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ARTICLE

Technological Upgrading and Educational Composition of the Workforce

Dev Nathan[1,2] · S. Rahul[3] · Joonkoo Lee[4] · Shengjun Zhu[5] · William Milberg[6] · Lauren Johnston[7]

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Abstract

In the global production system, there is a division of labour, based on a division of knowledge between lead (headquarter) firms and contract suppliers. While lead firms have, so far, largely been located in the Global North, some countries of the Global South have advanced along to progress from supplier to headquarter firms. This paper studies the manner in which the skill requirement or educational composition of the workforce changes in this process of technological advancement. The countries studied are China, India, and South Korea with the United States of America (USA) taken as the comparator country. The paper starts with the overall trajectory of technological upgrading in these countries. It then analyses the ways in which firm-level research & development (R&D), taken as the indicator and driver of firms' technology development strategies, is related to changes in productivity and the educational composition of the workforce. The paper shows that there is a broad positive correlation between the three variables, R&D investment, labour productivity and educational composition of the workforce. It points to the need to advance this analysis to look at other workforce indicators, such as the gender composition, wages, the quality of employment and the nature of supervision. At a methodological level, the paper argues that it is necessary to look at the role of a firm within a global value chain (GVC) to understand the composition of its workforce.

✉ S. Rahul
rahulthnu@gmail.com; rahul.s@tiss.edu

1 Southern Centre for Inequality Studies, Johannesburg, South Africa

2 Institute for Human Development, Delhi, India

3 School of Management and Labour Studies, Tata Institute of Social Sciences, Mumbai, India

4 School of Business, Hanyang University, Seoul, South Korea

5 Peking University, Beijing, China

6 Heilbroner Center for Capitalism Studies, The New School for Social Research, New York, USA

7 Heilbroner Center for Capitalism Studies, The New School for Social Research, New York, USA

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1 Introduction

There are two types of analysis of the division of labour (Fagerberg et al. 2010). First is that of Adam Smith, who deals with the division of labour within productive units. In this analysis, the division of labour by tasks increases productivity through specialisation, increasing specialised capabilities and reducing time lost in shifting from one task to another. In a sense, the capitalist gender division of labour within a household, e.g., the man earns a wage, while the woman carries out production of self-consumed and unpaid household goods and tasks, could be regarded as a type of division of labour within a productive unit, taking the household as a productive unit (Storper & Walker 1989).

The second analysis of the division of labour is that of David Ricardo, who deals with international trade and the way a division of labour between, say, manufacture and agriculture, is established through following the doctrine of comparative advantage and the policy of free trade (Ricardo 1817).

The productive unit analysis of the division of labour is included within labour economics; while the inter-country division of labour is the domain of international trade or development paths. In this paper, we argue that the two types of analysis need to be brought together. The results of the international division of labour define or characterise the productive units in different countries and, thus, the structure of production within which the enterprise-based division of labour takes place. In the contemporary global economy, this division of labour between enterprises takes the form of global value chains (GVCs) or even domestic value chains.

We look at this division of labour, which is also a division of knowledge, in the splintered production of value chains, in which a distinction is made between lead or headquarter firms concentrating on pre- and post-production tasks, such as design, branding and marketing, and supplier firms focusing on manufacturing or production tasks. At the global level, headquarters firms have been located in economies of the Global North, while supplier firms have been concentrated in the economies of the Global South. This picture, however, has not remained static. Over time, some countries have developed both as supplier and headquarter firms.

The shift from being suppliers to becoming lead firms can be understood as upgrading in GVCs (Gereffi & Fernandez-Stark 2016). This upgrading involves a change in tasks undertaken by the former supplier firms and countries. Corresponding to this change in tasks performed at firm and country level is a change in the composition of the workforce. The first sign of a change in strategy from being users to creators of technology seems to be an increase in the share of research & development (R&D) in a firm's expenses. When this strategic change has been successfully carried out, it will require and be reflected with a lag in a change in the educational composition of the workforce of a sector. These changes could be seen at both macro- or sectoral levels. National-level R&D and firm-level R&D would be related to each other. But since our focus is on changes in particular product chains, we focus on changes in firm-level R&D expenses as both an indicator and instrument of strategic change in production tasks.

We look at the manner in which this change in R&D and then educational composition of the workforce occurred in China, (South) Korea, India and the United States of America (USA) in the period 1995–2015. The USA is the original lead-firm country in this sample. The sample was deliberately chosen to include one country, Korea, which has clearly been successful in upgrading, developing its own technologies and brands; China, which is seen to be challenging the USA for domination in a few sectors; and, India, which we understood to be a laggard in moving from being a user to a creator of technology. We looked at features of the workforce in selected industries (garments, footwear, automobiles, pharmaceuticals, electronic hardware and information technology [IT] services) in the countries of China, India, South Korea and the USA. The industries were chosen as being important in production and exports from Asia and areas of technological capabilities in the United States.

Our analysis requires a few steps. Firstly, we need to clarify what is meant by technological upgrading. Next, we take up the question of how to measure upgrading. What drives upgrading and how is that seen in the data? Finally, we take up how this upgrading is reflected in the composition of the workforce. As mentioned, we use data for the twenty-year period 1995–2015. We had initially drawn data for 2020, but found that in that year product output and productivity had declined in some sectors. This decline was quite likely due to the recessionary impact of COVID-19. Therefore, for most of the analysis we stick to the period 1995–2015.

2 Upgrading Technological Capabilities

The concept of upgrading has been criticised for its lack of precision (Milberg & Winkler, 2011). In this paper, we seek to cut through some of the muddle created by the vagueness of the concept and go back to some earlier formulations in the work of Abramovitz (1986), and Lall (1992,1996) to assess industrial change.

The process of developing technological capabilities was characterised by Lall (1992,1996) as falling into three stages: (1) basic technological capabilities, developed through experience-based learning or Arrow's learning by doing; (2) intermediate technological capabilities, which is assimilative and adaptive involving some search-based and related forms of R&D; and (3) advanced technological capabilities, which is research-based and involves process and product design.

We modify Lall's schema by introducing development of managerial capabilities in addition to Arrow's learning by doing by workers. In GVCs, it is often observed that without initiating any technological change, supplier firms may advance from basic assembly or manufacture to enhancing capabilities in management functions, such as undertaking supply chain management, including sourcing inputs and even carry out detailed engineering. This is what is referred to as the movement from 'cut-make-trim' in garment manufacture to full package supply. This basic managerial capability requires little R&D (Gereffi 2018).

