# The Developmental Trinity: Institutions, Infrastructure, and Technology*

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**Abstract**

This paper studies technological and economic convergence in middle income countries. It first constructs a novel index of technological prowess using international patent data. Encouragingly, it finds technological convergence is achievable; it has been achieved by numerous countries throughout history; and it is done via a sequential progression from what is termed "inventive" imitation into original innovation. However, the paper argues that unless societies alleviate misallocation—in the form of subpar institutions and infrastructure—technological convergence fails to translate into commensurate economic gains. Motivated by these historical findings, it concludes by proposing a report card on contemporary, country-level performance along the three dimensions—institutions, infrastructure, and technology—that it identifies as being central to explaining escape from the middle income trap.

**Keywords**:

**JEL Codes**: .

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# 1 Introduction

In 1990, Robert E. Lucas Jr. famously asked, "Why doesn't capital flow from rich to poor countries?" His question, beguilingly simple in its formulation, posed a challenge to the entire postwar consensus on macro-development economics. Indeed, the venerable multilateral institutions forged at Bretton Woods in 1944 were set up with the express purpose of channeling capital from rich to poor countries for the dual purposes of macroeconomic stabilization—the remit of the International Monetary Fund (IMF)—and macroeconomic development—the remit of the World Bank. If, as Lucas (1990) charged, the stark differences in income per capita witnessed between the developed and developing worlds resulted from technological differences and not from widespread financial frictions in international capital markets, any actions by these institutions to transfer capital at the intergovernmental level would be, absent those same frictions, optimally offset from transfers by private agents.[1]

Where does this leave the benevolent practitioner of macro-development? Inasmuch as we believe the political economy of transmogrifying institutions such as the World Bank and IMF into conduits for North-South technology transfer to be prohibitively costly, we are left somewhat adrift, even cynical. If poor countries are poor because they are not at the technological frontier, and we are ill-equipped to get them there through forced technology transfer, we must answer two questions before embarking on remediating policy. First, is technological convergence possible: have we observed it in the wild? Second, is it, in fact, enough? Do all countries at the technological frontier manage to unlock the dividends of their technical expertise, or are there enabling institutions required to channel technical capacity into material prosperity? For answers to these questions, we appeal to a mix of theory and empirics.

Turning first to the international patent data, we document the flow of knowledge across space and time. We show there is good cause for optimism: there are indeed countries that have caught up to the frontier—making what, in retrospect, is astounding progress—and we argue that they have done so first through what is termed "inventive" imitation, and then through a successful transition to original innovation.[2] We then

[1] Subsequent empirical work by Caselli and Feyrer (2007) confirmed that measured marginal returns to physical capital were essentially equalized across countries when accounting for developing countries' stocks of natural capital. Caselli and Feyrer (2007) and Hsieh and Klenow (2007) also found a large role for differences in relative prices of investment between developing and developed countries, perhaps resulting from developing countries' low productivities in the production of capital goods.

[2] The paper relies on international patent data; it is unconventional to classify any patenting as

document that those societies that were able to translate their technological catch-up into material prosperity were characterized by comparatively more open and robust institutions as well as higher quality social infrastructure. We thus find that progress is not just technological; there are antecedent institutional thresholds that are required to transform advances in technology into advances in per capita income. We feel these results reinforce the consensus on the primacy of institutions for economic prosperity (Hall and Jones, 1999; Acemoglu et al., 2001).

What do we make of the existence of technologically advanced and yet materially poor countries in light of Lucas and others' contentions that what separates the rich countries from the poor is technology? We argue that if a country is unable to utilize technology efficiently—be it frontier or stale technology—due to misallocation or mismanagement, the "effective" level of technology will be low.[3] We are far from the first to point out that misallocation can have aggregate effects on the level total factor productivity (TFP).[4] However, we view our contribution as operationalizing the misallocation literature by validating its predictions historically, and distilling its insights for the challenge of macroeconomic development moving forward.

Our results buttress the new growth theory that places ideas, and not physical capital, at the forefront of modern economic growth.[5] The theory posits that ideas are distinct from physical capital due to their nonrivalry: The use of a machine in production by one agent excludes its use by a competing agent; in contrast, once developed, an idea can be used unlimited numbers of times by unlimited numbers of agents—at least among the subset of agents with a legal right to exploit the idea. We argue that this theory of economic progress, augmented with a proper role for institutions, ought to become

"imitative" since a prerequisite for patent grants in nearly all jurisdictions is novelty. Imitation is better captured by activities such as technological licensing, for which comprehensive international data is unfortunately lacking (see Choi and Shim, 2023 for a notable exception). Thus, we use cross-country patent citations to proxy for technology adoption. See Cai et al. (2022) for a paper employing a similar strategy.

[3]Our measures of institutions and social infrastructure capture the general levels of political and economic freedoms as well as the basic level of educational attainment, up to the secondary levels, and stocks of physical infrastructure in the forms of roads, railways, and electrical generation capacity. One form of misallocation could be economic policies that favor unproductive state-owned enterprises at the expense of the private sector; another form of misallocation could be an undereducated workforce that, due to a skill-based complementarity with new technologies, leads to an inability to exploit best practices and new technologies in production.

[4]See Restuccia and Rogerson (2008) and Hsieh and Klenow (2009) among others.

[5]For examples of this new growth theory, see Arrow (1962), Romer (1986), Lucas (1988), Romer (1990), Aghion and Howitt (1992), Kortum (1997), and Klette and Kortum (2004), among others.

the dominant paradigm through which macro-development is practiced. In short, the empirical evidence is telling us that capital accumulates just fine; technology is what separates countries, and until multilateral institutions reckon with this fact, there is no amount of lending they can do to augur economic convergence.

Motivated by our findings, we conclude by proposing a novel indicator, itself a composite index of indicators sourced from various international organizations and academic papers. Our "report card" seeks to assess conditions in currently middle income countries in light of the historical experiences of the countries that successfully converged to the frontier. It measures a country's performance along three key dimensions: institutions (political and economic), infrastructure (social and physical), and technology (public and private). It functions as a diagnostic that helps the policy maker to understand which aspects of a country's political economy are on track versus which require remediation in order to successfully escape low or middle income. We also validate a version of our report card methodology using a "skinny" version of the indices for institutions, infrastructure, and technology that has wide historical coverage. This validation exercise shows that our three factors explain a large proportion of cross-country variation in income per capita, after accounting for time-series variation in income per capita. We hope this country-level "report card" proves useful to policy makers endeavouring to elevate the prosperity of their societies.

The remainder of the paper is organized as follows. Section 2 describes the international patent data we use to construct a novel index of technological prowess. It shows historical examples of technological and economic convergence. Section 3 performs cross-country regressions, arguing that middle income success stories—middle income countries that converged to high income—had comparatively better institutions and infrastructure than their peers, who remain mired in middle income. Section 4.1 presents a contemporary report card on each country's institutions, infrastructure, and technology based on preceding and newly available data and conducts the historical validation of this methodology. Section 5 concludes.

# 2 International Flows of Knowledge

## 2.1 Data

We use Google Patents data to quantify cross-border knowledge flows as embodied in patent citations.[6] When counting inventions, we count only the first patent associated with a given patent family.[7,8] This is done to avoid overcounting the invention of a given technology; inventors often seek to protect identical technologies across multiple jurisdictions. When counting citations, in contrast, we count all citations to all member patents within a given family, as it is likely that local inventors and patent examiners are predisposed to cite the local patent document for a given invention and not necessarily the originating document. We geolocate patents using inventor location.[9] When a patent has multiple inventors spread out across multiple locations, we assign fractional shares of the patent to each location. For example, if a patent has three inventors, two of whom are Japanese and one of whom is American, then the patent is 2/3 Japanese and 1/3 American.

