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 that technological convergence is achievable, and that it has been achieved by numerous countries throughout history. Leveraging data on citations of international patents, it shows that countries begin this transition by first learning from the technological frontier. It then proceeds to ask: Is technological convergence alone sufficient to beget economic convergence? It finds that the answer is "No." The paper concludes by examining the necessity of doing well along two other dimensions—institutions and infrastructure—which must work in concert with technology. These three dimensions constitute a developmental trinity that is essential to achieving economic convergence and escaping middle-income status.

Keywords: *Economic growth, Macro-development, Middle-income trap*

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Introduction

This paper studies economic convergence in middle-income countries. It poses a two-part question: Is technological convergence among middle-income countries possible, and is technological convergence enough to beget economic convergence? It finds that the answer to the first part is "Yes," and the answer to the second is a qualified "No."

Why does the analysis begin with a focus on technology? Differences in country income per capita are mainly attributable to differences in country total factor productivity (TFP)—the measure in the economic literature that synthesizes the productivity of all factors of production, as Lucas (1990) and Caselli and Feyrer (2007), along with a wide supporting literature, have established. Therefore, given a focus on growth in income per capita and global convergence to standards of living in high-income countries, it seems only natural to start by ascertaining whether convergence in TFP, or technology, is indeed a realistic goal to set. Second, the *World Development Report 2024* (WDR 2024) aims to provide actionable advice to policy makers in middle-income countries, utilizing the wisdom of Schumpeterian growth theory (Aghion and Howitt 1992; Klette and Kortum 2004), and this theory places technology developed by private, maximizing agents at the forefront of the growth process.

Thus, the paper begins by drawing on the most direct and comprehensive, albeit imperfect, data available to study levels of technology around the world: international patent data. It constructs a novel index of technological prowess and studies its evolution at the country level from 1970 to the present. The index captures the remarkable technological convergence of four Asian economies: China; India; the Republic of Korea; and Taiwan, China. Moreover, leveraging patent citations data, it provides suggestive evidence on *how* these exemplar economies generated such impressive levels of technological catch-up: their early citations are directed toward the countries on the technological frontier at the time—evidence of "learning from the frontier." [1]

The citations data are instructive but far from conclusive. A key finding is that China; Korea; and Taiwan, China have similar levels of technology but very different levels of income per capita. Borrowing findings from the literature on resource misallocation (Hsieh and Klenow 2009; Restuccia and Rogerson 2008) and the importance of institutions (Acemoglu, Johnson, and Robinson 2001; Hall and Jones 1999), this paper concludes by attempting to provide some insights as to why this might be. It argues that technology alone is a necessary condition for economic convergence but not a sufficient one. Rather, technology must be complemented by sound institutions and robust complementary infrastructure to translate into gains in material prosperity. These three elements—technology, institutions, and infrastructure—constitute a "developmental trinity" that is essential to economic and social development.

A novel index of technological prowess

Data

Google Patents data are used to quantify the number of patents granted, as well as cross-border knowledge flows as embodied in patent citations.[2] When counting inventions, only the first patent associated with a given patent family is counted.[3] This is done to avoid overcounting the invention of a given technology; inventors often seek to protect identical technologies across multiple jurisdictions. In contrast, when counting citations, all citations to all member patents within a given family are counted, because 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. Patents are geolocated using inventor location.[4] When a patent has multiple inventors spread across multiple locations, fractional shares of the patent are assigned to each location. For example, if a patent has three inventors, two of whom are Japanese and one of whom is American, then Japan is considered to have two-thirds of the patent and the United States is considered to have one-third.

The technological frontier

This section discusses the construction of the technology index.