Our second modification, or, rather, elaboration of Lall's schema is in intermediate technological capabilities. This is assimilative and adaptive, but can also include reverse engineering, i.e., the copying or re-creation of technology that was either purchased or acquired through collaboration. As Wesley Cohen and Daniel Levinthal point out, 'Economists generally think of R&D as generating one product: new information. We suggest that R&D not only generates new information, but also enhances the firm's ability to assimilate and exploit existing information' (Cohen & Levinthal 1989, p. 569), thus building what Lall calls intermediate technological capabilities. Studies of India and China (Kathuria 2002; Hu et al. 2005, both quoted in Nollen 2009) show the role of firm-level R&D in assimilating imported technology and leading to improved productivity. This intermediate technological capability can also be taken to include reverse engineering, which has been an important part of the spread of technological knowledge. Japan in the first half of the twentieth century was known to excel in reverse engineering (Morris-Suzuki 1994).

All firms that remain in production would necessarily have developed basic technological capabilities. But the move to improved managerial capabilities or to intermediate and advanced technological capabilities all require upgrading strategies of firms, along with supportive national capabilities. But the critical part, signifying an upgrading strategy, is that of firm-level R&D. Public sector R&D usually plays a large role in national research spending (Pallante et al. 2023) (Mazzucato & Perez 2014), but firm-level R&D expenditure is what tells us about firm strategies of upgrading in value chains. We use firm-level R&D expenditure as a percentage of firm output, or R&D intensity, as an indicator of firm strategies and attempts at upgrading.

The knowledge-based division of labour between countries in the contemporary global economy, impacts on the structure of the workforce in the respective countries, even in the same product or sector. Firms and countries that carry out assembly or straightforward manufacture of products require mainly low-skilled workers, while firms that specialise in the design of products would require a large proportion of high-skilled workers. Further, the workforce structure does not remain constant over time. As firms move to assimilate technology and even upgrade from being users of technology to reverse engineering and then becoming creators of technology, the structure of the workforce is likely to change with an increase in the proportion of high-skill workers. We use the educational level of workers as a proxy for the skill level of the workforce. These data are divided into three levels—workers with elementary (up to Class 8) education, secondary (high school graduate) and tertiary (post-secondary degree or diploma). We take the proportion of employees with tertiary education as the indicator of skill intensity of the workforce.

Our thesis is that a change in the skill composition of the workforce is driven by an increase in the share of R&D in firm expenses. This, along with technological upgrading, is expected to lead to an increase in productivity or output per employee. The independent variable in this analysis is R&D as a proportion of firm expenditure, representing firm strategy. The higher the proportion of R&D in firm expenditure, the more the firm can be said to be attempting to upgrade or move up the value chain. When successful, this results in an increase in the skill composition of the workforce and the outcome is an increase in output per employee. The change in the skill intensity of the workforce is an intermediary output of R&D intensity. The outcome of both together is an increase in per capita output or productivity.

An increase in worker productivity is then our simple definition of economic upgrading. The first increase in productivity is the result of acquiring basic technological capability with Arrow's learning by doing. The second, intermediate technological capability is that of incremental innovations and even reverse engineering, both requiring some amount of firm-level R&D. The third, advanced technological capability is that of the creation of new products, requiring substantial R&d resulting in product innovation. Here a product can also be a service, as in IT software services.

2.1 National Strategies

We start with a broad picture of national strategies before going on to discuss particular GVC strategies. Figure 1 shows R&D expenditure as a percentage of gross domestic product (GDP) for our four countries from 1996 to 2020. The first point that stands out is that not only is India much lower than the other three countries but it also stagnates at around that low level of around R&D as 0.65% of GDP over the whole 25-year period. At a national level, India clearly does not demonstrate a strategy of upgrading, indicated by the percentage share of R&D in GDP.

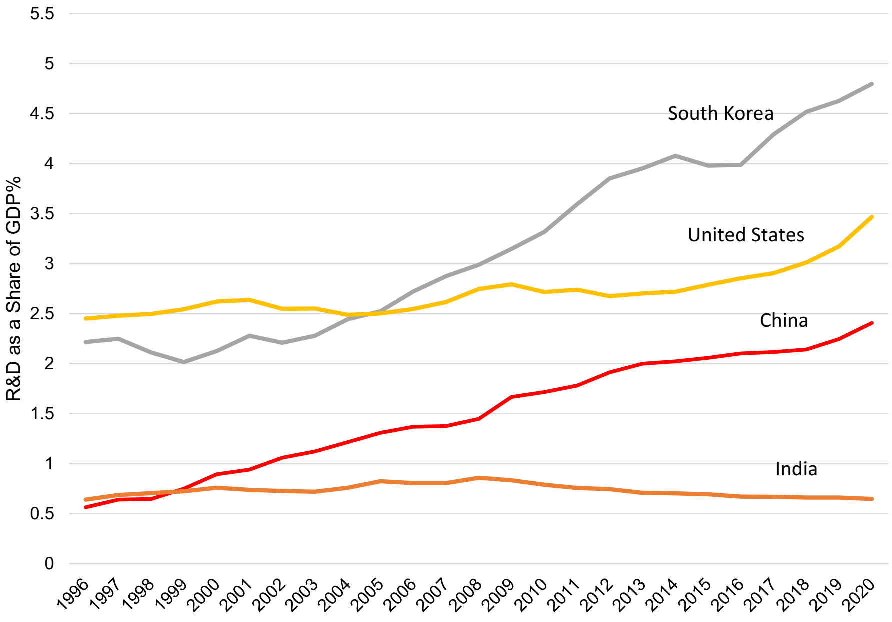

Fig. 1 R&D as a share of GDP. *Source* World Development Indicators

Both China and South Korea have clearly increased their share of R&D in GDP. China has moved from being below India in 1996 to 2.4% of GDP in 2020. Korea was already above 2.2% in 1996, but it has more than increased the share of R&D spending to a massive 4.8% of GDP. Of further interest are the inflection points in these developments. After the Asian Financial Crisis of 1998–1999, both China and Korea increased their shares of R&D spending. Korea increased its share more than China, and by 2020 it was virtually double China's share. Of course, the Chinese economy was much larger than the Korean economy, meaning total spending on R&D was higher in China than Korea.

The USA is the leader in our group. But its share of R&D stagnated, with some ups and downs, at around 2.5% of GDP from 1996 till 2016. It is only from 2016 that we begin to see an increase in the USA's share of R&D going up to 3.5% in 2020. Does this change reflect an appreciation of the technological (and military) challenge posed by China?