## 2.2 The technological frontier

In this section, we identify the world technological frontier and show that its spatial distribution has changed over time due primarily to the technological convergence of Asia.

We begin by constructing a novel index of technological prowess using the patent data.[10] First, we construct patent per capita for each country and each year. This is the

[6]Google Patents data is derived from DOCDB, the EPO's database containing worldwide bibliographic data. See Liu and Ma (2021) for discussion on the similarity of Google Patents data to the more commonly used PATSTAT database.

[7]A patent family, as defined by the EPO, "is a collection of related patent applications that is covering the same or similar technical content"—https://link.epo.org/web/Patent_Families_at_the_EPO_en.pdf.

[8]As discussed in Berkes et al. (2022), there has been a sharp uptick in the number of patents granted in China since the third revision to the patent law in 2008, without a corresponding rise in the number of patents granted protection at the triadic level (protection granted by the USPTO, the JPO, and the EPO). Therefore, in our analysis, we require that Chinese patent families contain at least one patent that has been granted protection by at least one of the triadic jurisdictions.

[9]When inventor location is missing, we assign the location using assignee location. When assignee location is missing, we assign the location using patent office location, which requires us to drop EPO patents that lack inventor or assignee information (since the geographic resolution would be no finer than the European Union, a bloc with 27 member states).

[10]See Appendix D for a comparison of our index with the Economic Complexity Index (ECI) of Hidalgo and Hausmann (2009) and extensions developed by Xu and Lybbert (2017) and Stojkoski et

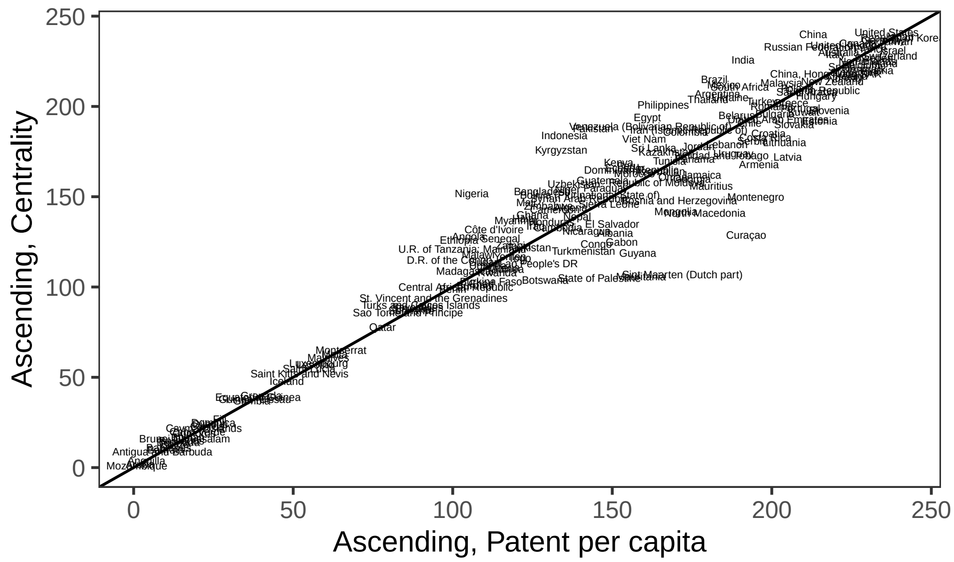



Figure 1: **Components of technology index.** Correlation coefficient is 0.96 and $R^2 = 0.93$.

number of granted patents in a given country in a given year $t$ divided by the population in year $t$.[11] Then, we assign the patent to its country of origin. This first component is scale-dependent and disfavors more populous countries.

As a second measure of a country's "frontierness," we develop a measure of network centrality. Following Acemoglu et al. (2016) and Liu and Ma (2021), for each period $t$, we construct a matrix $\mathbf{M}_t$ such that:

$$\mathbf{M}_{ij,t} = \frac{\text{Citations}_{i \to j,t}}{\sum_{j'} \text{Citations}_{i \to j',t}} \tag{1}$$

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 dominant eigenvector of $\mathbf{M}'_t$, $\underline{m}_t$, normalized so that $\sum_k \underline{m}_{tk} = 1$.[12] Note that this measure is scale-dependent, too, but in a countervailing way. A country that issues very many patents will naturally absorb a large percentage of world citations, regardless of its population size. Note further that this measure embeds a notion of

al. (2023).

[11] Following Akcigit et al. (2022), we assign the year $t$ to a patent's filing date as there is often a significant lag between filing and grant, and the inventive activity takes place closer to filing.

[12] 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.

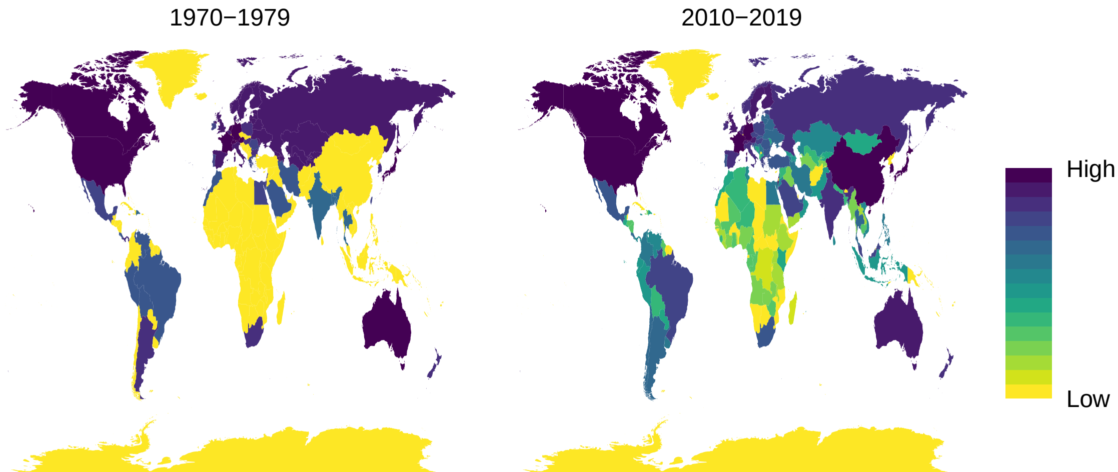
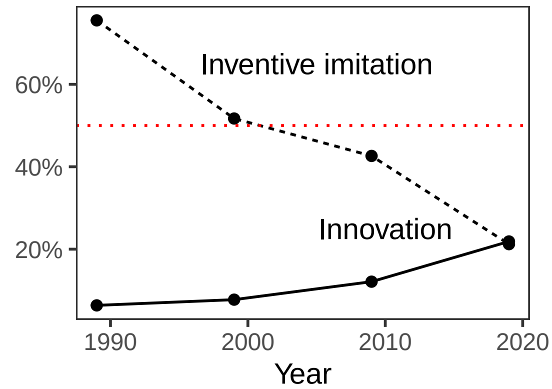



Figure 2: **The world technological frontier.** The index is the product of a country's normalized patent centrality and normalized patent per capita. Darker colors correspond to higher scores.

