



(b) India



(c) Korea



(d) Taiwan

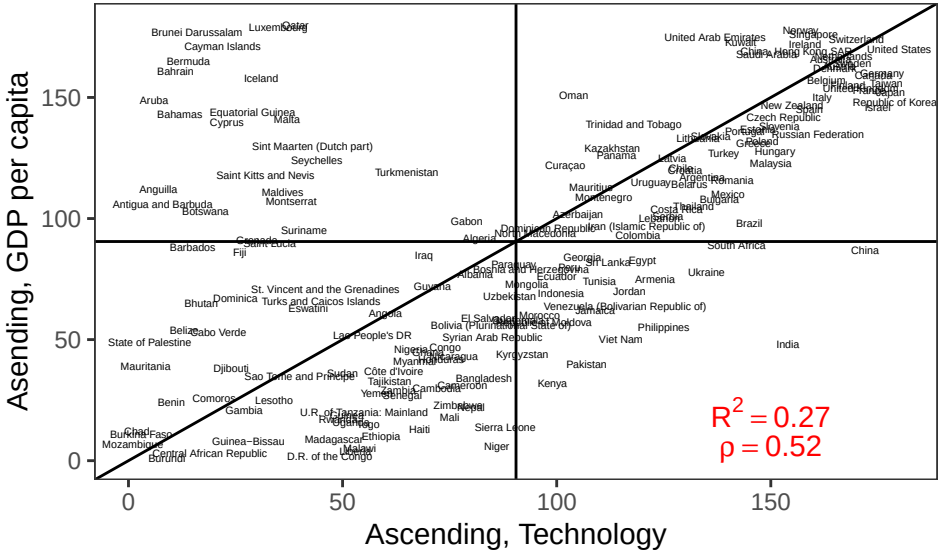
Technology

- China, Korea, and Taiwan give fewer citations to "old frontier"
- India remains mired in imitative patenting

Income per capita

- Korea and Taiwan have caught up to the U.S. in per capita income (solid black line)
- China and India lag

Technological colossuses and economic minnows



Misallocation as the through line

How do we square insights of Abramovitz (1956), Solow (1956), Arrow (1962), and Lucas (1990)—it's all technology—with experiences of India and China?

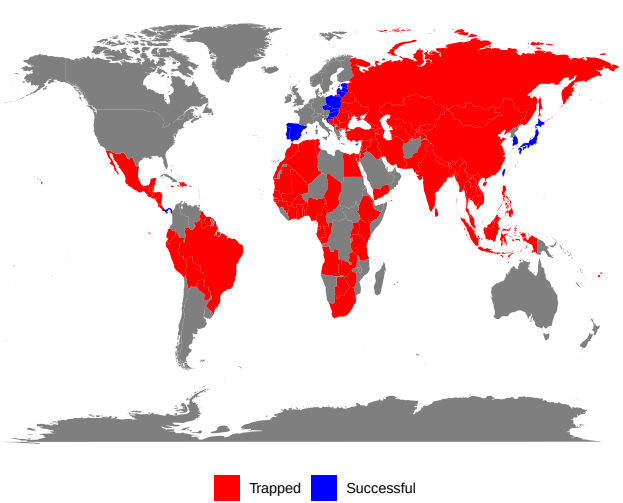
- **Misallocation**—Restuccia and Rogerson (2008) and Hsieh and Klenow (2009)—can lower measured TFP
- We argue this occurs through **poor institutions and insufficient complementary infrastructure**—Hall and Jones (1999), Acemoglu et al. (2001), and Alfaro et al. (2008)
- Takes the form of policies favoring inefficient producers and that underinvest in basic social and physical infrastructure
- What good are tools if you:
  - Put them in the hands of workers that cannot use them?
  - Put them in the hands of firms that use them inefficiently?