First, patents per capita are calculated for each country and each year. This is the number of patents granted in a given country in a given year *t* divided by the population in year *t*.[5] As a second measure of a country's closeness to the frontier, a measure of network centrality is developed. Following Acemoglu, Akcigit, and Kerr (2016) and Liu and Ma (2021), for each period *t*, a matrix $\mathbf{M}_t$ is constructed, such that:

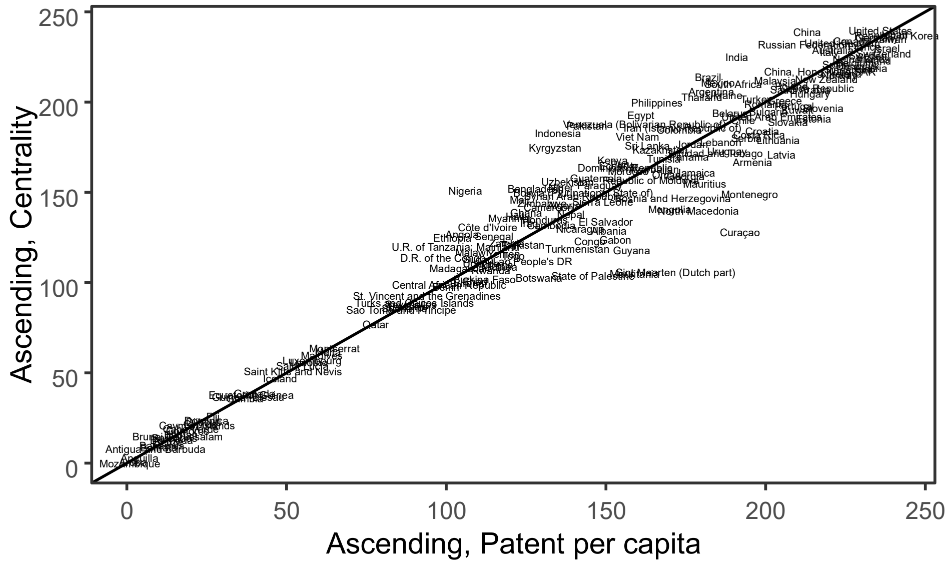
$$\boldsymbol{M}_{ij,t} = \frac{Citations_{i \to j,t}}{\sum_{j'} Citations_{i \to j',t}}$$

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*.[6]

The measure of network centrality is the first dominant eigenvector of $\mathbf{M_t}$, $\underline{\mathbf{m}}_t$, normalized so that $\sum_k \underline{\mathbf{m}}_{kt} = 1$.[7] This measure embeds a notion of patent "importance." A country that issues many patents but receives few citations would not score highly on centrality but might score highly on patents per capita.

The two measures are then normalized to be between 0 and 1, multiplied, and ranked. The final index thus embeds complementarity between quantity and quality. To be ranked highly in the index, a country must generate many high-quality patents, and it must generate them at a scale that is commensurate with its raw inputs (population). Figure 1 shows the components in the technology index. There is clearly a very strong correlation between the two components, but deviations from perfect correlation are revealing. In particular, China and India appear to be more "central" to global knowledge flows than their overall level of patenting, relative to the size of 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.

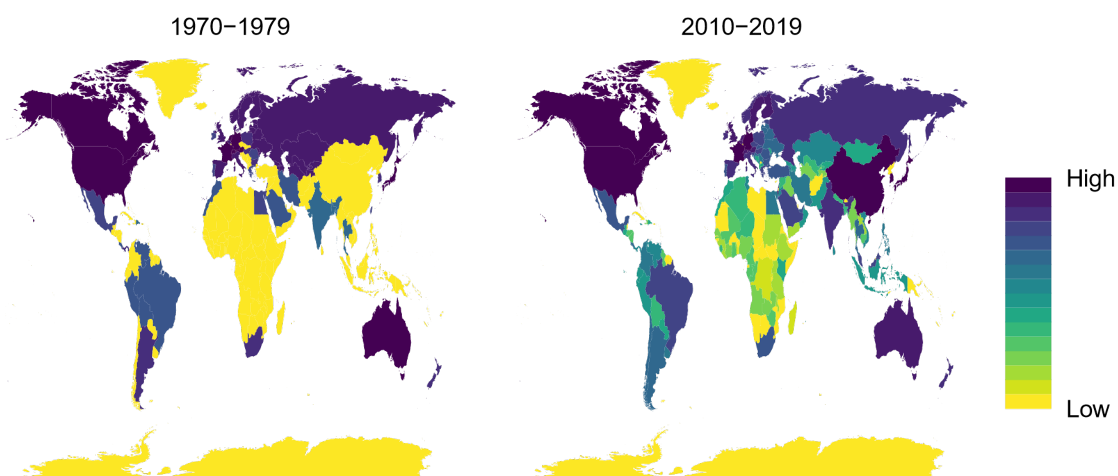
Figure 1. Country rankings according to the technology index



Source: Original calculations for the *World Development Report 2024.*
Note: Correlation coefficient equals 0.96. R^2 equals 0.93.