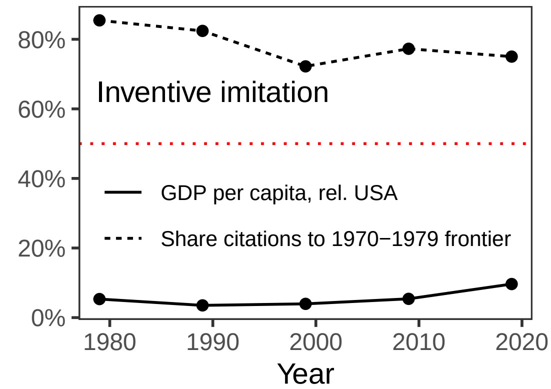
patent "importance." A country that issues very many patents but receives few citations would not score highly on centrality but might on patent per capita.

We then normalize our two measures to be between 0 and 1, multiply them, and rank them. Our final index thus embeds complementarity between quantity and quality. To be ranked high in the index, a country must generate very many high quality patents, and it must generate them at a scale that is commensurate with its raw inputs: people. Figure 1 shows the components in our technology index. There is clearly very strong correlation between the two components of our index, but deviations from perfect correlation are revealing. In particular, we highlight that China and India appear to be more "central," to global knowledge flows than their overall level of patenting, relative to their populations, would predict. Thus, even though, from a raw input perspective, they perhaps underutilize their populations in the generation of ideas, they are quite central to the generation of ideas at the global level. Conversely, many Eastern and Central European countries appear to generate a high number of patents relative to their populations but are somewhat disconnected from global knowledge networks.

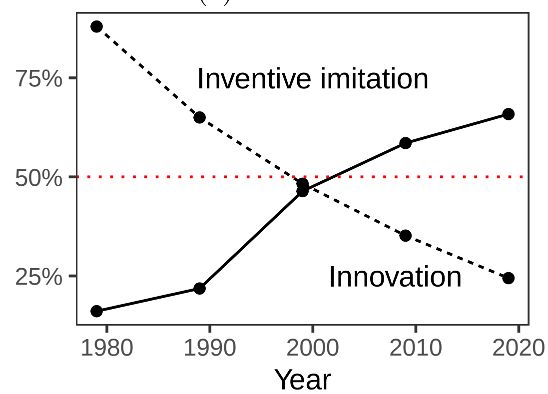
Figure 2 presents our composite index for two decades: 1970-1979 and 2010-2019. An immediate finding is there has been a noticeable shift in the world frontier of knowledge, from Western Europe toward Asia—specifically toward China, India, Korea, and Taiwan. Coinciding with this shift, of course, was a stark rise in income per capita in some of these very same countries. How did they achieve such a rise?



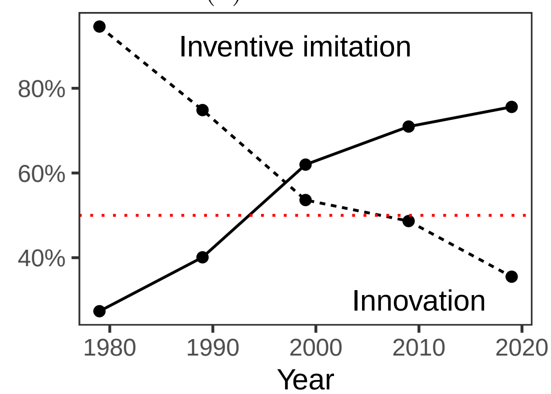

(a) **China.**




(b) **India.**




(c) **Republic of Korea.**



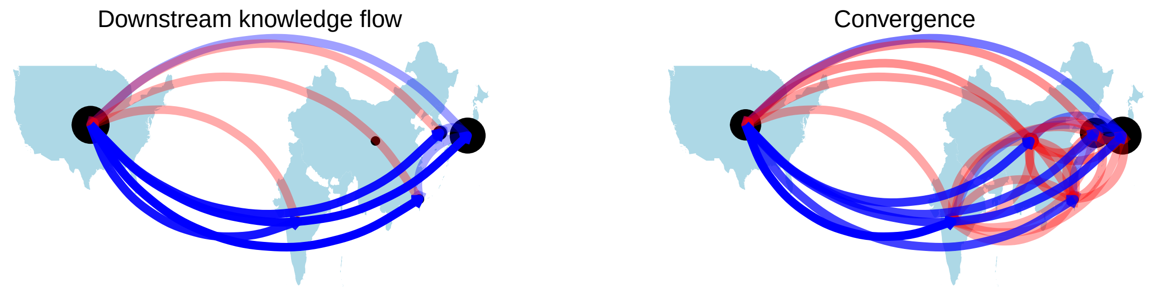

(d) **Taiwan.**

Figure 3: **Asian convergence.** The solid black line in each sub-panel shows the ratio of focal country GDP per capita to U.S. GDP per capita. The black dashed line in each sub-panel shows the fraction of external citations that are given to the frontier countries of 1970-1979.

Figures 3 and 4 are suggestive. First, Figure 3 shows that income per capita rose in precisely those countries that were able to successfully transition from "inventive" imitation to innovation. The solid black line plots the ratio of income per capita in each focal country relative to income per capita in the United States.[13] The dashed black line plots the fraction of external citations made by the focal country's patents to the frontier countries of 1970-1979.[14] When a high proportion of a country's patents are citing the older frontier countries, we say that these countries are imitating. An immediate implication is the heterogeneous paths of income per capita in the four countries examined in Figure 3: Korea and Taiwan have experienced much higher rates of material prosperity

[13]In this figure and what follows we use GDP per capita at market exchange rates. Our results are robust to using GDP per capita that is PPP adjusted. See Dowrick and Akmal (2005), Almås (2012), and Pinkovskiy and Sala-i-Martin (2020) for a discussion on these issues.

[14]The frontier countries are defined as the top 5 countries in the index constructed for Figure 2. For 1970-1979, they are, in descending order, the United States; France; Germany; Canada; and Japan.




(a) **Citations from the frontier—Asia, 1970-1979.**

(b) **Citations from the frontier—Asia, 2010-2019.**

Figure 4: **Global citations flows, Asian development.** Arrows represent "exports" of citations: more darkly shaded arrows correspond to a larger proportion of citations are being exported to the focal country. Black dots correspond to the country's share of world patents.

than China and India. Understanding why will be a key goal of this paper.

Figure 4 examines the world citation network, specifically honing in on the Asia-U.S. nexus. A clear pattern of imitation, followed by innovation emerges. In the early period, when Asia was relatively technologically undeveloped, the United States and Japan were "exporting" knowledge to China, India, Korea, and Taiwan. This is the imitation period. As domestic inventors and firms catch up to the frontier, Asian countries begin exporting knowledge to the United States and Japan and to one another. A robust internal network of knowledge spillovers has developed that feeds internally sustainable levels of inventiveness. Figure 4 is also a good visualization of how the innovation centrality measure is constructed; locations exporting citations to many countries and exporting citations to countries that themselves export many citations score highly, underscoring why China, India, Korea, and Taiwan moved as far up the rankings as they did between the two periods.

The question remains, however, as to why Korea and Taiwan have grown so much more than India and China. An easy point to note is that the experiences of India and China, themselves, are distinct. Indian and Chinese per capita GDP have grown, but Chinese per capita GDP has grown much more robustly, and China has pivoted from imitation to novel innovation, whereas India remains mired in imitative patenting. Moreover, China's rise in the rankings has been even sharper than India's. To some extent, these are not like comparisons. However, even granting that distinction between Chinese and Indian growth dynamics, there still remains a qualitative difference in prosperity between China and Korea and Taiwan that has a nonobvious origin. Indeed, Figure

5 shows that this imperfect concordance is quite general; it plots, in ascending order, the rankings of countries based on their levels of technology, as measured in the index constructed for Figure 2, and their levels of income per capita. Points along the 45° degree line correspond to countries whose levels of technology and income correspond one-for-one. Points below (above) the 45° line are countries that are underperforming (overperforming) relative to their levels of technology. We see China and India—though especially China—are prominent outliers in the southeast quadrant, and numerous resource rich economies and tax havens are outliers above the 45° line in the northeast and northwest quadrants.[15]

Where does this leave us? First, as Figure 2 makes clear, the spatial distribution of technology is dynamic; technological convergence (Figures 4) is possible, but economic convergence (Figures 3 and 5) is not guaranteed to follow. What is missing? In what follows, we will argue there are two key omitted variables to the above analysis: qualities of institutions and basic infrastructure. These two factors are necessary complementary and pre-requisite factors to escaping the trap of middle income. Korea and Taiwan are illustrative examples, but in what follows we will seek to be more precise through the use of cross-country and panel regressions.

