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ECONOMICS OF TECHNOLOGICAL LEAPRGFROGGING

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Economics of technological leapfrogging

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Abstract

One of the key issues of latecomer economic development is whether they should follow the path of forerunners or whether they should create a new or follow a different path of development. An emerging view (Lee and Lim, 2001; Lee, 2013) is that latecomers do not simply follow advanced countries' path of technological development but occasionally skip certain stages or create their own path which differs from that of forerunners. This observation is consistent with the idea of leapfrogging (Perez and Soete, 1988), according to which some latecomers may be able to leapfrog older vintages of technology, bypass heavy investments in previous technological systems or stages, and make pre-emptive investments in emerging technologies to catch up with advanced countries in new markets.

The answer to the question whether the 4IR represents a new window of opportunity for leapfrogging or whether it constitutes a source of further risks for latecomers is that this depends entirely on the country's response and readiness, i.e. its industrial policy, digital literacy, the skill and education level compared to wage rates, as well as domestic market size and position in the GVC. We identify three groups of countries. The first group of economies have a manufacturing basis and seems to be the group with the most promising potential for proper leapfrogging from Industry 2.0 (mass production) to Industry 4.0 (smart factories) and bypass the intermediate stage of Industry 3.0 (automation). The second group of economies have an FDI-based manufacturing sector, where leapfrogging hinges on MNCs which have several options at their disposal, such as relocating to other economies in search of cheaper wages or reshoring back to home countries. The key factor for success in this context are the local institutions – if they foster the training and upskilling of the local workforce, they can persuade MNCs to remain in the country. The last group includes latecomer economies that have the potential of making promising 4IR-related strides in the service sector or in servicitized manufacturing industries. It is quite plausible that success in services may have a boosting effect on local manufacturing.

Policy recommendations for leapfrogging can also be made for different types of firms with different levels of initial capabilities. We divide the firms in an economy into 'incumbents' and 'start-ups'. The former comprises three types of firms, namely leaders, followers and laggards, depending on their level of capabilities. Path-creating type leapfrogging is more likely to take place in start-ups because they have invested the least in existing modes of technologies or business models. In other words, diverse technologies associated with the 4IR can be a source for product (or business model) innovations; process innovation, on the other hand, is more relevant for incumbents. Leader or follower type firms in emerging economies tend to have some experience with technology and absorptive capacity and are thus likely to be in a position to skip one or several stages, while remaining aware of the risks associated with leapfrogging. Lastly, laggard firms should not attempt pre-mature leapfrogging but should first build some absorptive capacity in their niche area and upgrade by moving up the higher end of the GVC.

Keywords: leapfrogging; window of opportunity; 4th industrial revolution; GVC; path-creating; catch up; technological development.

List of abbreviations

4IR: Fourth Industrial Revolution

AI: artificial intelligence

CDMA: code division multiple access

ETRI: Electronics and Telecommunication Research Institute

GRIs: government research institutes

HD: high-definition

IoT: Internet of Things

IPR: intellectual property rights

NIS: national innovation system

US ITC: US International Trade Commission

TRIPS: Trade-Related Aspects of Intellectual Property Rights

VC: venture capital

WTO: World Trade Organization

1 Introduction

One of the key issues of the economic development of latecomers is whether they should follow the path of forerunners or create a new or follow a different path of development (Lee and Lim, 2001). Early literature (Lall, 2000; Kim, 1980; Westphal, Kim and Dahlman, 1985; Hobday, 1995) observed that latecomers tend to pursue economic development by assimilating and adapting forerunners' obsolete technology. This is consistent with the product life cycle theory (Vernon, 1966). However, the view is emerging (Lee and Lim, 2001; Lee, 2013) that latecomers do not necessarily simply follow advanced countries' path of technological development but occasionally skip certain stages or create their own path which differs from that of the forerunners. This observation is consistent with the idea of leapfrogging (Perez and Soete, 1988), according to which some latecomers may be able to leapfrog older vintages of technology, bypass heavy investments in previous technological systems or stages, and make pre-emptive investments in emerging technologies to catch up with advanced countries in new markets.