Map 1 presents the novel index for two decades: 1970–79 and 2010–19. There has been a noticeable shift in the world frontier of knowledge, from Western Europe toward Asia—specifically toward China; India; Korea; and Taiwan, China. Coinciding with this shift, of course, was a stark rise in income per capita in some of these same countries. This is documented in figure 2. The solid black line represents the ratio of focal country GDP per capita to US GDP per capita in each decade.

Map 1. The world technological frontier

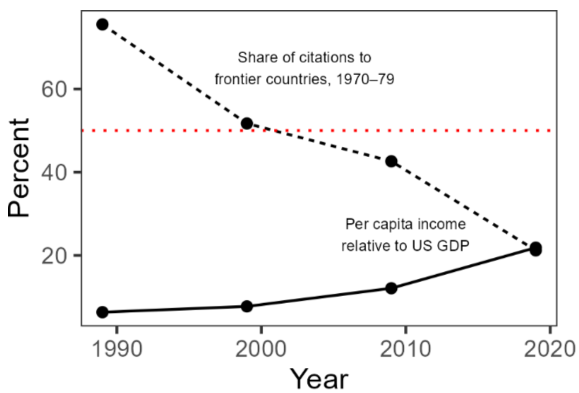


Source: Original calculations for the *World Development Report 2024.*
Note: The index is the product of a country's normalized patent centrality and normalized patents per capita. Darker colors correspond to higher scores.

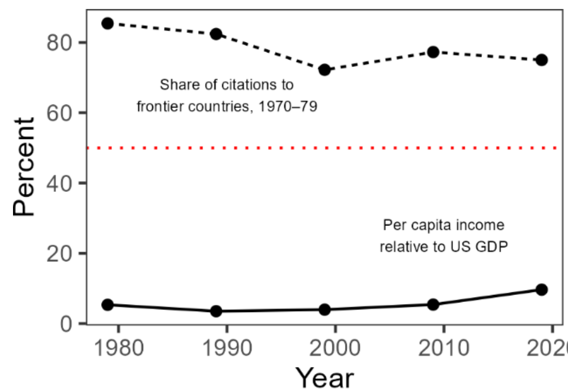
Figure 2 also provides suggestive evidence on *how* countries achieved technological convergence. The dashed black line represents the share of focal country citations received by the top 5 countries in the index in the decade 1970–79.[8] Early in the time series, countries are making many citations to the frontier, suggesting that they are building atop the global state of the art in designing their own domestic innovations: that is, that they are learning from the frontier.[9]