There is an interesting contrast between India and the other Asian economies. India's share of R&D in GDP peaked at a still low 0.85% in 2008. However, after the Financial Crisis of 2008 and resulting Great Recession, R&D percentage fell steadily till it went back to 0.65% in 2020 and subsequently too has continued at that level. In contrast, both China and Korea show the opposite kind of inflection—an increase in R&D share of GDP. Recession seems to have spurred China and Korea to be at the technological frontier, while that did not happen in the case of India. This is a topic for further research on the political economy of R&D spending and national development strategies.

We now look at the relation between R&D and, first, educational composition of the workforce and then worker productivity. The above plots in Fig. 2 indicate the correlation between R&D intensity and workforce educational composition, R&D intensity and worker productivity, and worker productivity and workforce educational composition. Since we are concerned with the catch-up strategies of the three supplier countries, China, India and South Korea, we look at them across the five manufacturing sectors (garments, shoes/footwear, automobiles, pharmaceuticals and consumer electronics). Since IT software services has a high proportion of workers with tertiary education at any level of productivity, we leave it out of this broad analysis of manufacturing production.

As per our hypothesis, the correlations between R&D intensity and workforce composition and productivity should be positive. The correlation coefficient between R&D intensity and share of workers with tertiary education reports at 0.460**, that of the R&D intensity and worker's productivity reports at 0.767** (Abramovitz 1986), and share of workers with tertiary education and worker's productivity reports at 0.367**, indicating moderate positive relationship in the first, a strong positive relation in the case of the second and moderate in the third case. The strongest correlation is for R&D intensity and productivity, in line with our assumption that R&D intensity drives productivity increase. Overall, the correlations are in line with our analysis.

We then turn to the country differences in these relations, comparing China, India, South Korea, and the USA.

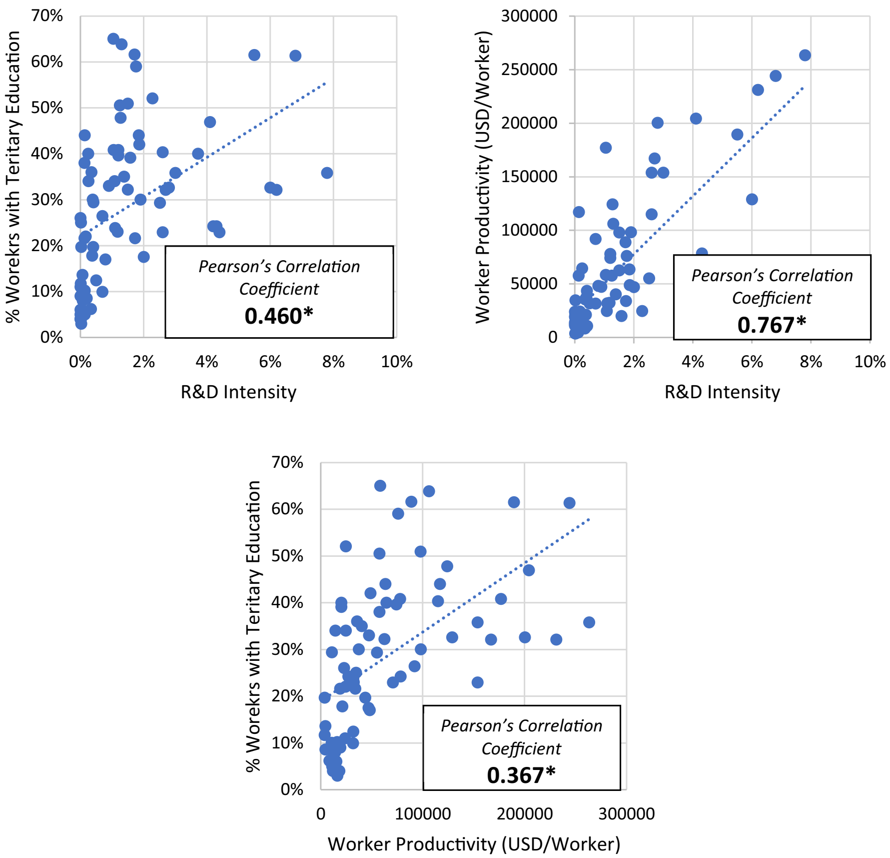

Fig. 2 Correlation between R&D intensity and share of workers with tertiary education and worker productivity (USD/Worker). *Source*: Author's calculations from compiled data

In the above panel (Fig. 3), correlation matrix looks at the interaction between the variables R&D intensity and share of workers with tertiary education across each of the countries separately. The figure indicates that the relationship is very strong and patterned in the USA followed by China, India and then South Korea. This is also clearly established by the Pearson's correlation coefficients of 0.817**, 0.679**, 0.512* (Yan et al. 2022) and 0.303**, respectively. South Korea despite reporting a positive correlation is not significant and as evident from the figure is quite dispersed.

In the above panel (Fig. 4), correlation matrix looks at the interaction between the variables R&D intensity and real per capita output across each of the countries separately. The figure indicates that the relationship is very strong and patterned in South Korea, followed by China and then USA and India. This is also clearly established by the Pearson's correlation coefficients of 0.719**, 0.476*(Cohen & Levinthal 1989) and 0.166 and 0.050, respectively. However, in the case of India the productivity has remained almost constant despite the improvement in R&D

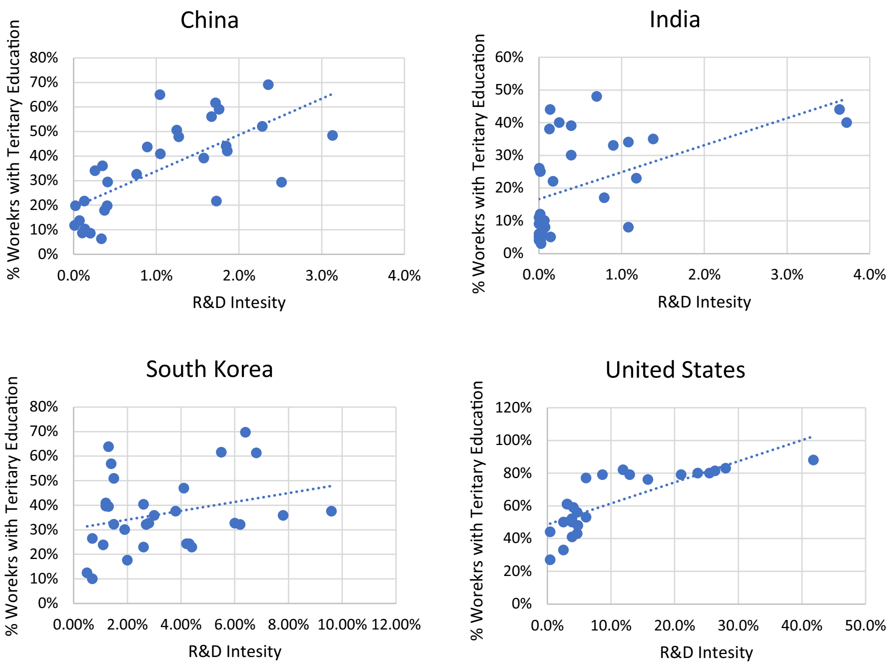

Fig. 3 Correlation between R&D intensity and workforce share in tertiary education. *Source*: Author's calculations from compiled data

intensity of the sectors. This would mean that increases in R&D intensity had not yet resulted in productivity increases.

