Chapter 8

The Technology Gap in the Developing World and the G20: An Empirical Profile

Haroon Bhorat, Caitlin Allen Whitehead, and David de Villiers

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Chapter 8

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1. Introduction

The Fourth Industrial Revolution refers to the rapid technological advancement launched, in many ways, by the microelectronics revolution and the information and communication technology (ICT) advances that ensued in the 1970s (Baldwin, 2019). These new technologies have significantly impacted on the sectors and workplaces of domestic economies around the world. The pace of change is likely to accelerate with the introduction of frontier technologies such as artificial intelligence (AI), the internet of things (IoT), big data, blockchain, 5G, 3D printing, robotics, drones, gene editing, nanotechnology, and solar photovoltaic. These 11 technologies alone are estimated to represent a US$350 billion market which could grow to US$3.2 trillion by 2025 (UNCTAD, 2021).

We introduce the notion of a 'technology gap' at the country and regional level and measure its evolution since 2000, with a distinct focus on the features of both technology adoption and technology production – which may be differentially driving overall country and regional trends in this gap. Additionally, we measure the accumulation of tertiary education focused on STEM subjects – and how this shapes the technology gap in the developing world.

Our model assumes that the technology gap is a function of country and region-level endowments (and changes in these endowments) in the adoption of technology, production of technology, and human capital accumulation. Simply:

$$TG_i = f(TA_i, TP_i, HK_i) \qquad (1)$$

TG_i represents the technology gap at the country or regional level *i:* and TA_i, TP_i, and HK_i are technology adoption, production, and human capital at country or region *i* – all of which empirically coalesce into a measure of TG_i. The composite measure of the technology gap is presented through the application of the Alkire-Foster Multi-Dimensional Poverty Index widely used in poverty studies (Alkire and Foster, 2011). Hence, our proposed *TG* measure involves deriving a threshold 'technology poverty line' – which we set as the mean for each indicator – and then estimating the mean normalised gap for each subgroup's deviation from this technology line. The two key measures for our technology gap index are denoted as TG_0 and TG_1. TG_0 measures the proportion of countries that can be denoted as below the global mean for the given measure of technology. TG_0 is analogous to the headcount index in household poverty estimates. TG_1 measures the average distance below the technology gap line. The summary measures – our Alkire-Foster technology gap index – thus allow for an assessment of the changing nature of technology vulnerability in the developing world and the G20 over time.

2. Technology Adoption and Production: Stylised Facts

Table 8.1 shows that on average, internet usage has rapidly expanded from 2000 to 2020. Hence, the number of internet users per 100 individuals in the world has increased fivefold from an average of 11 internet users per 100 over 2000–2003 to 55 users per 100 in 2016–2020 – an average annual growth (AAG) rate of 10% per year consistently for two decades in the world economy. Particularly noteworthy is how low-income countries exhibited the highest growth rates – at about 30% per annum – in internet usage rates. Yet, disparities remained large in 2020: whilst internet usage rates exceed 80% for high-income economies and are close to this rate for the G20 – they remain below 15% for low-income countries and less than 35% for lower middle-income countries. If we accept that the countries require internet capabilities to engage with frontier technologies, we conclude that inequitable internet usage could hinder technology adoption and have a spillover effect on an economy's ability to produce new technologies, thereby creating a technology gap on both fronts.

Table 8.1: Average Technology Adoption Rates by Country Income Classification and in the G20, 2000–2020

Country group	Average no. of internet users (per 100 people)			Average ICT goods imports (% of total goods imports)		
Year	2000–2003	2016–2020	% change p.a.	2000–2003	2016–2020	% change p.a.
High income	31.59	84.28	6.13	11.14	9.35	–1.06
Upper middle income	5.54	58.61	15.37	8.57	6.95	–1.26
Upper middle income (excl. China)	5.57	59.96	15.49	8.22	6.63	–1.29
Lower middle income	1.30	34.84	22.05	5.19	4.95	–0.29
Low income	0.19	12.41	28.83	3.77	3.13	–1.12
G20	23.42	76.72	7.46	11.81	8.61	–1.90
World	10.99	54.86	10.23	7.98	6.87	–0.90

ICT = information and communication technology, p.a. = per annum.
Source: Authors' calculations based on World Bank (various years), World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (10 December 2021).