Figure 2. Convergence of four Asian economies to the technological frontier

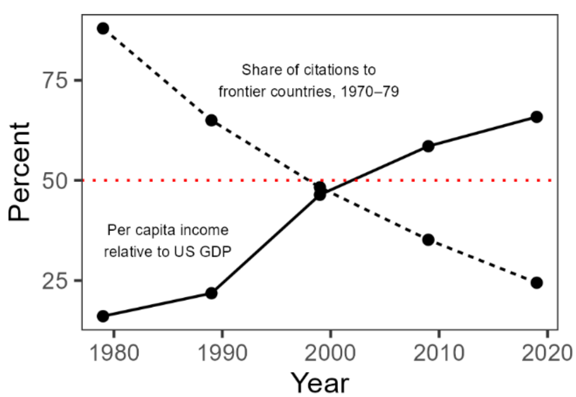
a. China



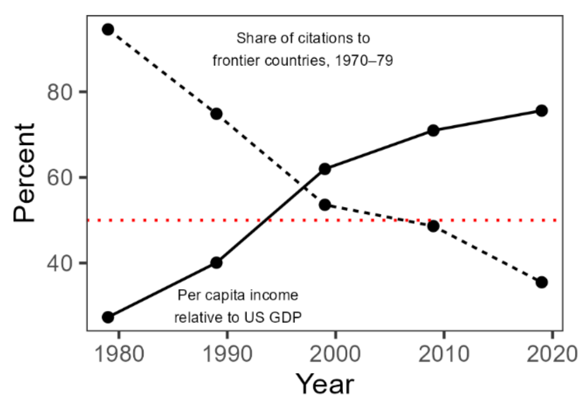
b. India



c. Republic of Korea



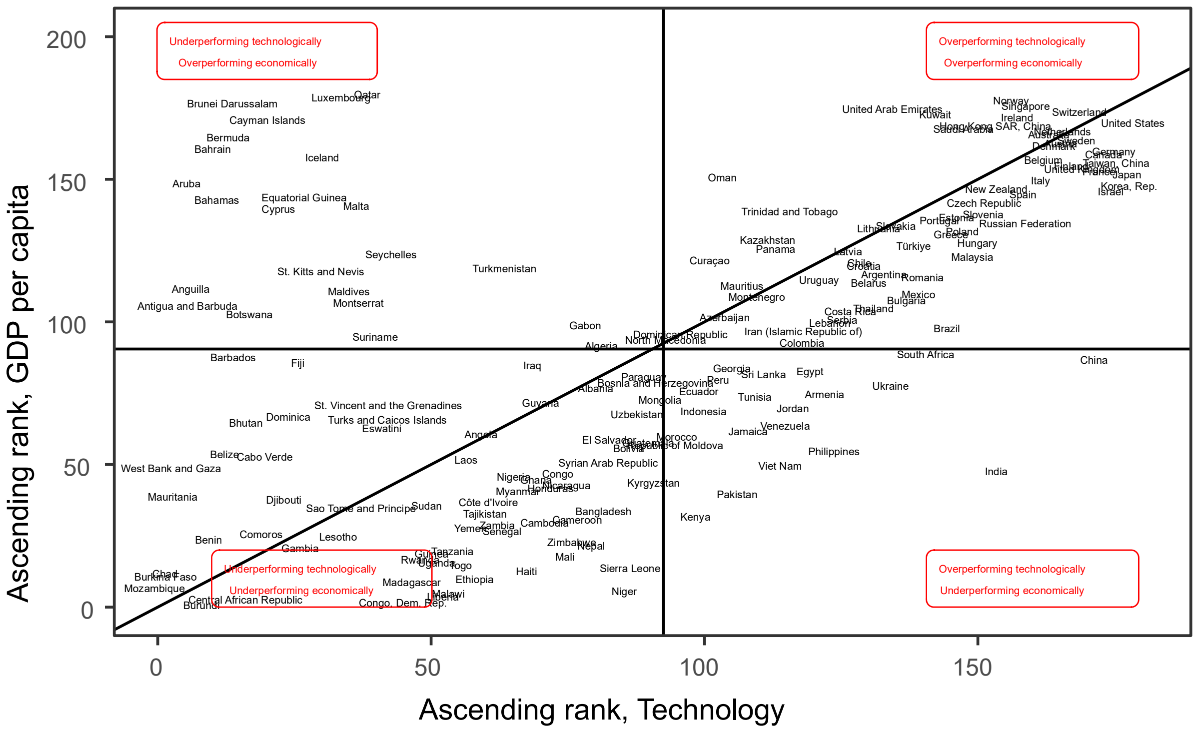
d. Taiwan, China



Source: Original calculations for the *World Development Report 2024.*
Note: The solid black line in each subpanel shows the ratio of focal country GDP per capita to US GDP per capita. The black dashed line in each subpanel shows the fraction of external citations that are received by the frontier countries of 1970–79.

Figure 2 provides other insights. First, it appears that India's experience has been noticeably distinct from that of China; Korea; and Taiwan, China. India has experienced neither explosive growth in its income per capita nor a cessation in learning from the "old guard" frontier countries. In contrast, Korea and Taiwan, China have witnessed spectacular growth in income per capita and a coinciding decline in the share of their citations made to the old guard frontier countries, whereas China has experienced only the latter. This heterogeneity is not limited to these four case studies, as figure 3 relates.