In the above panel (Fig. 5), correlation matrix looks at the interaction between the variables worker's education and real per capita output across each of the countries separately. The figure indicates that the relationship is very strong and patterned in India, followed by China and then South Korea, and shows no pattern in USA. This is also clearly established by the Pearson's correlation coefficients of 0.733**, 0.610**, 0.529** and 0.293, respectively. The USA did not show any pattern and the clusters are more or less the same in each industry. Further, in the case of India the strong positive relationship is not uniform across all sectors studied, as we will see later.

Both China and South Korea have significant correlations in all the three relations. They both exhibit clear upgrading effects in all the sectors studied. Neither India nor the USA show similar significant correlations. Since USA is at the technological frontier, it is to be expected that further advances in productivity would be more difficult. But for India, despite not being at the technological frontier, the non-significant correlations strengthen the point about a lack of strategy. If Fig. 1 shows a lack of strategy for India at the national level, these non-significant correlations in Table 1 show a lack of strategy at the sectoral level. This is something that we will take up in the analysis of particular sectors.

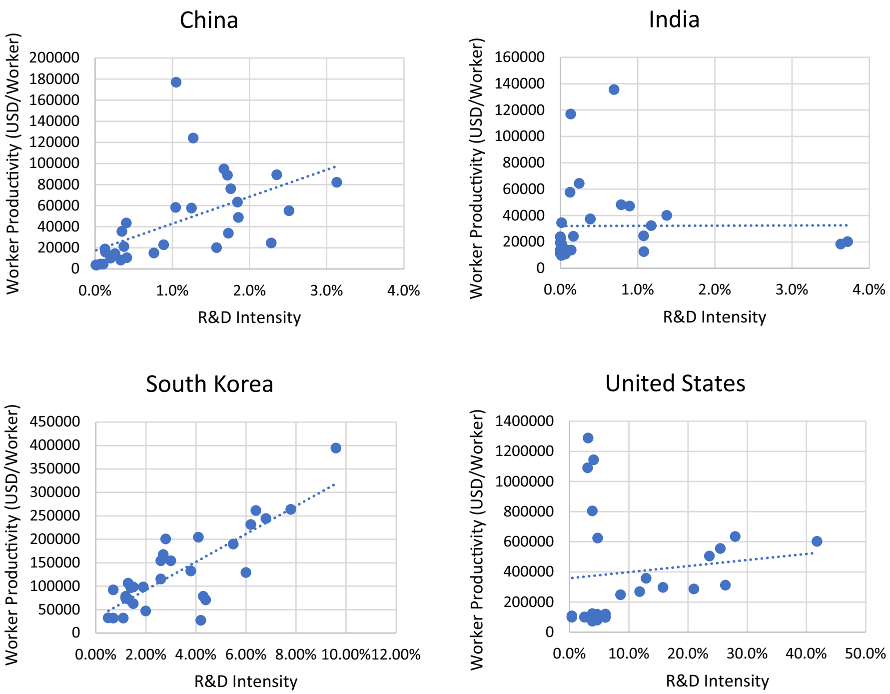

Fig. 4 Correlation between R&D intensity and worker productivity. *Source*: Author's calculations from compiled data

2.2 Country Sector Strategies

We now try to decompose the above changes through firm strategies of upgrading in each sector. Taking R&D intensity (the proportion of firm expenditures spent on R&D) in relation to per capita output across all six sectors and four countries for the period 1995–2015, there is a positive correlation, which means that our basic hypothesis is in line with the data. However, for particular sectors and countries, there is not necessarily a positive correlation.

As seen in Table 2, the USA has a higher R& D intensity than the Asian countries in every sector in 2015. In 1995, only Korea had a higher R&D intensity than the USA in electronics. In Korea, R&D investments diverged across the sectors. While R&D intensity in the electronics and pharmaceutical sectors increased considerably, it decreased in the automotive and IT services sectors. Overall, similarly in labour productivity in Korea, the two high-tech sectors led R&D investment, and R&D intensity was stagnant or declined in all the other sectors except garments in 1995–2015.

In China, all sectors have seen an increase in R&D intensity except for the IT services sector. And the electronics and pharmaceuticals sectors have the highest relative percentage. Yet for a horizontal comparison, IT services outperformed other sectors in 1995, nearly nine times the R&D intensity of the pharmaceuticals sector,

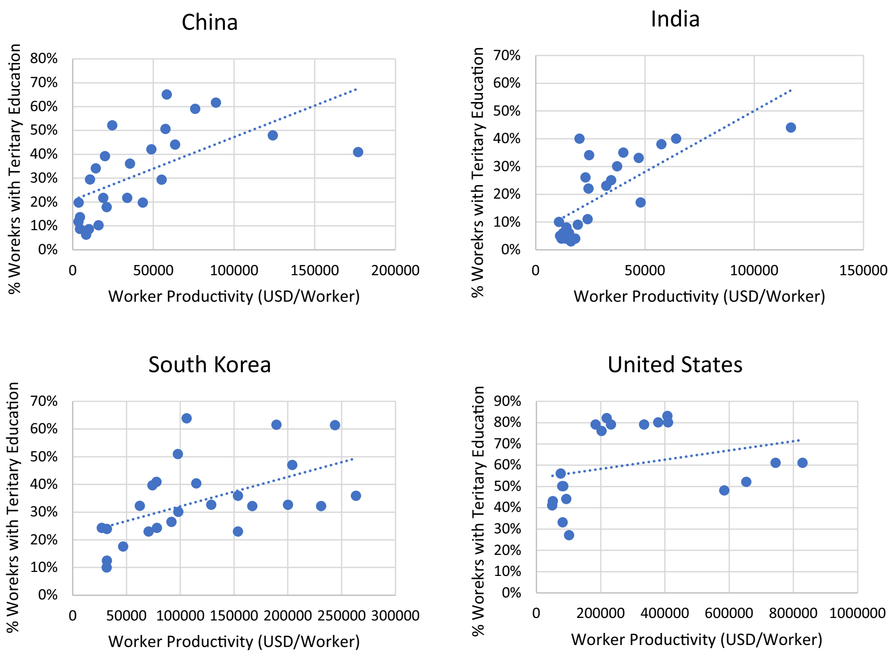

Fig. 5 Correlation between tertiary education and worker productivity. *Source*: Author's calculations from compiled data