Table 8.1 also contains data for our second indicator of technology adoption: ICT goods imports as a percentage of total goods imports. Whilst there are income level differences in ICT import shares, these are not as stark as internet usage rates. Additionally, ICT import shares did not change substantially over the 20-year period. Interestingly, all regions of the world reveal a slight contraction in the share of ICT imports in total goods imports. For high-income countries, the average share of ICT imports was 11% over 2000–2003 – less than 3 percentage points higher than for upper middle-income countries. This difference had not changed substantially two decades later.

In terms of our second measure of the technology gap – technology production – Table 8.2 estimates the number of patent applications by residents since 2000. Global average data show that the total number of patent applications increased from about 820,000 in 2000 to more than 2.1 million by 2019 (World Bank, various years), representing a 2.5-fold increase in patent application activity in the world economy. These data show a clear and stark divide between higher- and lower-income countries' tepid patent application performance relative to China's massive increase over the same period. Table 8.2 thus shows that in the early period, the average number of patent applications by residents in high-income countries was about 20,000, dropping to about 500 for lower middle-income countries – and ultimately falling to a paltry 41 patents on average for low-income countries. Patent applications in China during 2000–2003 totalled about 25,000, increasing by 23% per year to reach 1.2 million by 2019 (World Bank, 2000-2003). Put differently, China's patent applications as a share of the global total increased from 3% in 2000 to 58% in 2019. It is notable that the upper middle-income sample including China records a patent application annual growth rate of 17% compared with a marginal decline in high-income countries and a growth rate of 1% in the G20. This measure of technology production reveals a clear widening of digital inequality, as low-income and indeed middle-income country (excluding China) patent numbers have not only grown slowly but on average are at levels ranging from 13 to 320 times less than the number of patent applications in high-income economies.

Table 8.2: Average Technology Production Rates by Country Income Classification and in the G20, 2000–2020

Country group	Average number of patent applications, by residents ('000)			Average high-tech exports (% of manufactured exports)		
Year	2000–2003	2016–2020	% change p.a.	2004–2007	2016–2020	% change p.a.
High income	19,861.13	18,895.69	–0.30	15.22	15.04	–0.10
Upper middle income	2,679.25	38,480.31	17.53	8.77	9.56	0.69
Upper middle income (excl. China)	1,359.23	1,381.43	0.10	7.76	9.00	1.19
Lower middle income	521.33	1491.17	6.58	3.00	7.34	7.42
Low income	41.68	68.54	1.70	0.50	5.20	20.60
G20	43,468.64	112,104.70	5.91	15.06	15.30	0.13
World	9,269.35	19,888.24	4.74	11.42	10.20	–0.90

p.a. = per annum.
Source: Authors' calculations based on World Bank (various years), World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (10 December 2021).

As with patent applications, there is strong variation in the average share of high-tech exports by income group, with the share increasing by country group income level. There are some positive trends, though, as the lower middle-income and low-income country growth rates in high-tech exports were the highest in the world economy over the period.

Table 8.3 provides estimates of the global Gini coefficient for our two measures: technology adoption and technology production. We see that in 2000, the measure of global inequality of internet usage was very high – with a Gini of 0.63. However, this Gini of internet usage declined steadily to its current value of 0.32 in 2016–2020. The extent of the decline in internet usage inequality is more pronounced when limiting the sample to G20 countries, with the Gini index shrinking by 5.7% p.a. from 0.48 to 0.15 over the period. Inequality in ICT goods imports notably is about half of that for internet usage at the start of the period, at 0.39. It also declines over the period, albeit at a rate of only 0.5% p.a., to reach a Gini of 0.35.