Several studies have confirmed leapfrogging or path-creating through case studies of catching up in East Asia (Lee and Lim, 2001; Lee et al., 2005; Mu and Lee, 2005). Here, catching up refers to a substantial reduction in the market share gap between firms in a leading country and those in latecomer or follower countries. A recent article (Lee and Malerba, 2017) and the companion articles published in a special issue of Research Policy examined the cases of catching up of latecomers to determine whether they leapfrogged or not.[1] Many industries have witnessed changes in industrial leadership more than once owing to the successive catching up process by late entrants; this phenomenon is referred to as the catch-up cycle in contrast to the product-life cycle (Vernon, 1966), which only involved changes in factory location but not in leadership.

A common finding from this literature is that successful cases of catching up tend to involve latecomers that do not simply follow the path of technological development of incumbents but skip one or several stages or create their own individual path, although they may tend to imitate and learn from the incumbent at an early stage of catching up. Similarly, Oh et al. (2016) analyse data of patent citations of Huawei and Ericsson to determine whether the latecomer (Huawei) caught up with the incumbent (Ericsson) by developing similar or different technologies than those of the forerunner (Ericsson).[2] The results indicate that Huawei's patents initially tended to imitate those of Ericsson but this reliance eventually diminished and a new path was created that

[1] The special issue on catch-up cycles include cases from various industries, such as cell phones, the memory chip segment of semiconductors, cameras, steel, mid-sized jets and wine.
[2] Developing similar technologies implies that the latecomer is simply attempting to imitate the incumbents, whereas the development of different technologies indicates that the latecomer is seeking to create new technologies and to follow a different technological path or trajectory from that of the incumbents.

diverged from the incumbent's. Thus, the catching-up paradox (Lee, 2019) is that a country cannot catch-up (meaning overtake) if it continues to work on catching-up (meaning imitation). In other words, catching up and overtaking more advanced countries and firms requires the latecomer to pursue a path that diverges from that taken by forerunners.

In his most recent book, Lee (2019) proposes a comprehensive theory of economic catch up, consisting of "late entry→ three detours→ leapfrogging", and views leapfrogging as being the final stage of the catching-up process following several detours to build technological capabilities. The detours, in terms of innovation, include the following: during the first detour, minor innovations are promoted via petit patents rather than high-level innovations via regular patents. In the second detour, firms specialize in short cycle rather than in long cycle technologies, although they would have to shift towards long cycle technologies eventually; in the third detour, while the latecomers would ultimately be highly integrated in the GVC, they must first increase the share of domestic value added in exports, which means less backward participation in GVCs. Taking detours is necessary because of failures in capability and size in latecomer economies and the barrier of IPR protection in the North and the limited space for intervention policy under the WTO regime. According to this theory, leapfrogging is necessary because the detours do not suffice to raise latecomers to the high-income level beyond the middle-income trap.

In other words, leapfrogging often entails the latecomer adopting new technologies ahead of the forerunners, thus actually leaping over them. This is a necessary step to bypass forerunners' IPR, which can be achieved by jumping ahead into new generations of technologies. Thus, leapfrogging is highly likely to succeed when it is executed during a paradigm or generation shift or during an exogenous moment of disruption, which early Schumpeterians, such as Perez and Soete (1988), coined as "windows of opportunity." Finding ways to overcome entry barriers is one of the key motivations for leapfrogging. A window of opportunity is a moment in time in which entry barriers for latecomers recede.

Hidalgo et al. (2007)'s concept of product space and economic complexity does not consider entry barriers and related competition with the incumbent. Latecomers tend to experience difficulties because of entry barriers that exist in many product spaces, and because they have to compete with the incumbents to be able to enter and occupy the product spaces. Hence, in our dynamics of economic catch up, the role of leapfrogging is similar to "flying on a balloon when the conventional ladder used to catch up has been kicked away" (Lee, 2019). As we can only fly balloons under favourable weather conditions, economic leapfrogging only becomes successful when exogenous windows of opportunity become available. Certain preconditions for flying also exist, such as the existence of absorptive capabilities, i.e. possessing navigating skills. Otherwise, we might fall to the ground instead of flying into the sky.