Table 1 Correlation of R& D intensity, Percentage of workers with tertiary education and real per capita output. *Source*: Author's calculations from compiled data

	China	India	South Korea	United States
R&D intensity and tertiary education	0.679**	0.512 (NS)	0.303**	0.817**
R&D intensity and real per capita output	0.476**	0.05 (NS)	0.719**	0.166 (NS)
Tertiary education and real per capita output	0.610**	0.733**	0.529**	0.293 (NS)

NS: not significant; **Significant at 0.05

Table 2 R&D intensity (R&D as % of output) 1995 and 2015. *Source*: Author's calculations from compiled data

	China		India		South Korea		USA	
	1995	2015	1995	2015	1995	2015	1995	2015
Garments	0.01	0.41	0.01	0.04	0.50	1.30	0.50	4.68
Footwear	0.02	0.35	0.00	0.06	0.70	0.70	–	–
Automobiles	0.37	1.27	0.00	1.38	4.30	3.00	4.35	3.15
Electronics	0.26	1.76	0.17	0.13	4.20	7.80	1.42	21.02
Pharmaceuticals	0.41	1.72	0.02	3.72	1.90	6.80	15.36	28.00
IT services	3.56	2.10	0.00	1.60	2.70	2.00	–	3.31

which ranked second in 1995. And the IT services sector still ranks first among all the sectors in R&D intensity in 2015, indicating the high proportion of firm expenditures spent on R&D and high managerial capability in IT sectors.

In India, in keeping with its low share of R&D to GDP, firm-level R&D intensity has also been lower than for the other Asian countries. In garments and footwear, it is much lower than China. In automobiles, it is a little higher than China in 2015. It is only in pharmaceuticals, where India concentrates on the manufacture of generic drugs through R&D-based reverse engineering that India's R&D intensity is higher than that of China, though not Korea.

We now discuss the posited connection between these changes in R&D intensity and productivity in each sector in each country.

2.3 Consumer Electronics

In consumer electronics (see Table 2), R&D intensity increased in the USA from 1.42% of total output in 1995 to as much as 21.02% in 2015. The high share of R&D can be taken to be the result of the US strategy of concentrating on the creation of products. In China, the share of R&D increased from a minimal 0.26% in 1995 to 1.76% in 2020. In Korea, the increase in R&D was even greater as it went from 4.20% in 1995 to 7.80% in 2015.

Productivity per worker in consumer electronics in South Korea was 143% that of the USA in 2015, while productivity in China increased by a lesser extent. But in both Korea and China, there is a relatively low share of R&D. This could be explained by Chinese and Korean firms being primarily engaged in reverse engineering of technologies developed elsewhere. This reverse engineering is likely to be accompanied by some incremental technological improvements, which could be seen in the Chinese firms, such as Huawei and ZTE, emerging over the past few years among firms with the largest number of patents (WIPO 2017). In the consumer electronics sector, which relies heavily on advanced knowledge, productivity has increased with advancements in knowledge use. During the research period, the consumer electronics sector's productivity levels have grown steadily and quickly. This shows that the accumulation of knowledge through incremental technological improvements has set the stage for long-term growth and boosted economic upgrading.

Korea has also developed its own mobile phone brand, Samsung, with its patent pool, though it did not pioneer the creation of smart phones. Also, the country has become the world's leading producer and exporter of memory chips and computer panel display products. Such advancement was enabled by Korean firms' increased commitment to advanced technologies and R&D activities and moving up to a higher value-added market segment with branded products. This shift was largely due to the intensified competition they faced with Chinese firms in low-tech product segments. A notable example is Korean firms' rapid adoption of organic light-emitting diode (OLED) technologies in panel display in the face of Chinese firms' growing dominance in the conventional liquid–crystal display (LCD) market.

The productivity gains, thus, can be explained by a combination of advanced R&D activities and product upgrading.

Compared to these two economies, the USA seems engaged in the production of frontier technologies as a way of keeping its economic lead. Frontier technologies are likely to require more investment in R&D than reverse engineering and incremental innovation. Along with this, the high productivity of South Korea could also be due to its monopoly position in the supply of some critical inputs, such as flat screens, whether in computers, TVs or mobile phones.

2.4 Pharmaceuticals

In the USA, the ratio of R&D expenses to total output in pharmaceuticals increased from 15.36% in 1995 to 28% in 2020. In this period, real output per capita also increased by 40%. In China, India and South Korea R&D as a percentage of output was much lower at 1.72%, 3.72% and 6.80%, respectively, in 2015. Again the much higher share of R&D in the USA, compared to the other three countries stands out. Here too it is the USA that seems to have concentrated its R&D in developing new pharmaceutical drugs, while India is known for developing generic versions. Such reverse engineering will obviously be much cheaper than developing original drugs.

Along with differences in R&D shares, there is also a big difference in productivity. With its proprietary IPR-protected drugs, the USA output per capita was $408,220 2015, as against $20,140 for India. The output per capita for India actually declined from $34,564 in 1995, probably reflecting greater competition in the market for generics as many countries, such as Bangladesh, Brazil and South Africa, also developed the capabilities to produce generic drugs.

In China, however, real output per capita in pharmaceuticals went up from $10,764 in 1995 to $86,772 in 2015, with a CAGR of 8%. China is the major supplier of active pharmaceutical ingredients (API) and could have a monopoly price advantage. In the pharmaceutical sector, where knowledge inputs have been continuously strengthened, productivity has also improved, ranking fourth in 1995 among the six sectors and second in 2015. After initial development supported by the Chinese government's financial subsidies in the early 2000s, the pharmaceutical sector expanded its scale and established market-oriented sales channels, gradually achieving economic upgrading.

In South Korea too, both the R&D ratio and output per capita increased over this period. R&D intensity increased from 1.9 to 6.8% and labour productivity more than doubled, from $98,200 to $243,900. These figures in 2015 were quite matched with those of the electronics sector (7.8%, $263,400).