Institutions and Infrastructure

Considering the middle income trap

- Focus of WDR2024 is growth of middle income countries: How well do institutional and infrastructural covariates predict middle income escape? (Gill and Kharas, 2007)
- First classify all country-year pairs based on GDP per capita relative to the United States (roughly, World Bank definitions) beginning in 1950
  1. Low income: $[0, 0.01]$
  2. Middle income: $(0.01, 0.20]$
  3. High income: $(0.20, \infty)$
- Subset to countries that were middle income for at least 10 years
- We remove from the sample countries that have strongly regressed (i.e. Venezuela)
- A country escapes middle income if it transitions to high income, persistently
- Otherwise it is "trapped"

Cross-country evidence



- We identify 25 countries that escaped middle income and 103 that are trapped
- Countries in gray are omitted from the sample either because they are too persistently rich or too persistently poor
- Run the following cross-country regressions:

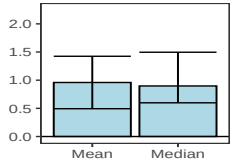
$$\text{Index}_c = \alpha + \delta \mathbb{1}\{\text{Escaped middle income}\}_c + \varepsilon_c$$

- Index_c will be composite indices for institutional and infrastructural quality

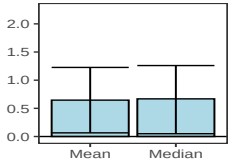
Results, institutions and infrastructure

- Countries that successfully transition out of middle income had:
  1. Higher measures of political and civil liberties (Freedom House)
  2. Higher measures of economic freedoms (Fraser Institute)
  3. Lower top income inequality (World Inequality Database)
  4. Higher educational attainment (Barro and Lee, 2013)
  5. Better physical infrastructure (Canning, 1998)
  6. More financial openness (Chinn and Ito, 2006)
- Utilize parametric and nonparametric statistical tests
- Weakest result is for financial openness (Lucas, 1990; Caselli and Feyrer, 2007; Gourinchas and Jeanne, 2013)

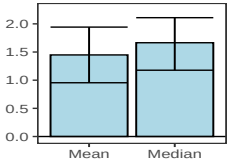
Results, institutions and infrastructure



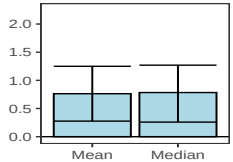
(a) Freedom



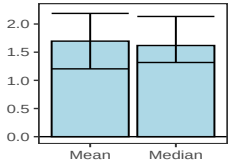
(b) Economic freedom



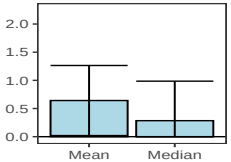
(c) Income inequality (re-normalized)



(d) Educational attainment



(e) Physical infrastructure



(f) Financial openness

The report card methodology

Motivating a country-level report card

- We have conjectured:
  1. Cross-country income differences are primarily driven by technology
  2. Technological convergence is attainable
  3. But that it must be complemented with sound institutions and infrastructure
- Aim to validate that **Institutions**, **Infrastructure**, and **Technology** matter for explaining cross-country income differences
- We construct two sets of indices
  1. Reliable, cross-country historical data is challenging to come by
  2. A different set of factors enter into our indices for historical analysis and contemporary analyses

Report card inputs

Institutions		Infrastructure		Technology	
Description	Historical availability	Description	Historical availability	Description	Historical availability
Political/civil liberty	✓	Educational attainment	✓	Technology index	✓
Economic freedom	✓	Power generation (kW per capita)	✓	Technical publications (per capita)	
Income inequality	✓	Roads (per km^2)	✓	Researchers (per capita)	
Financial openness	✓	Railroads (per km^2)	✓	Research technicians (per capita)	
		Hospital beds (per capita)		R&D to GDP	
		Access to electricity (% population)			
		Access to internet (% population)			
		High-tech. exports (% manufacturing exports)			

Procedure: ▸ Details

- Analyze the data at 5-year frequency to smooth out business cycle fluctuations
- Combine into composite index by taking simple average of normalized components
- Estimate

$$\ln(\text{GDP per capita}_{i,t}) = \lambda_i + \mu_t + \ln(\text{Index}_{i,t}) + \varepsilon_{i,t}$$