Our last observation is that although technological convergence is insufficient on its own for economic convergence, it does appear necessary—at least absent the good fortune of being endowed with plentiful and valuable natural resources. Thus, countries that are behind the curve technologically should look to the examples of China, India, Korea, and Taiwan and begin by imitating frontier technologies. Although they will have to eventually transition to original invention, imitation is a good first step and has resulted in meaningful, albeit comparatively disappointing, income gains for middle income countries, historically.[16]

[15]One way to think of the 45° line is as a counterfactual. That is: China could be as a wealthy a society—in real per capita income terms—as the United States, Germany, or Taiwan based on its level of technology. Conversely, the United Arab Emirates, based on its level of technology, would be as wealthy a country as Lithuania or Slovakia based solely on its level of technology. We caution, however, that the results represent mere correlations; true counterfactuals imply a causal interpretation.

[16]See Choi and Shim (2023) for a study of Korea's transition to original innovation through licensing, as opposed to mimicry, of frontier Japanese technologies. See also Perla and Tonetti (2014) and König et al. (2022).

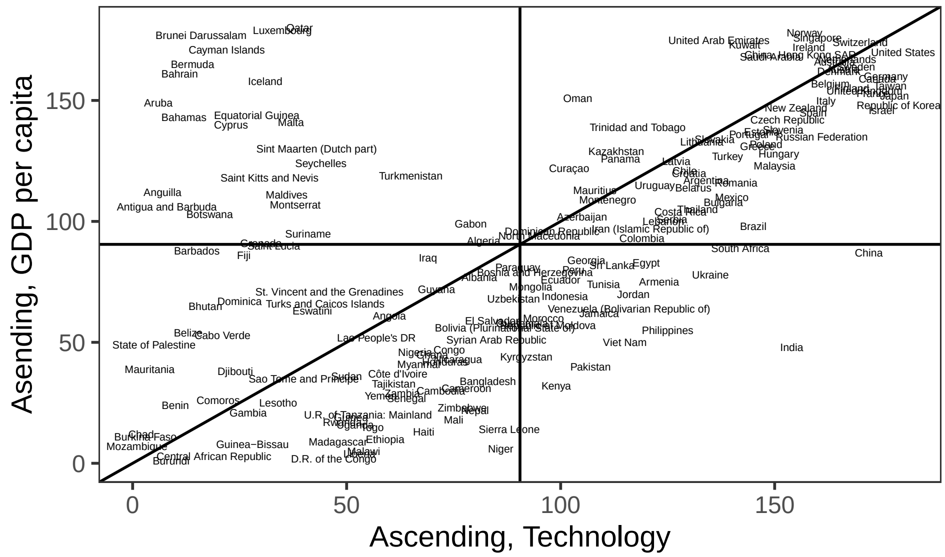



Figure 5: **Technology index and GDP per capita rankings.** Data on income per capita comes from Penn World Table 10.01 (Feenstra et al., 2015). Diagonal line is 45° line; horizontal and vertical lines bisect at median values along x- and y-axes. Correlation coefficient equals 0.52; $R^2$ equals 0.26.

# 3 Institutional Quality, Infrastructure, and Openness

## 3.1 Classification

The previous section presented extensive evidence concerning the possibility of technological convergence, honing in on the handful of Asian countries that have advanced to the frontier. Here we aim to be more precise: what was it about these countries that allowed them to translate technical advancement into material prosperity? We will argue it is openness and institutional quality.

To begin, we require a goalpost of success. To define this goalpost we look to countries that successfully transitioned out of middle income. We define countries as low, lower middle, upper middle, and high income according to the following cutoffs (defined as ratios of focal country GDP per capita to U.S. GDP per capita):[17]

[17] This roughly follows the existing World Bank thresholds for defining lower, middle, and high income countries. The thresholds change year to year and use GNI per capita, calculated using the Atlas methodology—`https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups`. As of July 28, 2023, the historical classifications range from 1987-2022.

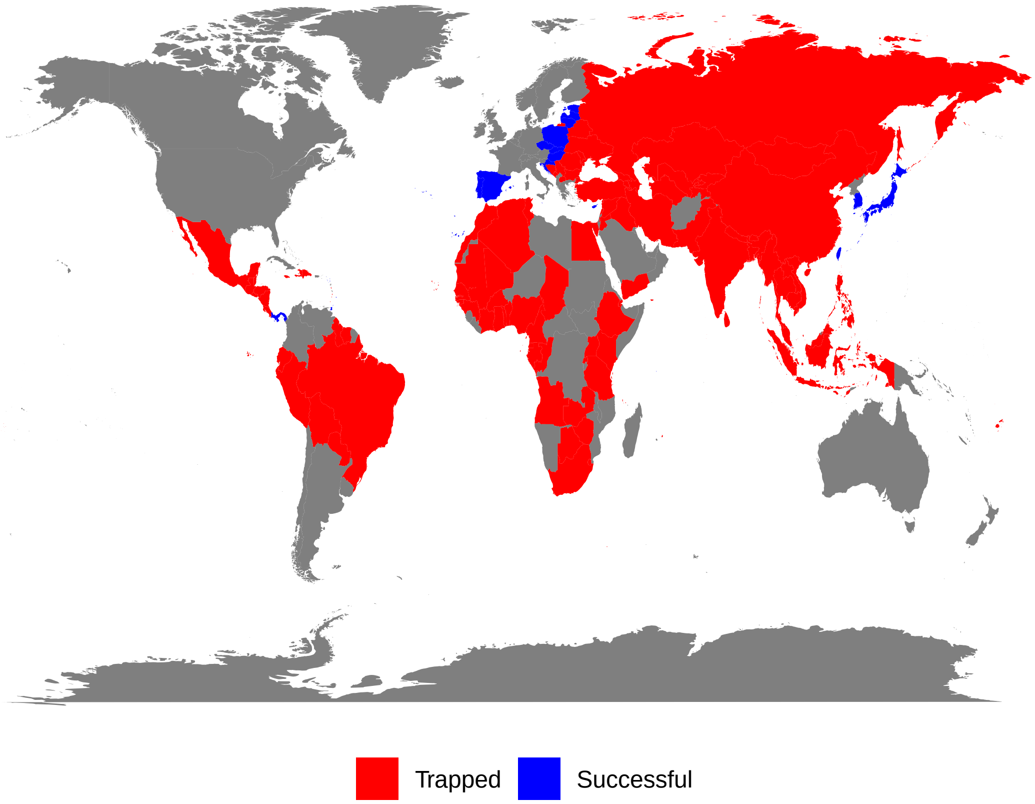
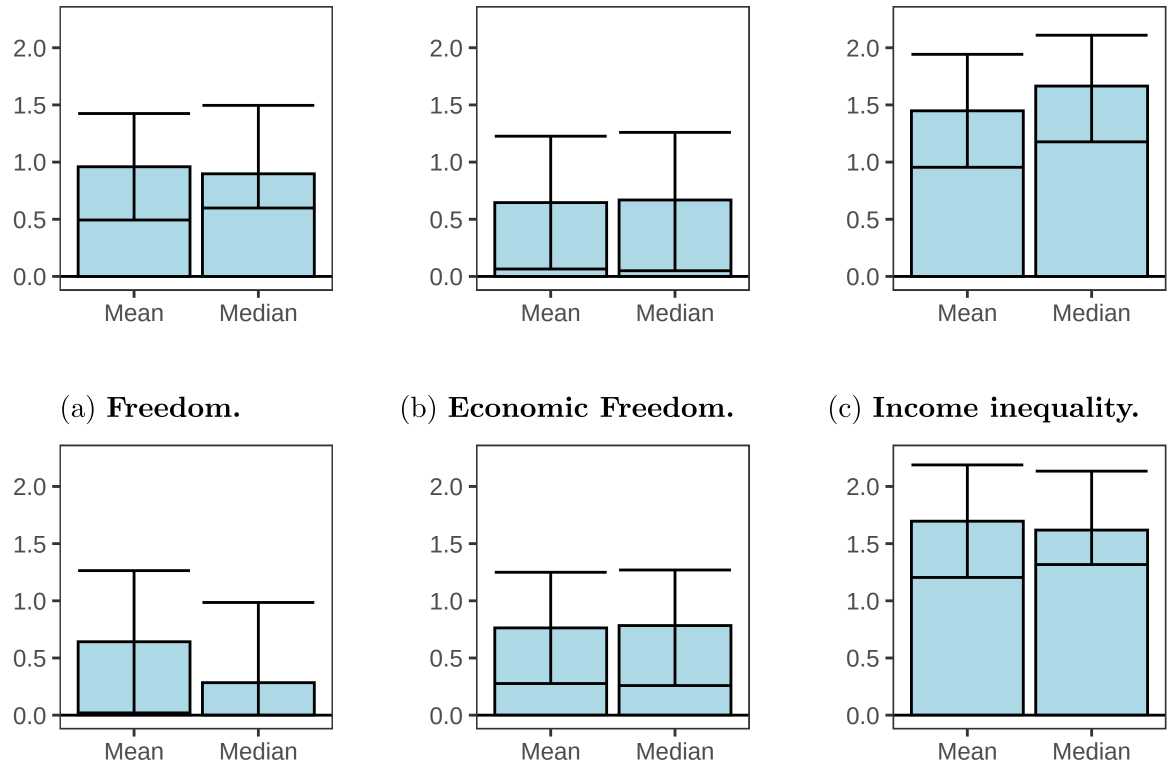