In India, the pharmaceutical industry adopting incremental innovation was characterised by innovating in production processes rather than developing new products (Mani, 2023). This also stems from the nature of pharmaceutical production from India which is featured by generic drugs. Further the pharmaceutical industry and its developments especially in R&D is an example of public and private and even global capital working towards a specific goal where majority of the R&D investments are in the private sector and is now established by global partnerships and government supporting in terms of subsidising R&D efforts of the firms.

2.5 Garments and Footwear

We discuss these two sectors together for two reasons. Firstly, they are both labour-intensive in their manufacture. Secondly, rather than direct R&D effects, changes in productivity are likely to be related to shifts in the position of suppliers in the respective value chains. They may move from simple assembly, or cut-make-trim, to adding more functions and moving to full package supply, with their own form of outsourcing. The shifts from assembly to full package supply do require an increase in knowledge and technological capabilities, but they may not require much R&D expenditures as in the other products.

China and even more South Korea increased productivity in both garments and shoes, more in garments than in shoes. India clearly lagged behind, with a very minimal change in garments and a reduction in comparative productivity in shoes. In both garments and footwear in China, there were changes in business models that could have resulted in observed productivity changes. As wages rose in coastal areas, which were the centres of outsourced production, the Chinese government promoted a policy of 'Go West, Go Up, Go Out' (Zhu 2018). Factories were encouraged to shift to China's western region, where wages were lower than in the coastal regions. 'Go Up' was a policy of going up the value chain, exactly the upgrading from assembly to full package supply. Finally, 'Go Out' was the shift to sub-contracting to factories in countries with lower wages, such as Cambodia and Vietnam. As a result, in the labour-intensive garments and shoes sectors, productivity grows steadily with the advancement in R&D intensity, achieving continuous economic upgrading, knowledge increase, and technological capabilities.

In fact, 'Go Out' was the explicit business strategy that South Korea adopted for labour-intensive products after the Asian Financial Crisis of 1998–1999. In a way, the Asian Financial Crisis signalled the end of Korea's earlier catch-up industrialisation process based on cheap labour. South Korean suppliers of garments and shoes took up sub-contracting their manufacturing to countries with lower wages, including China and countries of Southeast Asia. With their own functions confined to securing and managing orders, there would have been an increase in productivity in garments and footwear in Korea. Furthermore, some of Korean garment suppliers moved up to be first-tier, original design manufacturers (ODM) for western buyers. Thus, the rise of labour productivity accompanied by the moderate increase of R&D intensity in garments can be understood in this context.

In India in both garments and footwear there is little R&D—0.04% and 0.06% in 2015 in the two respectively. It is only in 2020 that we see some increase in R&D intensity in the garments industry—very likely due to brands requiring suppliers to carry out some portion of design and engineering tasks. Overall, however, low R&D in these two sectors seems related to India's poor productivity performance, compared to the other Asian countries, in increasing productivity.

2.6 Automobiles

In automobiles, USA productivity increased by 56% between 1995 and 2015. There were increases in productivity in the Asian countries, but of a much smaller magnitude. In general, Asian automobile production seems to have been of lower value per unit, while the USA production was of higher value. The extent of automation could also have differed between these countries. But technology did not change much in this period. The shift to electric mobility comes up post-2015.

As mentioned above, Asian R&D seems to have been mainly of the reverse engineering variety. China, India, and Korea all moved from acquiring technology through foreign direct investment (FDI) joint ventures to then copying or reverse engineering the technologies acquired. There are reports that China's joint ventures often required technology transfer as a condition of acquiring market access (WIPO 2017).

In China, the automobiles sector has the highest increase in absolute productivity and was ranked second in 1995 among the six sectors and first in 2015 in relative terms. The prosperous increase is due to the governments' financial subsidies for vehicle engineering and relevant plans for the new energy vehicle around 2010, boosting economic upgrading and a shift in manufacturing in the sector.

In Korea, the automotive sector fell behind the electronics and pharmaceuticals sectors in labour productivity. It grew steadily in 1995–2005 but has declined since 2005. R&D intensity remained largely stagnant over the period. This is somewhat at odds with the fact that the leading Korean carmaker—Hyundai/Kia—rose from the 9th spot to the 3rd in the world's car production in 2005–2015. Some of the plausible explanations are the overall rise of offshore production during the period, ageing of production workers at home, and the carmaker's reliance on engineers than shop-floor workers in maintaining quality and productivity.

2.7 IT Services

In IT Services, the USA productivity increased by 166% between 1995 and 2015. This is the only sector in which India did better than its Asian competitors. The increase in output per employee in India reflects an upgrade as Indian IT service providers moved from providing mainly middle- to lower-end programming and testing services to full package or end-to-end services, including conception, architecture and design.

In China, the IT services sector witnessed an extraordinary high R&D intensity and productivity level at the beginning of the research period, especially from 1995 to 2000. This coincided with deepening reform and opening up, and the arrival of the new century. The electronic information sector experienced rapid growth, with significant investments from the government. R&D investment in the IT services sector increased rapidly, as the country urgently needed to develop information infrastructure sectors such as software services, nurture research abilities, and strengthen the absorptive abilities of new technologies. The productivity level also reached its highest point in absolute terms in 1995, ranking first among the six sectors. However, the increase in the IT services sector decreased dramatically from 2000 to 2005. The decline in the IT services sector can be attributed to the rapid progress and strong market demand in the computer sector during 2000–2005, which is the Ninth Five-Year Plan period. Nevertheless, the sectors still maintained a relatively high level of R&D intensity and productivity. From 2005 to 2015, the IT services sector experienced a steady increase in knowledge use and productivity, which is in line with the need for transformation and upgrading, emphasising the use of advanced knowledge and continuous, independent innovation of products and systems.

In Korea, the IT service sector is the least dynamic among the six sectors, characterised by stagnant labour productivity and declining R&D intensity although it was the sector with the most educated people as shown below (92.2% of the workforce with tertiary education in 2015).

The case with the Indian IT services is a special case which reports the highest labour productivity both in terms of level and growth. This is significant in the last decade and has also survived the global recession of 2008 and the COVID pandemic induced recession. However, R&D in the sector is not in proportion to the tremendous growth seen in productivity. This is mostly accounted by the nature of innovation which is geared towards firms adopting newer and improved ways of delivering services by reducing the time spent to complete a project. And they arrive at the most innovative processes to reduce cost without performing much R&D (Mani, 2023). Upgrading in the Indian IT industry has mainly achieved through the movement from providing middle to lower programming services to providing end-to-end delivery of the software services. This is achieved increasing developing higher technological capabilities in architecture and design along with required domain knowledge, often acquired through cross-border mergers and acquisitions (M&A).