Figure 3. Technology index and GDP per capita rankings



Source: Original calculations for the *World Development Report 2024.*
Note: Data on income per capita come from Penn World Table 10.01 (Feenstra, Inklaar, and Timmer 2015). Diagonal line is 45° line; horizontal and vertical lines bisect at median values along the x- and y-axes. Correlation coefficient equals 0.52; R^2 equals 0.26.

Discussion

The preceding section discussed the construction of a novel index of technological prowess. It was composed of two measures: a raw patent count, normalized by country population; and a measure of patent quality, as proxied by the eigenvector centrality of patents in a directed graph of patent citations.

The index shows sharp technological convergence for a handful of countries. However those countries that attained convergence met with mixed success in escaping middle-income status. The experience of India is perhaps instructive. It clearly failed to establish a domestic cluster of frontier knowledge—evidenced by its continuing reliance on the "old-guard" frontier countries—and failed to bank income per capita gains on par with those of Korea and Taiwan, China. But this explanation seems unrewarding in the sense that China, as an example, achieved similar gains in technology when compared to Korea and Taiwan, China yet also failed to translate these gains as efficaciously into gains in income per capita. The next section explores this conundrum in further detail.

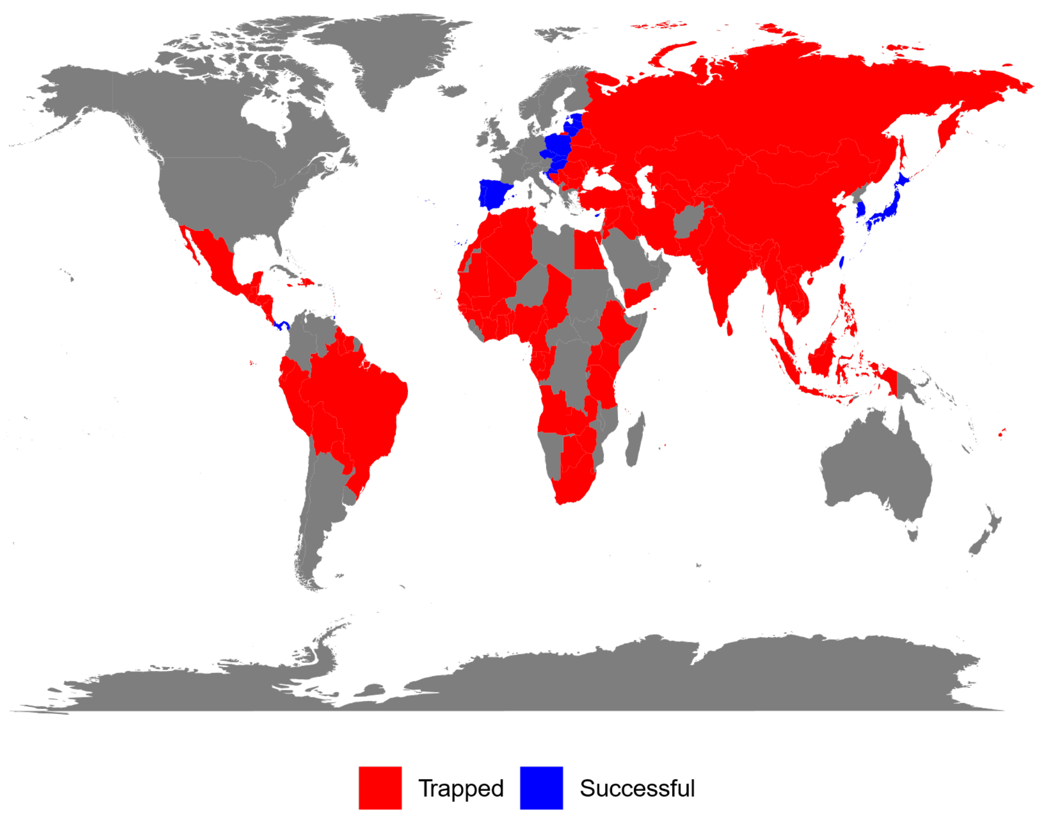
Institutions and infrastructure

Classification

The previous section presented extensive evidence concerning the possibility of technological convergence, focusing on the handful of Asian economies that have advanced to the frontier. What was it about some of these economies that allowed them to translate technical advancement into material prosperity? This paper argues that the answer is openness and institutional quality.