Figure 6: **Classification of countries.** Blue countries have escaped middle income; red countries are stuck in middle income. All other countries in gray are excluded from the analysis.

1. **Low income** $[0, 0.01]$
2. **Lower middle income** $(0.01, 0.06]$
3. **Upper middle income** $(0.06, 0.2]$
4. **High income** $(0.2, \infty)$.

Then, we sort and split our sample. We require a country to have been either lower or upper middle income for at least 10 years; to have a final observation for its income group that is at least as large, in an ordinal sense, as its first observation in the data; and to have been either a low, lower middle, or upper middle income country when it entered the data. We then define successful middle income countries to be those that are currently observed to be persistently high income; all other observations are trapped in middle income.[18] Figure 6 shows the result of our classification. As in the previous

[18] Persistent, here, means that we observe the country as being high income for at least five consecutive years.




(a) **Freedom.** (b) **Economic Freedom.** (c) **Income inequality.**

(d) **Financial openness.** (e) **Education, all.** (f) **Physical infrastructure.**

Figure 7: **Correlates of escape from the middle income trap.** All index values are z-score standardized. "Mean" shows the difference in means between the two groups; standard errors are robust to heteroskedasticity. "Median" shows the median of the difference between the two samples (Mann-Whitney U test). Error bars represent 95% confidence intervals. Data comes Canning (1998), Chinn and Ito (2006), Barro and Lee (2013), and Feenstra et al. (2015), as well as Fraser Institute; Freedom House; and World Inequality Database.

section, we observe the divergent paths of Korea and Taiwan versus India and China; we also see the dismal economic performance of Latin America and Africa in breaking free of middle income. Escape is indeed the exception.[19,20]

[19]Note that countries in gray are excluded from the analysis. In many cases, the excluded countries are excluded because they are either too persistently "rich" or "poor," as defined by our cutoffs, or because they moved "backwards," entering the data as high income countries and transitioning to middle income or low income. Our results are quite robust to inclusion or exclusion of these various edge cases (among them Chile, Argentina, Greece, and Hungary).

[20]See Gill and Kharas (2007) for a more fulsome, if dismal, discussion of the phenomenon known as the "middle income trap."

## 3.2 Institutions

How do institutions correlate with escaping middle income? To assess this, we analyze differences in mean and median values of indices that proxy for institutional quality. We collect indices from international organizations pertaining to political and economic freedoms and income inequality.[21] We then collapse these index values by taking the median value of the index during the period in which a focal country was middle income.[22] Lastly, we normalize the index values to be between 0 and 1; take an equal-weighted mean; and z-score standardize the mean to construct a single composite index. We then test for differences in means between "trapped" and "successful" countries by running the following linear regression:

$$\text{Index}_c = \alpha + \delta \mathbb{1}\left\{\text{Escaped middle income}\right\}_c + \varepsilon_c. \tag{2}$$

Here, a significant estimate for $\delta$ implies that the mean index value for institutional quality is significantly distinct in the two populations of countries: If good institutions correlate with escaping middle income, we should expect $\delta$ to be positive. Results are shown in Figure 7. Quite robustly, it is the case that countries that successfully escaped middle income had comparatively higher levels of political and economic freedoms and lower values of income inequality.[23]

## 3.3 Infrastructure

We perform the same exercise as the previous section for a country's infrastructure. When we construct our report card in the next section, we will adopt a broad notion of infrastructure, including medical and digital infrastructure. But, for the moment, due to historical data limitations, we will restrict our attention to a country's educational infrastructure as proxied for by the educational attainment data compiled by Barro and Lee (2013) and physical infrastructure as proxied by its roads, railroads, and electrical

[21] For more details, see Appendix B.

[22] For example, for Korea we take the median value of each index for the period 1953-1987; for China, we take the median value of each index for the period 1952-present.

[23] We renormalize measures of income inequality so that a positive estimate of $\delta$ means that middle income success stories had, on average, lower values of income inequality. The column labeled "median" is the median difference between the two populations from a Mann-Whitney U test, a test robust to misspecification and outliers. Roughly, if $X \sim F_X$ and $Y \sim F_Y$ and $X \perp Y$ the Mann-Whitney U-test is testing whether $|\text{Median}(X - Y)| > 0$. The advantage to this test is that we need not appeal to any asymptotics, such as the central limit theorem, to assess statistical confidence. Of course, $X \perp Y$ is likely a bad assumption.

generation capacity (Canning, 1998).[24] Figure 7 presents our results. As in the previous set of exercises, countries that managed to escape middle income had higher rates of educational attainment. The results do not vary much by gender, and they are robust to inclusion or exclusion of the various educational attainment series used to construct our composite index.

## 3.4 Discussion

These results gesture toward an explanation for the success of countries such as Korea and Taiwan and the relative stagnation of countries such as China and India. In short, technological convergence is not enough. Rather, it appears that institutions—as embodied in the overall levels of economic and political freedoms and equality in the distribution of economic resources—and infrastructure are prerequisite.