2.8 Changes in Workforce Composition

Now we look at how technological upgrading was accompanied by a change in the skill intensity of the workforce. This is measured in terms of the share of employees with tertiary education in the workforce. The proposition is that upgrading requires the adoption of skill-intensive tasks, such as product design, process innovation, or even taking up new managerial tasks such as managing supply chains, all leading to an increase in the share of employees with tertiary education (Table 3).

All the three Asian countries show an increase in the skill intensity of the workforce in each of the sectors. However, the USA still remains ahead of the Asian countries, except for China and Korea in IT services and Korea in garments.

A surprising result is the low skill intensity of the Korean workforce in automobiles. It could be largely because medium-skilled workers who graduated from high school or junior technical college, still play an important role in car production (55.2% in 1995 and 60.2% in 2015). It is still remarkable that skill composition in automobiles, electronics and pharmaceuticals was quite similar in 1995, but it shifted more dramatically in the latter two sectors, quickly replacing low- to medium-skilled workers with college graduates, more than in automobiles.

Table 3 Skill Intensity of Workforce (% with Tertiary Education) 1995 and 2015. *Source*: Author's calculations from compiled data

	China		India		South Korea		USA	
	1995	2015	1995	2015	1995	2015	1995	2015
Garments	11.7	19.7	4.0	6.0	12.4	63.8	–	43.0
Footwear	19.7	36.0	6.0	10.0	9.9	26.4	–	56.0
Automobiles	17.8	47.8	9.0	35.0	24.2	35.8	–	61.0
Electronics	34.0	59.0	22.0	44.0	26.0	57.7	–	79.0
Pharmaceuticals	29.4	61.6	25.0	40.0	30.0	61.3	–	83.0
IT Services	38.6	86.5	65.0	77.0	82.1	92.2	–	84.0

In China, the proportion of workers with tertiary education increased in all sectors. And this is most obviously in the IT Services and pharmaceuticals sectors, followed by the automobiles sector. For labour-intensive sectors, the footwear sector has a higher proportion of workers with tertiary education than the garment sector.

Overall, however, there has been a general increase in the skill intensity of the workforce in all sectors and countries. There is no reduction in skill intensity in any country in any sector. This could be the result of a combination of changes in the skill composition of tasks along with an increase in the proportion of those with tertiary education in the overall labour force. However, there is a positive correlation between skill intensity, measured by educational level, and output per worker (as seen in Fig. 5), which would suggest that firms increasing their employment of more educated workers is related to economic upgrading in terms of higher productivity.

In China, the IT services sector has seen the highest increase in the composition of employees with tertiary education. The knowledge-based division of labour has an impact on the structure of the workforce in different sectors, with firms specialised in the design of products requiring a large proportion of highly skilled workers. In China's case, the IT services sector has the highest skill intensity of the workforce, which requires knowledge creation, upgrading, and innovation. And this is followed by the pharmaceuticals and automobiles sectors, which may require more knowledge in assimilating technology and reverse engineering.

In Korea, workers with primary or secondary education were increasingly replaced with college graduates, which accounted for 64% of the employed in 2015. In electronics, low-skilled workers continued to be the smallest group while medium-skill workers (high school graduates) were gradually replaced with college graduates, which has become the largest group since 2010.

3 Discussion and Conclusion

All four economies show an increase in the educational intensity of their workforces, and this is positively correlated with increases in per capita output. The increase in productivity, however, in the case of the two East Asian economies is due to shifts in their role in the international division of labour within GVCs, moving on to higher value functions and developing their own lead firms. Conversely, the weakness in India's increases in productivity is due to its failure to develop from being a supplier to developing its own international lead firms.

The transformation of China from being an assembler of electronic products in 1995 to combining assembly with the creation of its own electronic brands is reflected in a change in the composition of the workforce. From being the mirror image of the USA's electronics workforce in 1995, China in 2020 came close to matching the USA in the proportion of employees with tertiary education. This reflects China achievement of economic and GVC upgrading generally, requiring a greater need for highly skilled labour and leading to an upgrading in roles in GVCs. Chinese firms such as BYD in electric vehicles and Huawei in consumer electronics have developed as headquarters firms with their own brands. And China now has more lead or headquarter firms focusing on product innovation, specialised industrialisation, and pre- and post-production tasks, occupying a more important role in the global market.

The USA's high R&D intensity in electronics and pharmaceuticals could be attributed to its concentration on developing new products in both these sectors. On the other hand, the ability of the Asian countries to upgrade with relatively low R&D intensities could be attributed to their reverse engineering products—Korea, China, and India in automobiles; Korea and China in electronics; and India in generic drugs. At the same time, the high levels of patents secured by Korean and Chinese firms in these industries also show that they are developing their own products, though reverse engineering accounts for a large part of their upgrading. In China, R&D intensity has shown an upward trend in all sectors, indicating that knowledge use has transitioned from direct operation to absorption, improvement, and even innovation in products or systems. And different sectors have shown different patterns in the process of developing technological capabilities and absorbing basic, intermediate, and advanced technological capabilities.

A third type of upgrading is seen in the case of labour-intensive products, such as garments, and footwear. Suppliers take on more functions, moving from cut-make-trim to full package supply. The latter involves taking on both more managerial functions and also carrying out detailed engineering in, say, turning a design into a product. Both full package supply and detailed engineering involve an increase in managerial-cum-technological capability.

In addition, after the 1998 Asian Financial Crisis, South Korea shifted from manufacturing these products to managing their third-country production in China and Southeast Asia. This involved an increase in knowledge intensity in taking on more managerial functions and also in R&D. To a lesser extent, there seems to have been similar trends in China. India, on the other hand, lags much behind the other Asian economies in increasing knowledge intensity by taking on more managerial and detailed engineering functions and this is reflected in much lower output per capita.

Overall, we see that there has been a change in the educational composition of the workforce of the Asian countries along with changes in R&D intensity and productivity. This is much more so for China and South Korea than for India. On the other hand, the USA remains ahead in terms of educational composition, R&D and productivity, but is facing increasing competition from China and South Korea.

Changes in the educational composition of the workforce seem related to changes in the roles in GVCs, role changes driven by R&D resulting in upgrading reflected in productivity. But we have also seen that in some cases there can be an increase in educational composition without any upgrading in GVCs reflected in no change in productivity. This seems to be the case of India, where the recent ILO-IHD Employment Report shows an increase in the share of graduates in employment carrying out shopfloor tasks (ILO-IHD 2024).