To begin, the analysis requires a goalpost of success: countries that successfully transitioned out of middle-income status to high-income status. For each year, countries are classified as low-income, lower-middle-income, upper-middle-income, or high-income according to the following cutoffs (defined as ratios of focal country GDP per capita to US GDP per capita): low-income [0, 0.01]; lower-middle-income [0.01, 0.06]; upper-middle-income [0.06, 0.20]; high-income [0.20, ∞].[10]

Map 2. Classification of countries



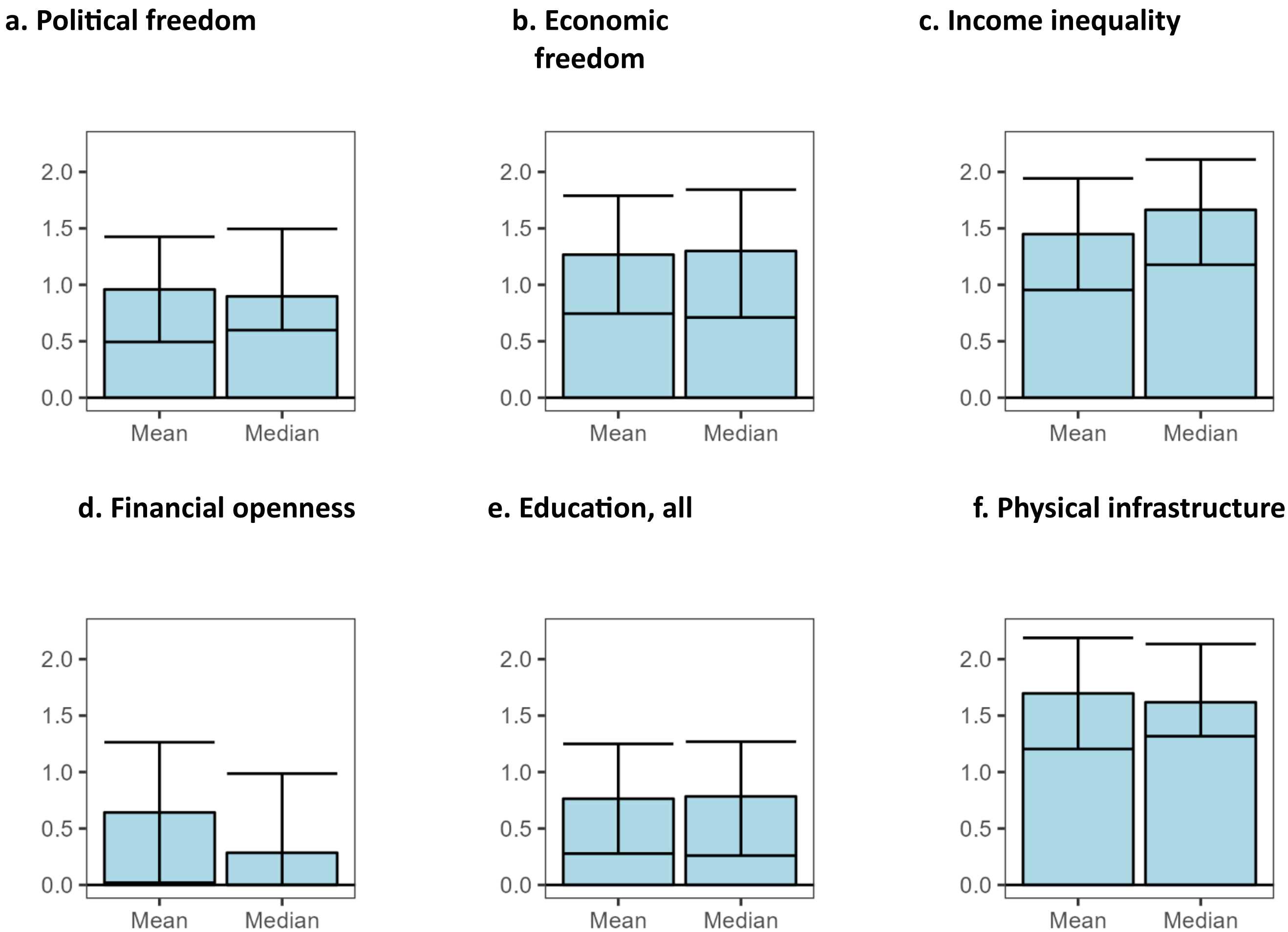
Source: Original calculations for the *World Development Report 2024.*
Note: Blue countries have escaped middle-income status. Red countries are stuck in middle-income status. All other countries in gray are excluded from the analysis.