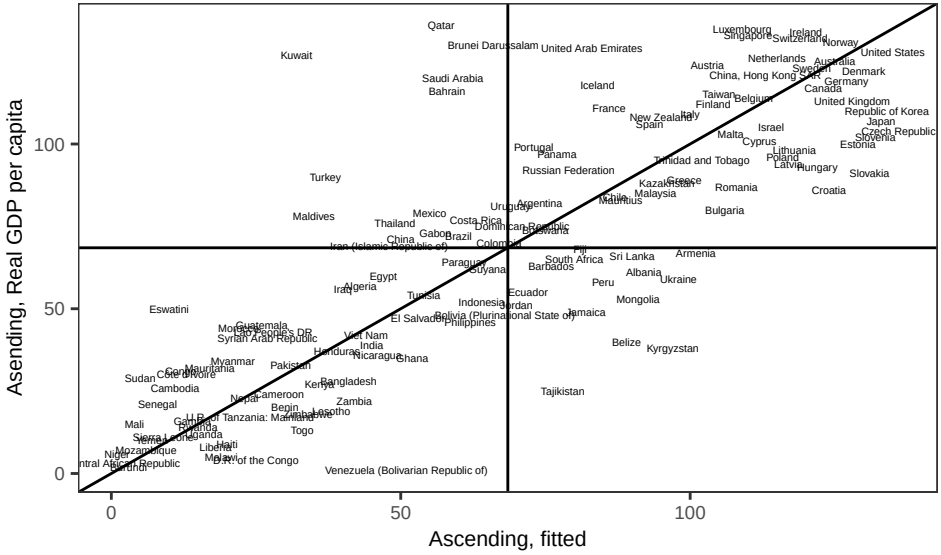
Results

Dependent Variable:	ln GDP per capita			
Model:	(1)	(2)	(3)	(4)
Variables				
(Intercept)	7.1***			
	(0.12)			
ln Technology	0.43***	0.38**	1.5***	1.3***
	(0.16)	(0.17)	(0.34)	(0.16)
ln Infrastructure	4.0***	4.3***	2.8***	0.89***
	(0.39)	(0.45)	(0.22)	(0.30)
ln Institution	1.5***	1.4***	1.1***	0.72**
	(0.42)	(0.44)	(0.25)	(0.28)
Fixed-effects				
Year		Yes		Yes
Country			Yes	Yes
Fit statistics				
Observations	1,339	1,339	1,339	1,339
R^2	0.63644	0.64139	0.93259	0.94365
Within R^2		0.61585	0.42539	0.05864

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

- All three factors load significantly in explaining income per capita
- This holds under a variety of different specifications
- Using preferred specification, we can see which countries over-perform and under-perform relative to their fundamentals