This paper provides an updated review of the literature on leapfrogging. Specific topics to be covered include the following: Section 2 discusses the origins and variations of the concept of leapfrogging, and explores why latecomer economies and firms should aim to leapfrog to reap its benefits as a strategy for technological development. Section 3 reviews the necessary pre-conditions that need to be met to be able to leapfrog and the associated risks and how to manage these. Section 4 identifies the three windows of opportunity that facilitate leapfrogging, such as the emergence of new techno-economic paradigms, changes in demand conditions and institutional windows, including asymmetric regulation and industrial policies.

Section 5 discusses how leapfrogging can be an effective response by latecomers in preparation for the Fourth Industrial Revolution (4IR hereafter) and to achieve the goals of sustainable development, and presents diverse cases of leapfrogging by latecomer economies. Finally, the last section, Section 6, addresses issues of implementing leapfrogging strategies in terms of enabling conditions and policies for leapfrogging, and discusses the prospects of leapfrogging-based development. In the last two sections, policy issues related to leapfrogging are based on the Schumpeterian conceptual framework, the NIS (national innovation system), which entails the relationships between the actors involved in creating, diffusing and utilizing knowledge and innovations, such as firms, public labs, government ministries, financial actors, IPR systems and education systems (Lundvall, 1992). The effectiveness of each nation's NIS determines its innovative and economic performance, and an improper response to innovations is considered a symptom of system failure which leads to the system's malfunction and consequently weak economic performance.

2 What is leapfrogging: origins and variations

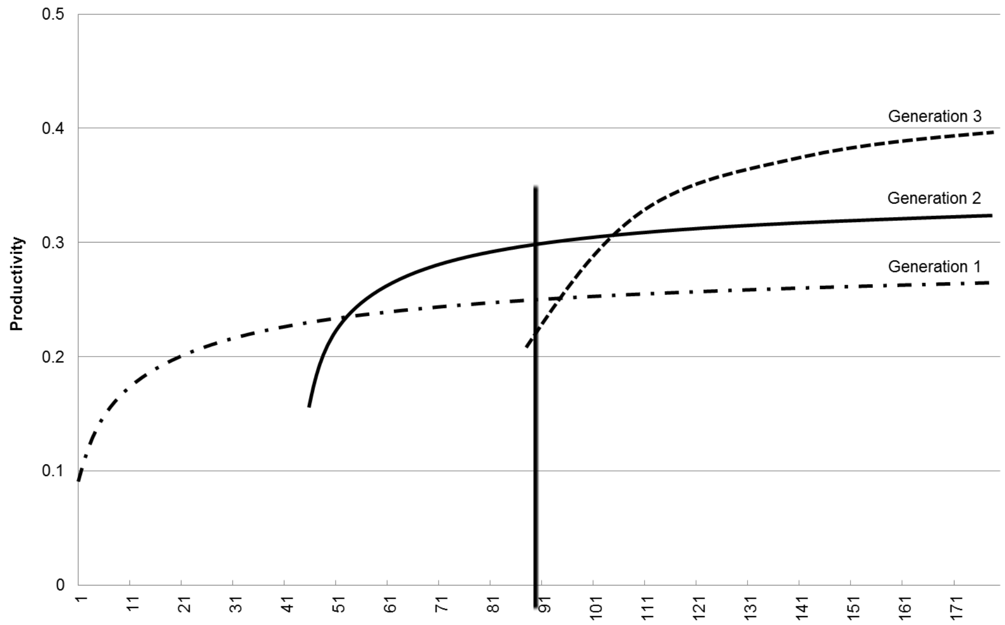
The discussion about the origins of the leapfrogging thesis goes back to the idea of the so-called latecomers' advantage introduced by Gerschenkron (1962; 1963). Such countries only adopt and use technologies after they have matured enough to have standardized capital goods in place suitable for mass production. This approach, however, was limited to catching-up to mature technologies. Freeman and Soete (1997) and Perez and Soete (1988) apply this notion with a focus on the role of the new technological paradigm which brings forth a cluster of new industries. They conclude that emerging technological paradigms serve as a window of opportunity for latecomers, who are no longer locked into the old technological system and are thus able to seize new opportunities in emerging industries.