Overall, we see our results as bridging two literatures. First, our results most directly lend support to the findings of Lucas (1990), Hall and Jones (1999), Acemoglu et al. (2001), and Alfaro et al. (2008). These papers argue poor countries are poor largely due to a lack of complementary factors and technology—the former being what we call institutions and infrastructure. But, how do we reconcile the latter with our findings in Section 2.2? That is: we showed the existence of technologically advanced societies that, in per capita terms, remain quite poor, at least relative to where their technological peers are in the world income distribution. We argue that these societies' institutional and infrastructural defects lead to severe misallocation, an argument put forward most prominently by Restuccia and Rogerson (2008) and Hsieh and Klenow (2009). That is: our technology index identifies what countries can do, but if policies are in place or complementary factors are lacking that prevent the utilization of these frontier technologies, for all economic purposes, it is as if the technologies did not exist—or that they existed at a lower level of efficiency.

Our novel contribution has been to highlight the sequential nature of these three pillars—institutions, infrastructure, and technology—in attaining economic convergence. Successful countries first build a solid base of institutions and infrastructure. Leveraging the stable governance and high human capital workforce that results, they employ

[24] Barro and Lee (2013) compile historical educational attainment data for the population ages 15-64 at the primary, secondary, and tertiary levels. We collapse these data into a single indicator. In particular, we focus on the fraction of the population that has attained at least secondary education and the average numbers of years of schooling in the population overall, and focusing on the primary and secondary levels.

| 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) | | | |

Table 1: **Inputs into the report card.** Data comes from Canning (1998), Chinn and Ito (2006), and Barro and Lee (2013) as well as Fraser Institute; Freedom House; Google Patents (author's calculation); World Inequality Database; and World Bank.

these resources first in an effort to imitate the existing frontier (Figures 3 and 4). As they "learn by doing," these societies transition to original, frontier innovation (Arrow, 1962; Lucas, 1988). Countries which miss any of these three enabling steps of development, absent effectively exploited and abundant stocks of natural resources, have been, historically speaking, unable to attain economic convergence.

# 4 The Report Card

## 4.1 The contemporary report card

In the previous sections we have shown the importance of constructing sound institutions and reinforcing said institutions with dependable infrastructure in order to enable countries to reap the benefits of technological convergence. In this section we aim to provide a contemporary diagnostic for middle income countries' performances. In doing so, we will augment our technology, institutions, and infrastructure composite indices with a variety of new data that is available to us for the most recent period. To our regret, we were unable to use this panoply of data to explore historical cross-country experiences due to historical data sparsity.

Table 1 lists the inputs to our composite indices. The second column in each subgroup, "Historical coverage," indicates whether there was sufficient coverage for inclusion of this component in the cross-country analyses performed in Sections 3.2 and 3.3.[25] We classify country performance using three broad categories. First, following our findings in Section 3.2, we rank countries by the quality of their institutions. We consider political and economic freedoms as well as the general level of income and wealth inequality in a society as a meaningful proxy for the quality of a country's institutions. Implicitly, we are saying that freer societies, and societies with less extremely skewed

[25]For more details on the construction of the indices, please see Appendix B.

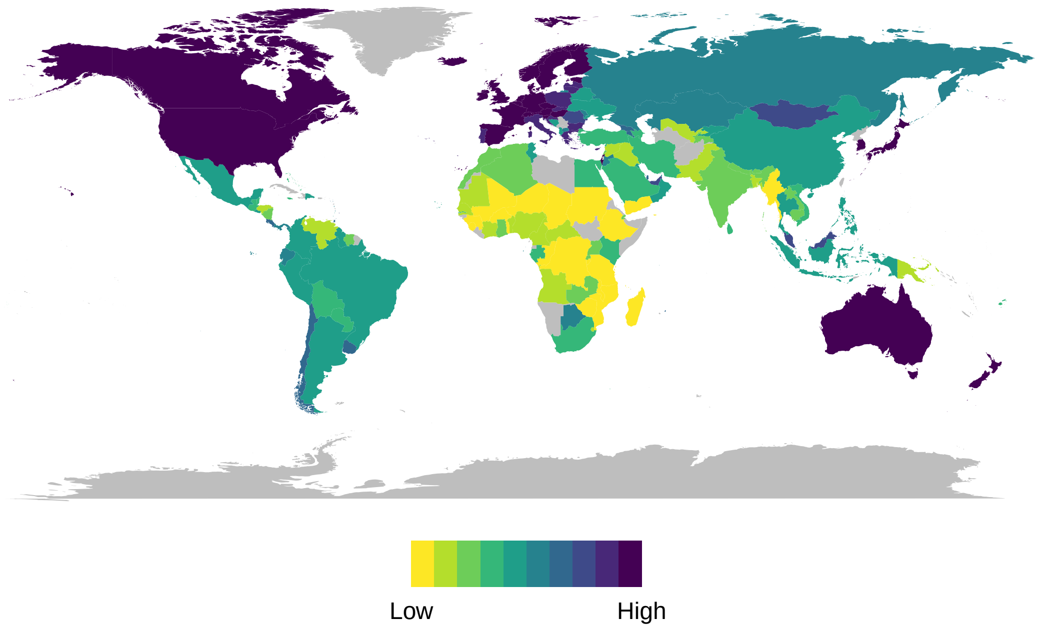



Figure 8: **Report card performance.** The map shows the average grade across the three categories laid out in Section 4.1. Darker colors correspond to higher scores.

distributions of income, have institutions that are more conducive to economic growth and broad prosperity. This is broadly validated from the cross-country results in Section 3.2. On infrastructure, we augment our measures of social infrastructure from Section 3.3—Barro and Lee (2013) educational attainment data and Canning (1998) physical infrastructure data—with the World Bank's World Development Indicators (WDI) on physical infrastructure—transportation and medical—and digital infrastructure—rates of internet access. Lastly, we augment our own novel technology index, constructed using the patent data (Figure 2), with additional indicators that speak to the technical capacity of a country. Namely, we consider the number of technical publications; the number of researchers and research technicians per capita; the percentage of exports that are high-tech; and the ratio of R&D expenditure to GDP (from both public and private sources). These additional measures are meant to correct for the inability of the patent data to capture the full breadth of an economy's innovative activity.[26]

We aggregate these data into single index values for each category according to Appendix B. We then "curve" the data. We normalize all scores to be between 0 and

[26]Far from all innovations are patented; many are the result of open-source collaborations on basic research at the academic level; conversely, firms may choose to maintain the propriety of their applied innovations through alternative means, such as the use of trade secrets (Hall et al., 2014; Akcigit et al., 2021).

| | 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+ |

Table 2: **Report card for select countries.**

100, and we impose that, on average, countries score an 85 within each category. These scores in $[0, 100]$ correspond to letter grades: For example, an "A+" maps to a given country's composite index being between $[97, 100]$. A "D," in contrast, maps to a score between $[60, 70)$. Figure 8 shows our results. It shows that index values are highest for those countries in North America, Europe, and East Asia that rank highest in terms of income per capita and material well-being. Table 2 breaks down the country-level performances in finer detail, focusing on a handful of familiar high- and middle-income countries.[27,28]

Consistent with our previous set of results, we see that our report card methodology is able to distinguish between the performances of Korea versus China and India by downranking India and China on institutions—due to repression of political freedoms in China and economic freedoms in India—and infrastructure. Moreover, India's ranking in technology falls considerably once broader measures of innovation are accounted for. China remains quite high, which is all the more impressive given the scale-dependence that punishes country size in so many of our technology indicators.