Then, the sample is sorted and split. A country is required to have been either lower-middle-income 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-income, lower-middle-income, or upper-middle-income country when it entered the data. Successful middle-income countries are defined to be those countries that are currently observed to have persistently achieved high-income status for at least five consecutive years, into the present; all other observations are trapped in middle-income status. Map 2 shows the result of the classification. Escape is indeed the exception.[11]

Institutions

How does institutional quality correlate with escaping middle-income status? To answer this question, this section examines differences in mean and median values of indexes that proxy for institutional quality between countries that did and did not escape middle-income status. These index values are collapsed along the time dimension by taking the median value of the index during the period in which a focal country was middle-income.[12] Tests for differences in means and medians are then performed using linear regression and nonparametric statistical tests. Results are shown in figure 4 for political freedom (panel a), economic freedom (panel b), income inequality (panel c), and financial openness (panel d). Quite robustly, it is the case that countries that successfully escaped middle-income status had comparatively higher levels of political and economic freedoms; lower values of income inequality; and more open financial accounts.[13]

Figure 4. Correlates of escape from the middle-income trap



Source: Original calculations for the *World Development Report 2024.* Data on political freedom (panel a) from Freedom House's *Freedom in the World Report*; on economic freedom (panel b) from Heritage Foundation Economic Freedom Index; on income inequality (panel c) from the World Inequality Database (WID); on financial openness (panel d) from Chinn and Ito (2006); on education (panel e) from Barro and Lee (2013); and on infrastructure (panel f) from Canning (1998).

Note: 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). Values above zero imply that countries that successfully escaped middle-income status had higher values of the focal index, with the exception of income inequality, which is renormalized so that a positive value implies that successful countries had lower income inequality. Income inequality is measured using the top 10 percent income share. Error bars represent 95% confidence intervals.

Infrastructure

The same exercise for institutions is performed for a country's infrastructure. Because of limitations of historical data, the analysis is restricted to a country's educational infrastructure as proxied for by its levels of educational attainment, using data compiled by Barro and Lee (2013), and physical infrastructure as proxied by its roads, railroads, and capacity to generate electricity (Canning 1998). Panels e and f in figure 4 present the results. As in the previous set of exercises, countries that managed to escape middle-income status 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 the composite index. Such countries also had higher-quality physical infrastructure.

Discussion

These results suggest an explanation for the success of economies such as Korea and Taiwan, China and the relative stagnation of economies 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 prerequisites.

These results could be seen as bridging the results of two sets of literature. First, this paper's results most directly lend support to the findings of Acemoglu, Johnson, and Robinson (2001), Alfaro, Kalemli-Ozcan, and Volosovych (2008), Hall and Jones (1999), and Lucas (1990). These papers argue that poor countries are poor largely due to a lack of complementary factors and technology—the former being what this paper calls institutions and infrastructure. But how does one reconcile this latter finding with 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? This section's results argue that these societies' institutional and infrastructural defects lead to severe misallocation, an argument put forward most prominently by Hsieh and Klenow (2009) and Restuccia and Rogerson (2008). That is, the technology index identifies what countries can do, but if policies are in place 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.

This paper's novel contribution has been to highlight the interdependent 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 these resources first in an effort to learn from the existing frontier (figure 2). As they "learn by doing," these societies transition to original, frontier innovation (Arrow 1962; Lucas 1988). Countries that miss any of these three enabling steps of development—absent effectively exploited and abundant stocks of natural resources—have been unable to attain economic convergence and escape middle-income status.