Perez and Soete (1988) discuss latecomers' advantages in leapfrogging in terms of three factors, namely 1) entry barrier, 2) accessibility of knowledge, and 3) the possibility of lock-in by the incumbents. First, since the necessary equipment to produce new industry goods has not yet been developed, general-purpose machines should be used, i.e. production volume will be low. Therefore, the entry barrier associated with economies of scale do not exist. Second, in the initial stages of a new technological paradigm, the performance of technologies is not stable, which means there are no dominant players. Hence, if only human resources can access the knowledge sources and generate new additional knowledge, the entry by latecomers into an emerging technology might be easier than during a later stage of technological evolution. Third, catching-up countries can be said to be in a relatively advantageous position, as they are not locked into old technologies whereas advanced countries tend to be locked into old technologies due to the sunk costs of their investment.

The idea of leapfrogging started gaining more attraction following the presentation of examples of industries in the Republic of Korea in Lee and Lim (2001). The concept was further elucidated on the basis of the technological development of latecomers, which is described as either path-following, stage-skipping or path-creating. In this respect, *path* refers to the trajectory of technologies and *stage* to the stages within this trajectory. Lee and Lim find that the path-creating and stage-skipping strategies represent two variants of leapfrogging.

Following Lee and Ki (2017), we illustrate these three strategies in Figure 1 which presents the different trends of productivity of technologies of different generations (shown on the vertical axis); the horizontal axis represents time. Let us assume that the current time period is 91 in Figure 1 and that the incumbent firms have adopted the currently most up-to-date, second generation technology, and have thus reached the peak of their productivity. Latecomer firms can pursue three options or strategies to make a late entry.

Figure 1: Leapfrogging and path-following strategies of latecomer firms



Source: Lee (2019: Figure 5-1), taken from Lee and Ki (2017), adapted by Lee et al. (2016)
Notes: Path-following strategy = adopting the oldest (Generation 1) technology
Stage-skipping strategy (leapfrogging I) = adopting the latest (Generation 2) technology
Path-creating strategy (leapfrogging II) = adopting emerging (Generation 3) technology.

The first option for latecomers is the adoption of first generation technologies (i.e. the oldest technology) at the lowest price, that is, to pursue a path-following strategy, meaning the latecomer moves along the previous technological trajectory of incumbents. One advantage of this strategy is that established firms are no longer preoccupied with the consequences of transfers or leakages of proprietary technologies. Old technologies tend to be readily available at low prices, particularly during business downturns. However, given their low level of productivity, late entrant firms cannot compete with incumbents in the same market. Thus, these firms must try to enter a different segment (low end segments).

The second option is for latecomers to implement a stage-skipping strategy, in which the latecomer firm follows the same path as that of incumbents but skips over older generations of technology (Generation 1 in Figure 1) to adopt the most up-to-date technology (Generation 2 in Figure 1); this technology is the same that is being used by incumbents. Thus, fierce competition may ensue between incumbents and late entrants as the latter adopts the most recent technology. Aside from the issue of available financial resources to purchase up-to-date technology, the market availability of such new technologies or the willingness of established firms to transfer such technologies to latecomer firms represents another problem (Lee and Ki, 2017). In this context, IPR-based protection of technologies may be an obstacle to catching up. If the late entrant is successful in resolving the issue of technology transfer or acquisition, it may emerge as a powerful rival of the incumbent because the late-entrant does not only attain the same productivity levels as the incumbent, but also benefits from low labour costs.