Why does technological upgrading result in a change in the educational or skill composition of the workforce? A first factor is that technological upgrading, based on R&D as an activity, itself requires a higher proportion of graduates than does shopfloor operation. More important, however, is the addition of new tasks to the production system. There is an increase in the requirement of management officials to undertake supply chain management in 'full package' supply. Or an increase in technical supervision tasks in shopfloor production. All in all, there is an increase in the service tasks in manufacturing. For instance, when garment manufacturers upgrade from 'cut-make-trim' to turning designs into products, there are many detailed engineering and technical tasks to be carried out; all of which require workers of higher skills than assembly line tailors. And, of course, when firms move being just contract suppliers to being own-brand producers there are not only design but also brand and marketing tasks added to the firm. In many of these additional tasks there would be an increase in the implicit rather than explicit knolwedge and thus require more skilled workers. All these increase the educational or skill requirement of workers.

Technological upgrading which we have identified as a key factor in changing the educational composition of the workforce is linked to changes in the roles of firms in the task-based distribution of labour in production. Consequently, what we are pointing out is that it is necessary to look at the role of firms in task-based GVCs in order to understand the educational composition of the workforce. A simple classification by the technological level of a product is not sufficient to understand the educational composition of the workforce. To take a well-known example that we dealt with in this paper, mere identification of electronics as high-tech does not tell us what the educational composition of the workforce in the electronics sectors in China and the USA would be like. When China basically carried out assembly of electronic products, its factories did not require many graduates in their workforce. But when Chinese brands began to develop their own products, even if initially reverse engineered but increasingly based on own research, the educational composition changed in favour of a higher production of graduates. This, then is the main conclusion of our analysis: that it is necessary to look at the roles of firms in the task-based distribution of labour in GVCs in order to understand the educational composition of their workforces. As Asian countries, particularly the three studied in this paper, move to developing their own products, we will see an increase in the demand for workers with more education and higher skills. Of course, we will have to see how the spread of AI will affect the volumes of such higher-skilled workers required.

Will looking at firm tasks make a difference to labour inequality as it is manifested in differences in labour remuneration between firms? The theory of human capital relates differences in labour income to the volume of human capital embodied in workers. But GVC theory (Nathan & Sarkar 2011; Milberg & Winkler 2013; Nathan 2024) shows us that margins or profit rates vary between firms in different GVC segments. The lead firms carrying out the pre- and post-production tasks earn monopoly profits, while supplier firms earn just competitive profits. Kalecki's theory (1970) predicts that wages will vary with the degree of monopoly, as firms with greater monopoly power share some of their monopoly profits with their workers. Then, unlike the prediction of the human capital theory, labour income for workers embodying the same human capital, would vary with whether they work for a lead or supplier firm. An IT engineer working for Apple with then earn more than a similarly qualified IT engineer working for firm assembling iPhones. A study by Sarkar et al. (2016) provided some empirical evidence in support of this analysis. They found that, in India, IT engineers working for IT service firms earned more than IT engineers working for manufacturing firms; in other words, IT engineers in the high-return IT service firms earned a premium over their counterparts in other product sectors.

The analysis in this paper would lead to the following hypothesis that could be empirically tested:

1. As firms move up the value chain, there will be an increase in the intensity of the skill/educational level of tasks.
2. With an increase in the intensity of the skill/educational of workers required there will be an improvement in some employment and working conditions of the workforce, with higher wages, and more secure employment.

It is very likely that the second set of positive changes may not come about. But there are some anecdotal instances of such improvements. Lee et al. (2013) found that in China and India, original equipment manufacturer (OEM) assemblers of the then-Nokia phones had better conditions than their suppliers in both countries. Gokuldas, a garment contract exporter in Bengaluru also had a factory manufacturing 'own-brand' products. Workers in the own-brand factory were reported to have both higher wages and more secure employment than workers in the contract manufacturing factory. Contract exporters in an industrial estate in Mumbai also reported that they were unable to compete with the higher wages paid by own-brand manufacturers of the same size (factory interviews by Nathan 2016).

When garment manufacturers technologically upgrade from 'cut-make-trim' to turning designs into garments, they need design and sample tailors of higher skills than assembly-line tailors. Design and sample tailors have been found to have tertiary and secondary education (or many years of high-level work) than assembly-line tailors. They also earn substantially more and generally have secure employment compared to assembly-line tailors. They have also been found to work in work circles with joint responsibility for outputs and not in Taylor-style assembly line. A study of maqilas or export factories in Mexico found that workers were given extra training for the required higher-skill tasks of quality control, and continuous improvement (Dutrenit & Vera-Cruz 2007). Requiring to retain the workers provided training for higher skills, wages also increased. More in-house training can be expected to lead to both higher wages and more secure employment.

However, a study of exactly the technological upgrading we are discussing in this paper, showed that the upgrading of China's Telecom Technologies Co., has led to the posited improvements (Yan 2022). Workers with at least a bachelor's degree and working in R&D, marketing and technical support did get higher salaries and had better office facilities. But they had long working hours, frequent overtime work, salary instability and job insecurity. New terms like 'IT Mingong', or 'programming apes' were reported to be used to refer to the unsatisfactory working conditions of IT workers. In India, the term 'cyber coolies' was used to denote the masses of programmers in India's relatively well-paid IT service companies (Ramesh 2004). New forms of Taylorism have developed in IT service companies (D'Cruz & Noronha 2016).

Thus, it would be an error to map increases in the educational and skill intensities of employment brought about by technological upgrading with overall improvements in labour conditions. The way labour processes, including management systems, intersect with technological upgrading needs to be investigated and not taken for granted that there will be uniformly positive outcomes. A larger and even cross-country study could be carried out to verify the key hypothesis that technological upgrading and movement up the value chain can enable an increase in the education/skill intensity of the workforce and that this can be accompanied by improvements in labour standards in terms of wage, security of employment and even more participatory supervision.

Technological upgrading makes possible an improvement in these labour standards due to the increase in productivity and even margins. Do technological and value chain upgrading also require such an improvement in labour standards? This can be studied both between firms in different segments of the value chain and also for firms that change their roles in the value chain. To what extent a technological upgrading requires an increase in educational/skill intensity, whether this enables an improvement in the quality of employment and the extent to which such improvements come about is an important question to be answered empirically. Labour processes, labour struggles and managerial and supervisory systems intervene between technical labour requirements and changes in the quality of employment.

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