The breakdown into separate categories is particularly instructive for middle income countries interested in developing policies for growth and convergence. For example, in Brazil and Mexico, we see the lowest hanging fruit would be to improve institutions. In the case of Brazil, which achieves a solid, passing mark on technology, this argues for

[27] Due to a lack of data—nearly all indicators, save for our novel patent-based index, in Table 1, are missing data for Taiwan—we regrettably exclude Taiwan from our broader report card results in this section.

[28] See Table C.1 for the full report card.

| Dependent Variable: | ln(Real 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*

Table 3: **Correlation of our report card indices with real income per capita.** Data come from PWT 10.01 (Feenstra et al., 2015); Canning (1998); Barro and Lee (2013); Freedom House; Heritage Foundation; and World Inequality Database.

a high amount of misallocation that is best addressed through policies that liberalize the economy; promote civil liberties and correct democratic backsliding; and lead to a more efficient allocation of incomes and wealth. Brazil would also do well to improve its physical, digital, and basic educational infrastructure. In contrast, Mexico seems to be struggling with both institutional quality and technological convergence. It should pursue policies focused on upgrading its technical capacity whilst simultaneously adopting many of the institutional reforms recommended in the Brazilian case.

## 4.2 Historical validation of the report card methodology

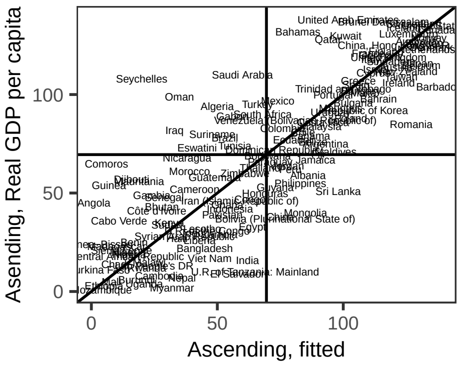
How do our indices correlate with historical country income levels? To answer this, we run several variations of the following regression

$$\ln\left(\text{Real GDP per capita}_{ct}\right) = \alpha + \beta^{\text{Tech.}} \ln\left(\text{Technology}_{ct}\right) + \beta^{\text{Inf.}} \ln\left(\text{Infrastructure}_{ct}\right) + \beta^{\text{Inst.}} \ln\left(\text{Institutions}_{ct}\right) + \varepsilon_{ct}. \quad (3)$$

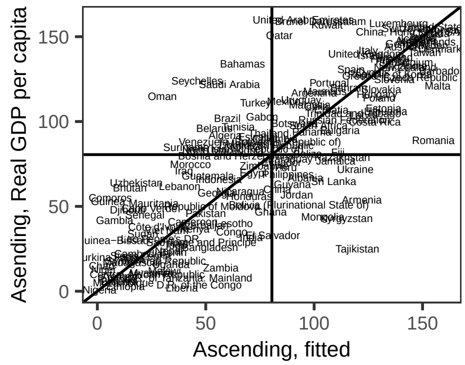
The $\{\beta^k\}_k$ have the interpretation of elasticities.[29] In several variants we add country and year-level fixed effects, $\{\alpha_c, \alpha_t\}$. Results are presented in Table 3. Our results are clearly robust to the inclusion or exclusion of various fixed effects. Moreover, our indices explain a substantial portion of variation in country-level income per capita both within and across countries and time, as evidenced by the variants with time and country fixed effects. Our preferred variant is column 2, which features a year-level fixed effect. Therefore, the within $R^2$ has the interpretation of what fraction of the variation in real GDP per capita is explained by our indices after accounting for between year variation. Our three indices all load significantly and positively. A 1% increase in our measures of technology, infrastructure, and institutions are associated with 0.38%, 4.3%, and 1.4% increases in income per capita, respectively. The fitted model in column 2 also allows us to construct country rankings based on predicted values of income per capita. This is a useful exercise inasmuch as it allows us separate over- and under-performers. This is shown in Figure 9.

Interestingly, although China, for example, was a major underperformer based solely on our technology index (Figure 5), based on the fitted model, which leverages information on China's institutional and infrastructural quality, China is now a minor overperformer, at least for the most recent period. In contrast, the Gulf oil states, which we classified as overperformers based on their levels of technology, remain overperformers based on all three factors. The policy implications of these results are less clear than before. In Figure 5, we proposed to interpret those results, loosely, as a counterfactual, arguing that mapping a country's position in technology space to the 45° line told one what their level of income per capita could be based solely on their level of technical expertise, absent considerations of institutional or infrastructural distortions or defects. In Figure 9, we are accounting for the remaining explanatory factors. Deviations from

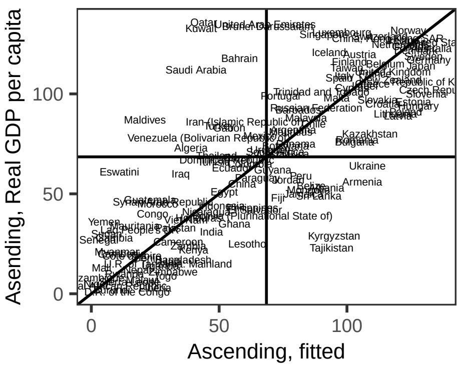
[29] Because our index is normalized to be between $[0, 1]$ we add 1 to the index to ensure it is well defined near 0.



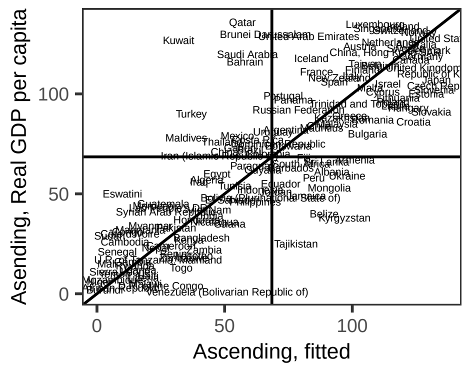

(a) **1985-1989.**




(b) **1995-1999.**




(c) **2005-2009.**




(d) **2015-2019.**

Figure 9: **Validating the report card.** This figure uses "skinny" versions of the report card indices for institutions, infrastructure, and technology. It plots the true GDP per capita ranking against the predicted GDP per capita ranking for the model in column 2, Table 3.

the 45° line are best understood as a limit of our empirical model's ability to match the country income distribution and should be interpreted as a reason to take our report card results with a grain of salt. Indeed, a natural interpretation of China's overperformance for the most recent period is that our empirical model is missing an important, unmodeled, or intangible factor that China has in abundance.

Although we explain a good chunk of the variation in cross-country income per capita, the within $R^2$ is only 0.64. This is seen most clearly for the Gulf oil states which remain very large outliers. Clearly, an empirical model based on economic fundamentals, completely ignoring the very real and unequal distributions of natural resource wealth throughout the world is going to do quite a poor job in explaining the economic performances of states such as Bahrain, Kuwait, Qatar, Saudi Arabia, and the United Arab

Emirates. Thus, although we are encouraged by the good fit and statistical significance of our empirical model, we caution the results and any conclusions drawn from them be interpreted with two key caveats in mind: the results represent mere correlations and the model is as a rule misspecified and astructural.

# 5 Conclusion

How should multilateral institutions counsel middle income countries to break free from the middle income trap? The preceding text has sought to provide the beginnings of an answer to this question. We highlight several key points. First, we argue that the gap between the rich and the poor countries, today, is one of technology. Second, we argue that technological convergence is possible; policy makers in middle income countries should focus, first, on imitating the frontier. As they develop and hone their expertise, they should invest in transitioning to original innovation. Third, we temper expectations: we show that technological convergence, as measured in the patent data, is not enough. If economies are severely misallocated—due either to poor institutions or underdeveloped infrastructure—no amount of frontier know-how will advance a middle income country to high income. Complementary factors are needed to implement frontier technologies. With these three key insights, we design a novel indicator of country performance, showing it can be used to guide policy makers in the design of remediating policy.