Conclusion

How should multilateral institutions counsel middle-income countries to break free from the middle-income trap? Several points bear consideration. First, as the literature indicates, the gap between developed and developing countries, today, is one of technology. Second, technological convergence is possible. Policy makers in middle-income countries should focus, first, on programs and policies that support domestic firms in learning from the frontier; as these countries develop and hone their expertise, they should invest in transitioning to home-grown innovation. Third, expectations need to be tempered: technological convergence, at least as measured in the patent data, is not sufficient. If resources in countries 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 status. Complementary factors are needed to implement frontier technologies.

Notes

[1] The technological frontier, to be defined in greater detail later in the paper, refers to the set of countries employing frontier technologies in production, as measured in the international patent data.

[2] Google Patents data are derived from DOCDB, the database of the European Patent Office (EPO) containing worldwide bibliographic data. For a discussion on the similarity of Google Patents data to the more commonly used PATSTAT database and the relative advantages and disadvantages of their use, see Liu and Ma (2021).

[3] 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). As discussed in Berkes, Manysheva, and Mestieri (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 United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), and the European Patent Office (EPO). Therefore, this analysis requires that Chinese patent families contain at least one patent that has been granted protection by at least one of the triadic jurisdictions.

[4] When inventor location is missing, the location is assigned using the location of the assignee. When assignee location is missing, the location is assigned using patent office location, which requires dropping EPO patents that lack inventor or assignee information (because the geographic resolution would be no finer than the European Union, a bloc with 27 member states).

[5] Following Akcigit et al. (2022), the year *t* is the year that a patent is filed because there is often a significant lag between the date of filing and the date the patent is granted, and the inventive activity takes place closer to the date of filing.

[6] This measure of citations respects the fractional distribution of patents across countries. For example, if a citing patent, *A*, is one-third American and two-thirds Japanese, and it cites another patent, *B*, that is one-half American and one-half German, then this event's contribution to Citations(USA→USA) is 1/3 x 1/2; to Citations(USA→DEU) is 1/3 x 1/2; to Citations(JPN→USA) is 2/3 x 1/2; and to Citations(JPN→DEU) is 2/3 x 1/2.

[7] 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 research and development (R&D) that maximizes the growth rate of a closed economy.

[8] These countries were, in descending order, the United States, France, Germany, Canada, and Japan. Own-country citations are excluded from this calculation.

[9] Using patent citations to measure knowledge spillovers is a common practice in the growth literature. See Akcigit and Kerr (2018), Bloom, Schankerman, and Van Reenen (2013), and Cai, Li, and Santacreu (2022), among others.

[10] This roughly follows the existing World Bank thresholds for defining low-income, middle-income, and high-income countries. The thresholds change year to year and use gross national income (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 to 2022. None of the results are sensitive to these cutoffs.

[11] Countries shown in gray in map 2 are excluded from the analysis. In many cases, these countries are excluded because they are either too persistently "rich" (high-income) or "poor" (low-income), as defined by the cutoffs in this analysis, or because they moved "backward," entering the data as high-income countries and transitioning to middle-income or low-income status. The results are quite robust to inclusion or exclusion of these various edge cases (among them Argentina, Chile, Greece, and Hungary). See Gill and Kharas (2007) for a more fulsome, if dismal, discussion of the phenomenon known as the "middle-income trap."

[12] For example, for Korea, the median value of each index for the period 1953–87 is taken; for China, the median value of each index for the period 1952–present is taken. If an index is composed of multiple components, the components are normalized to be between 0 and 1; an equal-weighted mean is taken; and the z-score mean is standardized to construct a single composite index.

[13] The measure of income inequality is renormalized so that a positive number implies a *lower* level of income inequality. The index for freedom is from the Freedom House Freedom in the World Report (2 components); the index for economic freedom is from Heritage Foundation Economic Freedom index (12 components); income inequality is the top 10 percent income share from the World Inequality Database (WID); and financial openness uses the financial openness index of Chinn and Ito (2006).

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