Table 8.3: Gini Coefficient of Technology Adoption and Production Rates, World and G20

TG measure	Technology adoption		Technology production	
Period	Internet users (per 100 people)	ICT goods imports (% of total goods imports)	Patent applications, by residents	High-tech exports (% of manufactured exports)
		Full sample		
2000–2003	0.63	0.39	0.93	-
2004–2007	0.58	0.36	0.93	-
2008–2011	0.49	0.34	0.92	0.47
2012–2015	0.39	0.35	0.94	0.46
2016–2020	0.32	0.35	0.95	0.45
% change p.a.	*–3.33*	*–0.54*	*0.11*	*–0.36*
		G20 countries		
2000–2003	0.48	0.25	0.79	-
2004–2007	0.39	0.22	0.77	0.36
2008–2011	0.28	0.20	0.75	0.33
2012–2015	0.19	0.21	0.80	0.32
2016–2020	0.15	0.21	0.83	0.33
% change p.a.	*–5.65*	*–0.87*	*0.25*	*–0.54*

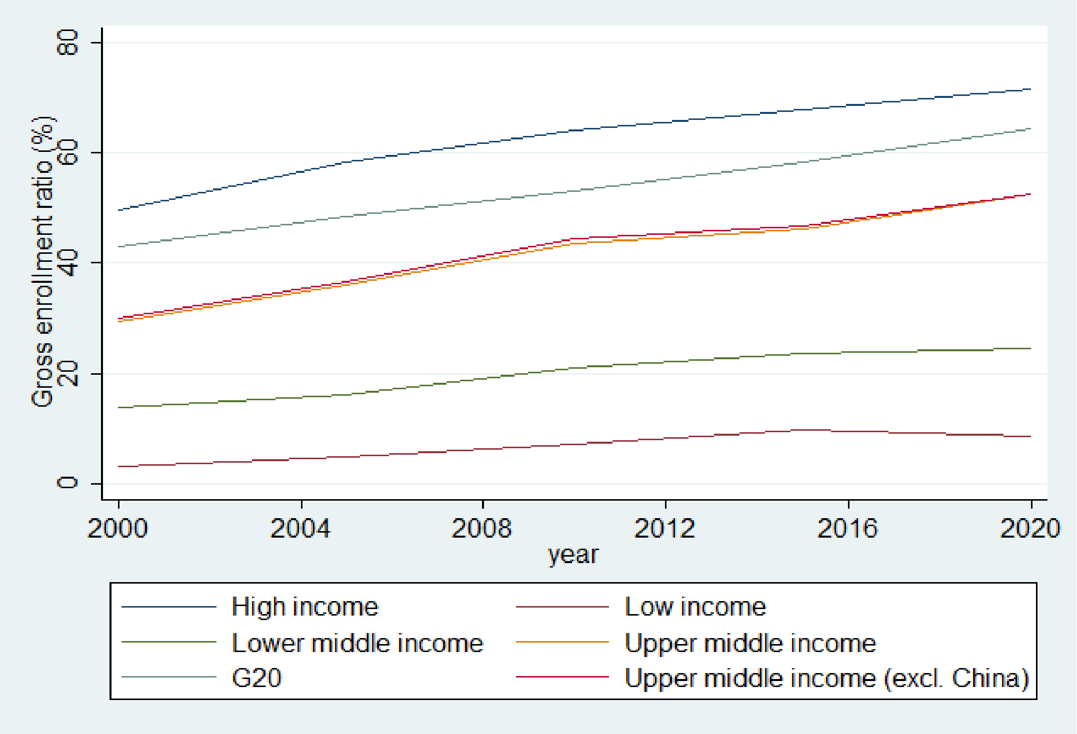
ICT = information and communication technology, p.a. = per annum, TG = technology gap.
Source: Authors' calculations based on World Bank (various years), World Development Indicators. https://databank.worldbank.org/source/world-development-indicators .