Predicted versus actual country income levels



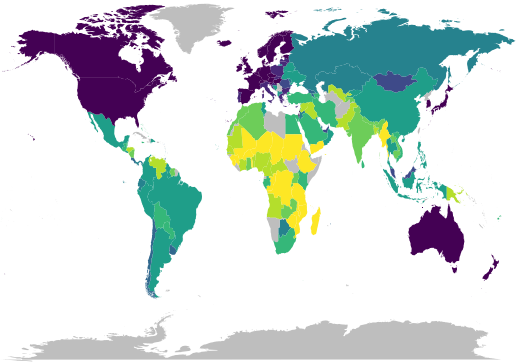
The modern report card

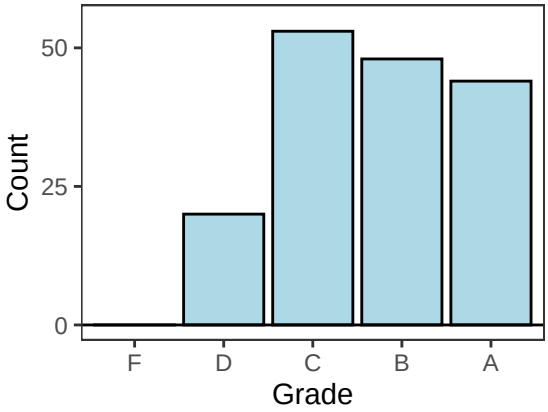
Institutions		Infrastructure		Technology	
Description	Historical availability	Description	Historical availability	Description	Historical availability
Political/civil liberty	✓	Education attainment	✓	Technology index	✓
Economic freedom	✓	Power generation (kW per capita)	✓	Technical publications (per capita)	
Income inequality	✓	Roads (per km^2)	✓	Researchers (per capita)	
Financial openness		Railroads (per km^2)	✓	Research technicians (per capita)	
		Hospital beds (per capita)		R&D to GDP	
		Access to electricity (% population)			
		Access to internet (% population)			
		High-tech. exports (% manufacturing exports)			

- Now include data that lacks historical coverage

- Assign three category-specific grades and then average these three into a composite grade

World report card





Report card, selected countries

	Institutions	Infrastructure	Technology	Overall
Brazil	C-	B	B	B
Chile	A	A	C+	A
China	D	B	A	B
Germany	A+	A+	A+	A+
India	D	C+	C+	C+
Mexico	C+	B+	C+	C+
Republic of Korea	A+	A+	A+	A+
Russian Federation	D	A+	B+	B+
Turkey	D	B	B-	B-
United States	A+	A+	A+	A+

Conclusion

- Country income differences primarily arise from differences in technology the quality of complementary institutions and infrastructure
- To study cross-country differences in technology, we construct a novel measure of distance to the technological frontier using the patent data
- We propose a report card methodology that provides a high-level summation of countries' weak and strong points along the development lifecycle

Thank you

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Centrality

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Following Acemoglu et al. (2016), for each period t, we construct a matrix $\mathbf{M}_t$ such that:

$$\mathbf{M}_{ij,t} = \frac{\text{Citations}_{i \to j,t}}{\sum_{j'} \text{Citations}_{i \to j',t}} \tag{3.1}$$

where $\mathbf{M}_t$ is a row stochastic matrix and $\text{Citations}_{i \to j,t}$ are citations given by country i's patents to country j's patents in period t. We define the measure of network centrality as the first eigenvector of $\mathbf{M}'$, $\underline{m}$, normalized so that $\sum_k \underline{m}_k = 1$.[2]

[2] This measure is known as the measure of eigenvector centrality. See Liu and Ma (2021) for a model where this vector corresponds to the allocation of R&D that maximizes the growth rate of a closed economy.

Details, report card

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Let Θ be a collection of indices. For example, Θ could equal the collection $\{\text{Political rights}, \text{Civil liberties}\}$ for the input for "Political freedom." Let $\theta \in \Theta$ be a particular score. We can think of θ as an unbalanced panel of C countries and T time periods. Let $\theta_{c\cdot}$ be the time series of country c for series θ and $\theta_{\cdot t}$ be the cross-section for series θ for given t.

We have C middle income countries and the periods T_c in which they were middle income. For each country c and each $\theta \in \Theta$ we define:

$$\bar{\theta}_c = \text{Median}\left(\theta_{ct}\right), \quad t \in T_c.$$

In contrast, for the report card exercise, we take the most recently observed observation, so that:

$$\bar{\theta}_c = \max_t \theta_{ct}.$$

Details, report card

With these $\bar{\theta}_c$, we construct $\bar{\boldsymbol{\theta}} = \left\{\bar{\theta}_c\right\}_c$. We then normalize according to:

$$\bar{\boldsymbol{\theta}}^n = \frac{\bar{\boldsymbol{\theta}} - \min_c \bar{\boldsymbol{\theta}}}{\max_c \bar{\boldsymbol{\theta}} - \min_c \bar{\boldsymbol{\theta}}}.$$