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# A Data

## A.1 Input data for Section 3.2

1. Freedom House—https://freedomhouse.org/report/freedom-world#Data
   - Political rights
   - Civil liberties
2. Fraser Institute—https://www.fraserinstitute.org/studies/economic-freedom
   - Legal system & property rights
   - Sound money
   - Freedom to trade internationally
   - Regulation
3. World Inequality Database—https://wid.world/
   - Top 10% income share
4. Chinn-Ito Index (Chinn and Ito, 2006)—https://web.pdx.edu/~ito/Chinn-Ito_website.htm

## A.2 Input data for Section 3.3

1. Barro and Lee (2013) data—http://www.barrolee.com/
   - Sum of `lsc` and `lhc`—Percentage of complete secondary and tertiary schooling attained in the population
   - Average years of schooling
   - Average years of primary schooling
   - Average years of secondary schooling
2. Canning (1998)—https://www.hsph.harvard.edu/david-canning/data-sets/
   - Paved roads
   - Railway lines
   - Electricity generating capacity

### A.3 Input data for Section 4.1

We include all data listed in Sections A.1 and A.2 as well as the following.

1. World Bank—https://data.worldbank.org/
    - Access to electricity (% of population)
    - Hospital beds (per 1,000 people)
    - Rail lines (total route-km)
    - Individuals using the Internet (% of population)
    - Scientific and technical journal articles
    - Researchers in R&D (per million people)
    - Technicians in R&D (per million people)
    - High-technology exports (% of manufactured exports)
    - Research and development expenditure (% of GDP)

## B Generalized construction of the indices

Let $\Theta$ be a collection of indices. For example, in Appendix A.1, $\Theta$ could equal the collection $\{\text{Political rights}, \text{Civil liberties}\}$ for the input for "Political/civil liberty" in Table 1. Let $\theta \in \Theta$ be a particular score. We can think of $\theta$ as an unbalanced panel of $C$ countries and $T$ time periods. Let $\theta_{c\cdot}$ be the time series of country $c$ for series $\theta$ and $\theta_{\cdot t}$ be the cross-section for series $\theta$ for given $t$.

From our classification exercise in Section 3.1, 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 of Section 4.1, we take the most recently observed observation, so that:

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

And for the historical validation exercise of Section 4.2, we take the median value over a series of five year partitions of the available time-series, $\{T_k\}_k$:

$$\bar{\theta}_{ck} = \text{Median}\left(\theta_{ct}\right), \quad t \in T_k$$

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:

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

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

# C Full report card

| | 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+ |

| | Institutions | Infrastructure | Technology | Overall |
|---|---|---|---|---|
| Azerbaijan | C- | B+ | C | C |
| Bahamas | C+ | B+ | C- | C+ |
| Bahrain | B- | A+ | C | B- |
| 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 |
| 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 |
| Czech Republic | A+ | A+ | A+ | A+ |

| | Institutions | Infrastructure | Technology | Overall |
|---|---|---|---|---|
| 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+ |
| 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+ |
| 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+ |

| | Institutions | Infrastructure | Technology | Overall |
|---|---|---|---|---|
| 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+ |
| 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+ |
| 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- |

| | Institutions | Infrastructure | Technology | Overall |
|---|---|---|---|---|
| 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- |
| 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- |
| 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+ |

| | Institutions | Infrastructure | Technology | Overall |
|---|---|---|---|---|
| Syrian Arab Republic | F | C | C- | C- |
| Tajikistan | D | B- | C- | C- |
| 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- |
| Yemen | D | D | C- | D |
| Zambia | B- | D | C- | C- |
| Zimbabwe | F | D | C- | D |

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

# D Comparison of our index with Hidalgo and Hausmann (2009) Economic Complexity Index (ECI)

Hidalgo and Hausmann (2009) propose a measure of technological complexity: the economic complexity index (ECI). ECI is constructed using the concept of revealed comparative advantage (RCA) to organize countries into a bipartite network (Balassa and Noland, 1989). In their first application, they used trade data from UN Comtrade. In subsequent extensions, Stojkoski et al. (2023) extend their methodology to the patent and academic publication data. In another contribution Xu and Lybbert (2017) augment the trade-based ECI using patent application data. In contrast, in this paper, we construct a novel index of technological prowess. It is a product of a normalized measure of patent per capita and a normalized measure of eigenvector centrality (which uses citation data to describe how central a given country is in generating global innovations).

How does the technological index we construct from the patent data contrast with ECI—both its mainstream and patent-based variants—and why is it preferable? As noted first by Xu and Lybbert (2017), there are reasons to believe that the ECI methodology is not well-suited for the international patent data. ECI relies on two key building blocks: country-level product diversity (the number of products a given country has a revealed comparative advantage in) and product-level country ubiquity (the number of countries that have a revealed comparative advantage in a given product). As Xu and Lybbert (2017) argue: "[The obstacle to using the patent data] arises from fundamental differences between goods and patents. In particular, a ubiquitous [traded product], such as cocoa, requires less capacity for a country to produce and is regarded as less demanding of economic capabilities. However, a ubiquitous patent is more a reflection of its widespread value in applications, generally across a range of industries, and may be more rather than less sophisticated than other less ubiquitous patents." The concern of Xu and Lybbert (2017) bears out in a patent-based ECI constructed by Stojkoski et al. (2023): In this index, the United States ranks as the $29^{\text{th}}$ most technologically complex country, behind countries such as Hungary, Mexico, Poland, South Africa, and Turkey. To us, this simply seems implausible.

Turning next to why our measure is more suitable that the conventional ECI of Hidalgo and Hausmann (2009): We are after a fundamentally different question. We are seeking to assess whether technological catch-up is possible among countries. We feel patent data is best suited to answer this question, as patent documents are the best, most tangible data we have on technical knowledge. Trade data indisputably embodies technical knowledge, but what a country exports or has a revealed comparative advantage in is subject to a variety of confounding forces, too: heterogeneous preferences for goods and services across countries; export subsidies and import tariffs for nationally favored industries and firms; and various shocks emanating from non-economic and geopolitical sources. Moreover, trade data give us no direct way to study technological spillovers. Citations data from patent databases such as PATSTAT or Google Patents allow us to track the flow of knowledge across space and time in order to develop a more granular understanding of technological development (Section 2.2).

Lastly, one final objection may be that the more natural index is the one proposed by

Xu and Lybbert (2017): this index uses patent application data to augment traditional ECI. We note that the United States is still ranked 11$^{th}$ in this new index; more plausible than in Stojkoski et al. (2023), but still questionable given the centrality of U.S. innovation as measured by nearly any other—admittedly more naive—measure. More substantively: our goal, unlike Xu and Lybbert (2017), is not prediction. Whereas they are seeking to show their index can explain variation in long-run growth rates, we, on the other hand, are merely trying to assess the degree to which countries are near the technological frontier. In some sense, deviations from perfect correlation in our index from present income levels (Figure 5) is entirely the point, as it helps us to identify countries where institutions and infrastructure are lacking in translating technical know-how into material prosperity. Moreover, our measure of centrality, which leverages citation data, is, we feel, more appropriate for our purposes, given our focus on *how* countries catch-up to the frontier, first through imitation, then through innovation. Lastly, simple applications data, as is used in Xu and Lybbert (2017), ignore the importance of certain countries in generating *central* innovations that other countries build atop of. This, in concert with our previous objections to trade data being contaminated with non-technological information, motivates our design of a novel technology index.

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