In terms of technology production, inequality of patent applications yields an extraordinary Gini of 0.93 in 2000, which increases over the period to reach 0.95 by 2020. The results for the G20 are no different as the Gini rises from 0.79 to 0.83 over the period. Inequality in technology production, as measured by high-tech exports as a share of manufactured exports, is represented by a Gini index 0.47 in the 2008–2011 period and shows a marginal decrease over the period. The G20 Gini index for high-tech exports is about 0.36 in 2004–2007, decreasing to 0.33 over the period. Whilst these data suggest that there have been marginal gains in reducing technology production inequality, this has been overwhelmed by the very high and sticky Gini for patent applications.

3. Human Capital Accumulation for Technology Production

Figure 8.1 shows average tertiary education gross enrolment ratios (GERs) for countries by income level over 2000–2020. We observe distinctly lower levels of tertiary GERs for lower middle-income and low-income countries – less than 25% for both groups – a trend that does not change significantly over the reporting period. In contrast, the tertiary GER for the upper middle-income countries ranges from 30% to 50%, while high-income countries have a tertiary GER of about 10 times that of low-income countries. Limiting the sample to G20 countries, the tertiary GER is between 40% and 65%.

Figure 8.1: Average Tertiary Education Gross Enrolment Ratios by Country Income Classification, 2000–2020



Source: Authors' calculations based on World Bank (2000--2021), World Development Indicators. https://databank.worldbank.org/source/world-development-indicators

Whilst a steady increase in tertiary GER is observed for all income groups – even lower middle-income and low-income countries – this did not result in a narrowing of the GER gaps by country income level.

Using the QS World University Rankings database (QS, various years), Table 8.4 provides data on the top 500 higher educational institutions by subject and income level. The data illustrate a significant maldistribution in the quality of higher education institutions in STEM fields in the world economy: more than 80% of the top 500 ranked universities in STEM fields in the world are in high-income countries, with an additional 16% located in upper middle-income countries.

Table 8.4: Top 500 Educational Institutions by Subject and Country Income Classification, 2021

Country group	Eng. & tech. (no.)	Share (%)	Natural sciences (no.)	Share (%)	Life sciences and medicine (no.)	Share (%)	Total STEM (no.)	Share (%)
High income	393	75.58	400	79.84	426	84.86	1,219	80.04
Upper middle income	96	18.46	81	16.17	64	12.75	241	15.82
Upper middle income (excl. China)	58	11.15	46	9.18	37	7.37	141	9.26
Lower middle income	31	5.96	20	3.99	11	2.19	62	4.07
Low income	0	0.00	0	0.00	1	0.20	1	0.07
G20	362	69.62	368	73.45	365	72.71	1,095	71.90
Total*	520	100.00	501	100.00	502	100.00	1,523	100.00

Notes: * Counting G20 countries once only.

Source: Authors' calculations based on QS World University Rankings by Subject, Institution, and Country (QS, 2022).

Put differently, 1,219 of the 1,523 best STEM universities in the world are in high-income countries; only one is in a low-income country and only 62 are in lower middle-income countries. There are about 8.6 times more top 500 STEM-field universities in high-income countries relative to upper middle-income economies outside of China. It is noteworthy that these shares do not change when examining subfields within STEM categories of data.

In trying to measure the extent of inequality in human capital accumulation, we present the Gini coefficient for tertiary GERs and QS STEM field rankings in Table 8.5. Whilst inequality in GERs for tertiary education has declined, inequality in quality differentials for the global sample has actually increased.

Table 8.5: Gini Coefficient of Human Capital Accumulation, Tertiary GERs, and STEM Field Rankings: The World and the G20

TG measure	Human capital accumulation	
Period	Tertiary GER	QS-ranked STEM fields
	Full sample	
2000–2003	0.45	-
2004–2007	0.44	0.60
2008–2011	0.42	0.63
2012–2015	0.37	0.61
2016–2020	0.34	0.61
% change p.a.	*–1.60*	*0.17*
	G20 countries	
2000–2003	0.32	-
2004–2007	0.31	0.58
2008–2011	0.28	0.61
2012–2015	0.23	0.54
2016–2020	0.22	0.53
% change p.a.	*–2.17*	*–0.79*

GER = gross enrolment ratio, p.a. = per annum, TG = technology gap.
Source: Authors' calculations based on QS World University Rankings by Subject, Institution, and Country (QS, 2022).