Note that all operations are elementwise. Lastly, with slight abuse of notation, we combine our normalized measures into composite indices according to:

$$\bar{\boldsymbol{\Theta}} = \frac{1}{|\Theta|} \sum_{\theta \in \Theta} \bar{\boldsymbol{\theta}}^{\boldsymbol{n}}$$

For exercises that perform regressions, we further standardize this composite measure to ease interpretation of regression coefficients:

$$\bar{\boldsymbol{\Theta}}^z = \frac{\bar{\boldsymbol{\Theta}} - \mu\left(\bar{\boldsymbol{\Theta}}\right)}{\sigma\left(\bar{\boldsymbol{\Theta}}\right)}.$$

Details, report card

Lastly, for the report card methodology, we have a collection of $\left\{\bar{\Theta}\right\}_{\Theta}$ which we equal-weight average one last time to create measures of Institutions, Infrastructure, and Technology.

Report card, full

Back

	Institutions	Infrastructure	Technology	Overall
Albania	B+	B+	C-	B+
Algeria	D	B-	C	C
Angola	F	D	C+	D
Antigua and Barbuda	A+	A+	C-	A+
Argentina	C	A-	C+	C+
Armenia	A	A-	C	A-
Australia	A+	A+	A+	A+
Austria	A+	A+	A+	A+
Azerbaijan	C-	B+	C	C
Bahamas	C+	B+	C-	C+
Bahrain	B-	A+	C	B-

Report card, full

Bangladesh	D	C	C-	C-
Barbados	A-	A+	B-	A-
Belarus	C-	A+	C+	C+
Belgium	A+	A+	A+	A+
Belize	C+	B-	C-	C+
Benin	C-	D	C-	C-
Bhutan	C-	B-	C-	C-
Bolivia (Plurinational State of)	C+	B-	C-	C+
Bosnia and Herzegovina	B-	B	C	B-
Botswana	A	B-	C	B-
Brazil	C-	B	B	B
Brunei Darussalam	B	A+	C	B
Bulgaria	A+	A+	B	A+
Burkina Faso	F	F	C-	F
Burundi	F	F	C-	F

Report card, full

Cabo Verde	A+	C+	C-	C+
Cambodia	C+	C-	C-	C-
Cameroon	F	C-	C	C-
Canada	A+	A+	A+	A+
Central African Republic	F	F	B	F
Chad	F	F	C-	F
Chile	A	A	C+	A
China	D	B	A	B
China, Hong Kong SAR	A+	A+	A+	A+
Colombia	C+	B+	C	C+
Comoros	D	D	C-	D
Congo	F	D	C-	D
Costa Rica	A+	B+	C+	B+
Croatia	A+	A	A-	A
Cyprus	A+	A	A-	A

Report card, full

Czech Republic	A+	A+	A+	A+
C te d'Ivoire	D	D	C	D
D.R. of the Congo	F	D	C-	D
Denmark	A+	A+	A+	A+
Djibouti	C	C	C-	C
Dominica	A+	B	C-	B
Dominican Republic	B+	B	C	B
Ecuador	A-	B	C	B
Egypt	D	B+	C+	C+
El Salvador	A-	C+	C-	C+
Estonia	A+	A+	A+	A+
Eswatini	F	C	C-	C-
Ethiopia	F	F	C	F
Fiji	C	A-	C-	C
Finland	A+	A+	A+	A+

Report card, full

France	A+	A+	A+	A+
Gabon	D	B+	C	C
Gambia	A	D	C-	C-
Georgia	A+	B	C+	B
Germany	A+	A+	A+	A+
Ghana	C-	C+	C-	C-
Greece	A+	A-	A	A
Grenada	B-	B-	C+	B-
Guatemala	A-	C	C-	C
Guinea	D	D	C-	D
Guyana	B+	B	C-	B
Honduras	D	C	C-	C-
Hungary	A+	A+	A	A+
Iceland	A+	A+	A+	A+
India	D	C+	C+	C+