Whilst there has been a narrowing in inequality in both human capital measures in the G20, the reduction has been much slower in terms of the QS rankings (quality differences) than that of tertiary GER (quantity differences).

4. An Integrated Global Technology Gap Index

Following the procedure to estimate the technology gap index described above, the headline result from Table 8.6 is that, for 2016–2020, 61% of countries in the global sample are classified as having a 'technology gap'. This estimate of the global technology gap declined from 72% in 2000 to 61% in 2020. The smallest gap is found in technology adoption, with 54% of global economies yielding a technology gap. Close to 70% of the global sample report a technology production gap. This persistence is driven by the significant country-level maldistribution in patent applications.

Table 8.6. An Alkire-Foster Global Technology Gap Index, 2000–2020

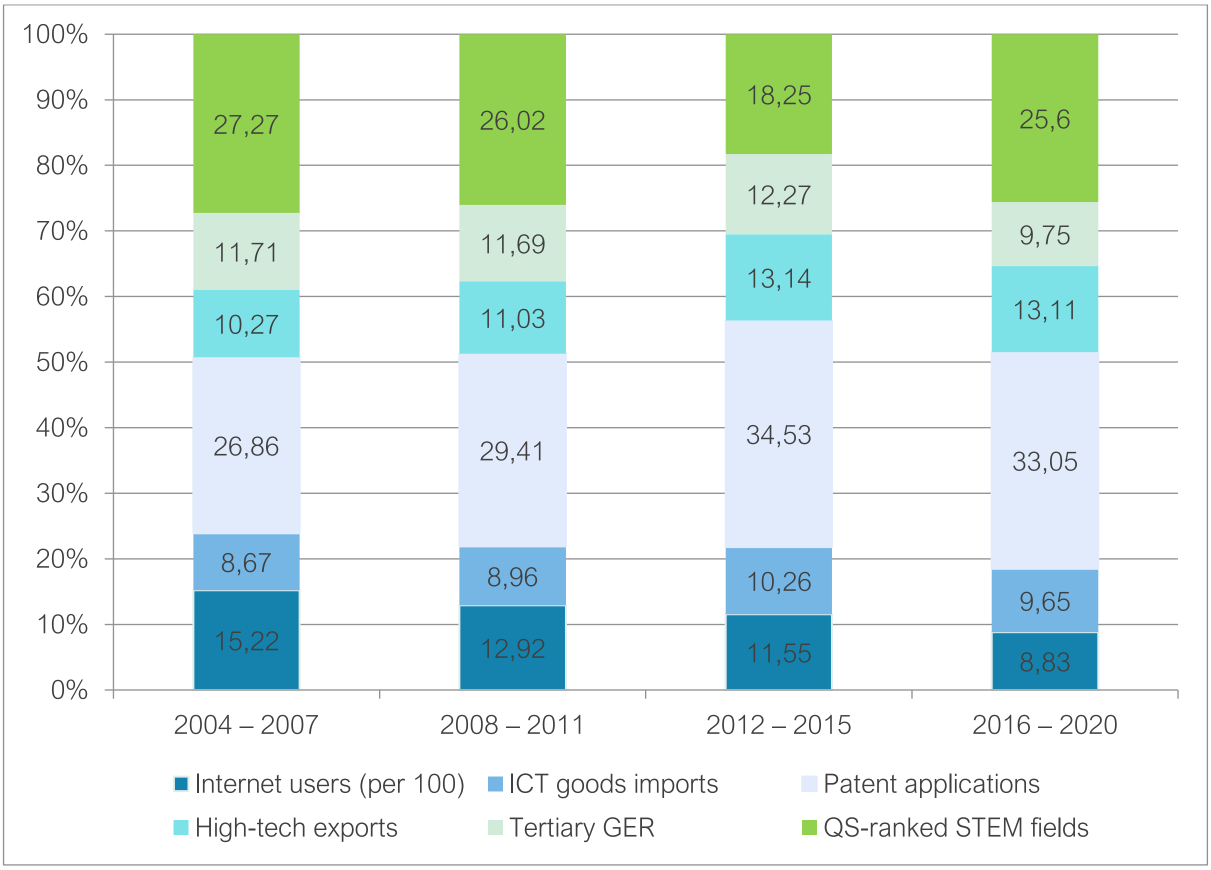
Period	Adoption	Production	Education	Total
Headcount index (TG_0)				
2000–2003	0.70	0.90*	0.55**	0.72
2004–2007	0.68	0.75	0.72	0.72
2008–2011	0.62	0.75	0.68	0.68
2012–2015	0.57	0.75	0.54	0.62
2016–2020	0.54	0.68	0.61	0.61
% change p.a. 2004–2007 to 2016–2020	*–1.84*	*–0.81*	*–1.27*	*–1.28*
Technology gap (TG_1)				
2000–2003	0.44	0.83*	0.34**	0.48
2004–2007	0.38	0.61	0.62	0.52
2008–2011	0.32	0.56	0.57	0.48
2012–2015	0.28	0.58	0.40	0.41
2016–2020	0.26	0.60	0.53	0.46
% change p.a. 2004–2007 to 2016–2020	*–3.06*	*–0.12*	*–1.23*	*–1.11*

p.a. = per annum.
Notes:
* Excludes high-tech exports.
** Excludes the number of top 500 QS ranked universities.
Sources: Authors' calculations based on World Bank (various years), World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed day month year); and World Bank (various years), Education Statistics (EdStats). https://datatopics.worldbank.org/education/ .

The average technology gap or TG_1 results are instructive. On average, the data show that the global average technology gap has declined from 0.52 to 0.46. This means that even though countries have remained 'poor' in the technology dimension, their position relative to the technology gap line has improved or narrowed. The largest reduction in this relative gap remains in the area of technology adoption, followed by human capital improvements. There has been no change in the relative technology production gap.

Figure 8.2 estimates the percentage contribution made by each of the individual six indicators to the overall Alkire-Foster technology gap index. The highest contributor to the index in the initial period is the QS ranking of STEM fields. During 2004–2007, about 27% of global technology vulnerability was due to disparities in the quality of STEM-offering higher education institutions across the world. Nevertheless, the QS share declined over time. For the full period under review, patent applications constitute the largest share of the overall technology gap in the world economy – ranging from 27% to 35% for the two decades since 2000. Ultimately, differences in STEM field rankings and patent applications together have consistently accounted for more than half of the overall technology gap.

Figure 8.2: Average Contribution by Indicator to the Technology Gap Index, 2000–2020



GER = gross enrolment rate, ICT = information and communication technology.
Source: Authors' calculations based on World Bank (various years), World Development Indicators. https://databank.worldbank.org/source/world-development-indicators; and World Bank (various years), Education Statistics (EdStats). https://datatopics.worldbank.org/education/.

In terms of technology adoption – through internet usage and ICT imports – these variables declined in importance over the period, suggesting again that technology adoption rates have served to reduce the overall technology gap in the developing world. Whilst GER enrolment rates have declined as a contributor to the technology gap, these are overshadowed by the inertial trends in STEM rankings. Finally, as an element of technology production, exports of high-tech goods – although less important for fuelling the gap – edged up to account for 13% of the global technology gap.

5. Policy Recommendations

We concentrate here on the policy proposals emanating from the core focus of this chapter: (i) improvements to internet usage at the firm and household level; (ii) technology policy solutions designed to ultimately increase patent applications; and (iii) a higher education strategy that is biased towards STEM-aligned graduates.