Report card, full

Indonesia	B+	B-	C	B-
Iran (Islamic Republic of)	F	B	B-	B-
Iraq	F	C+	C-	C-
Ireland	A+	A+	A+	A+
Israel	A+	A	A+	A+
Italy	A+	A-	A	A
Jamaica	C+	B+	C-	C+
Japan	A+	A+	A+	A+
Jordan	B+	B	C+	B
Kazakhstan	C	A+	B	B
Kenya	B	D	C+	C+
Kuwait	C+	A	C-	C+
Kyrgyzstan	C+	A-	C	C+
Lao People's DR	D	C+	C+	C+
Latvia	A+	A+	B+	A+

Report card, full

Lebanon	D	B	C	C
Lesotho	C+	D	C-	C-
Lithuania	A+	A+	A-	A+
Luxembourg	A+	A+	A+	A+
Madagascar	D	F	C-	D
Malawi	C-	F	C-	C-
Malaysia	B-	A-	A+	A-
Maldives	C+	A+	C-	C+
Mali	D	D	C-	D
Malta	A+	A+	A	A+
Mauritania	C-	D	C-	C-
Mauritius	A+	B+	C	B+
Mexico	C+	B+	C+	C+
Mongolia	A+	A	C+	A
Morocco	D	B-	C+	C+

Report card, full

Mozambique	F	F	C-	F
Myanmar	F	D	C-	D
Namibia	B-	C-	C-	C-
Nepal	B-	C-	C	C
Netherlands	A+	A	A+	A+
New Zealand	A+	A	A+	A+
Nicaragua	B-	C	C-	C
Niger	D	F	C	D
Nigeria	C	D	C-	C-
North Macedonia	A	B	C	B
Norway	A+	A+	A+	A+
Oman	B	B	C	B
Pakistan	D	C-	C-	C-
Panama	A+	B	C-	B
Paraguay	B-	B	C-	B-

Report card, full

Peru	A-	B	C-	B
Philippines	B-	C+	B+	B-
Poland	A+	A+	A-	A+
Portugal	A+	B+	A+	A+
Qatar	B	A	B-	B
Republic of Korea	A+	A+	A+	A+
Republic of Moldova	B	A-	C	B
Romania	A+	A+	B-	A+
Russian Federation	D	A+	B+	B+
Rwanda	C+	D	C	C
Saint Kitts and Nevis	B-	B-	A+	B-
Saint Lucia	A+	B-	C	B-
Sao Tome and Principe	A+	C+	C	C+
Saudi Arabia	C-	A-	C	C
Senegal	C-	D	C	C-

Report card, full

Seychelles	A+	B-	C	B-
Sierra Leone	C-	F	C-	C-
Singapore	A+	A+	A+	A+
Slovakia	A+	A+	A-	A+
Slovenia	A+	A	A+	A+
South Africa	D	B	C+	C+
Spain	A+	A	A+	A+
Sri Lanka	C	B+	C-	C
St. Vincent and the Grenadines	B	B	C-	B
Sudan	D	D	C-	D
Suriname	C-	B-	C-	C-
Sweden	A+	A+	A+	A+
Switzerland	A+	A+	A+	A+
Syrian Arab Republic	F	C	C-	C-
Tajikistan	D	B-	C-	C-

Report card, full

Thailand	D	B	B+	B
Togo	D	D	C-	D
Trinidad and Tobago	A	A-	C	A-
Tunisia	C+	B	B-	B-
Turkey	D	B	B-	B-
U.R. of Tanzania: Mainland	D	D	C-	D
Uganda	B	F	C-	C-
Ukraine	C-	A+	C+	C+
United Arab Emirates	B+	A	A-	A-
United Kingdom	A+	A+	A+	A+
United States	A+	A+	A+	A+
Uruguay	A+	B+	C+	B+
Uzbekistan	F	B-	C-	C-
Venezuela (Bolivarian Republic of)	F	B-	C-	C-
Viet Nam	D	B-	B	B-

Report card, full

Yemen	D	D	C-	D
Zambia	B-	D	C-	C-
Zimbabwe	F	D	C-	D

Table 1: **Full report card data.**

Quality vs. quantity

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