First, on improvements to internet usage in low-income and lower middle-income countries, work by Brookings and *Our World in Data* indicate that an individual who cannot afford a basic package of connectivity – which their empirical estimates set at 1.5 gigabytes (GB) per month, at a minimum download speed of 3 megabits per second (MBps) – should be defined as internet poor (Cuaresma et al., 2021). The analysis suggests that pricing rather than provision of infrastructure lies at the heart of improving and increasing internet usage rates in low-income countries. The policy prescription is clear: low- and middle-income countries should prioritise pricing by encouraging enhanced competitiveness amongst large telecommunications and data providers as well as regulation, to encourage and facilitate the provision of cheaper data packages for poor households either at the individual or firm level.

In terms of the patent gap, increased patent registrations require the introduction of an innovation policy package that ranges from higher education institutions and linked research divisions to small and medium-sized enterprises (SMEs) and finally large dominant firms. If one thinks of this as a discrete technology policy approach, domestic policy design could focus segmentally on higher education institutions; microenterprises; SMEs; and larger, more dominant, high-productivity export-oriented firms. In each segment, arguably a different mix of policy options would be required.

In the case of higher education institutions, the clear metric here is the national government expenditure on research and development (R&D). Tertiary institutions lie at the heart of early innovation and new technologies, which can ultimately drive key technology breakthroughs. Most developing economies spend insufficiently on R&D, particularly in the STEM fields. Such R&D support should be extended to include support and guidance to universities on management and internalising of the potential gains from research and innovative ideas in the STEM fields.

Linked to this is the need for governments to have a well-funded technology and innovation centre, which is focused on isolating ideas that the market may not initially value or where venture capital funds can partner with such a government-run innovation centre. Such public–private partnerships could bring universities, governments, and the private sector into a growth-enhancing partnership. Technology and innovation centres that are funded and run by the government are often an after-thought or do not exist in many developing countries.

In the case of firm-based support, microenterprises – particularly low-productivity firms in many developing countries – would require support designed to reduce the cost of technology adoption. This support could involve subsidised internet costs, together with active government support for the delivery of frugal innovation solutions to firms operating in poorer communities.

For higher-productivity, formal SMEs, governments should also consider subsidising the cost of technology, perhaps in a slightly more targeted form. Many of these SMEs lie at the heart of generating frugal innovative solutions and adaptive technologies in developing country settings. The government’s role here would be to support initiatives through supply-side incentives designed to encourage new local technological innovation to solve issues that foreign technology firms do not address.

Finally, large, often export-oriented, firms require a more nuanced support package from governments. These could range from healthy tax breaks to venture capital funds focused on new and adaptive technology solutions as well as explicitly encouraging firms to internalise the gains from knowledge spillovers and transfers from foreign direct investment.

In the area of higher education, two clear interventions should anchor government support: first, a focus on increasing the number of STEM field offerings in university programmes. Tuition costs, in terms of government subsidies for STEM courses, should strongly reflect these preferences; and second, it is also critical that such a special focus on the quantity of STEM graduates be combined with an attempt at increasing the quality of these programmes. Quick wins may be possible here. For example, a strategy followed by a number of East Asian economies is to enter into arrangements with the top 500 STEM universities in developed economies, wherein students from developing economies take advantage of exchange and/or knowledge transfer opportunities at top STEM institutions. Government bursary programmes could facilitate such students' access to these programmes.

6. Conclusion

First, internet usage has risen dramatically, yet the headcount and the relative gap measures of internet usage are still very high in poorer countries. Second, patent applications yield inordinately high levels of inequality – reflected in the dominance of China and high-income countries. Patent registrations as one of proxies of technological gap recorded significant divide across countries. Third, whilst there are income gaps in tertiary education enrolment rates, the data show that inequality in the QS rankings of STEM fields looms large as a key driver of the technology gap. The contribution of this variable to the overall global technology gap is 26%, with this measure's headcount index high for most categories of economies in the global sample. Taken together, the global and regional level analysis of the technology gap confirms that patent applications and STEM rankings jointly shape and drive the technology gap in the world economy.

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