The third option for latecomers is to pursue a path-creating strategy. In this scenario, the latecomer explores a new path of technological development based on a new generation of technology. In this strategy, the late entrant chooses an emerging or third generation technology ahead of the incumbent, which is consistent with the idea of leapfrogging as discussed by Perez and Soete (1988). One advantage of this path-creating strategy or leapfrogging is that it focusses on technologies that have a high and long-term potential or productivity as illustrated in Figure 1. However, the risk is that the emerging or new technology is neither stable nor reliable, and that it has low productivity or is associated with high costs at the early stages as shown in Figure 1. Despite the high potential of such emerging technologies, a firm that adopts them will have to bear high costs. Thus, latecomers might incur losses during the initial stage in the market.

According to Lee and Ki (2017), their approach to leapfrogging is consistent with the theory of S-curves (Foster, 1986), which states that the inferiority of a new technology when it first emerges discourages incumbents from introducing it. In this sense, a new technology can represent a trap for the incumbent but a window of opportunity for latecomers that are free from the "replacement effect of new technology" (Arrow, 1962). In other words, incumbent firms tend to disregard emerging technologies that have great potential based on a rational calculation or due to faulty decision-making, remaining complacent with the high productivity of current technologies. Although this decision might be rational in the short run, incumbent firms may lose out to other firms that are willing to take the risk of adopting emerging technologies and achieve higher productivity in the long run, thereby grabbing the market from incumbents.

Interestingly, late entrants or inferior firms with lower productivity levels than leading firms have numerous reasons to quickly shift to new technologies. Latecomers have a greater incentive than incumbents to take a leap of faith and adopt new technologies. Taking such risks, however, usually requires some initial support from the government. Without subsidies or incentives, few latecomer firms will take the risk of adopting emerging technologies because they tend to face low or weak demand during the initial entry stage and therefore face difficulties in achieving the initial production volume that generates some degree of economies of scale.

Thus far, technologies have been treated as exogenous, and firms, particularly latecomer firms, are seen as facing a binary choice of either adopting new technologies or not. Latecomers, however, do not usually only assimilate adopted technologies but also substantially improve them, an approach often referred to *follow-on innovation*, *incremental innovations* or *reinvention* (Lee and Ki, 2017). Rogers (2003) observes that reinvention occurs for numerous innovations and for many adopters at the stage of implementation, and reinvention leads to an increased rate of adoption of an innovation. Following this line of reasoning, we conceive of two types of path creation, depending on whether a new path is created by in-house, endogenous innovation activities of the latecomer, or whether an exogenous or supplier-driven innovation is adopted even before the incumbents adopt it and further improve those technologies. The former path is common in product innovations or IT industries, such as semiconductors, whereas the latter path is found in industries characterized by process innovation, such as the steel industry, and can be termed the *adoption and follow-on innovation mode*.[3]

Another dimension of leapfrogging can be conceived in terms of inter-sectoral and intra-sectoral leapfrogging, depending on whether it takes place within the same sector or across different sectors. Inter-sectoral leapfrogging, to a certain extent, is similar to a "long jump" according to Hidalgo et al. (2007), who argue that latecomer economies must shift to core product space located far away from their current or periphery position. By contrast, intra-sectoral leapfrogging involves jumping across generations of technologies within the same sector. Intra-sectoral leapfrogging is easier or less risky than the inter-sectoral long jump, if latecomers have already built certain absorptive capabilities, such as manufacturing experience, in the relevant industries.

Table 1 summarizes the above discussion on the variations of the concept of leapfrogging.

[3] This observation was suggested by Martin Bell as a comment to the paper of Lee and Ki (2017).

Table 1: Variations of technological leapfrogging

1) Compared with the path of the incumbent (Lee and Lim, 2001) a) Stage-skipping b) Path-creating c) Path-following catch up
2) Two variations of path-creating leapfrogging (Lee and Ki, 2017) a) Follow-on innovation-based leapfrogging b) Radical innovation-based leapfrogging
3) Inter- vs. intra-sectoral leapfrogging (Lee, 2019) a) Intra-sector leapfrogging b) Inter-sector leapfrogging

Source: Author

Why latecomers need it: two reasons

The two reasons latecomers try leapfrogging is discussed in what follows.

One reason for attempting to leapfrog is the possible diminishing of the so-called catch-up effect as the latecomer moves closer to the frontier. At an earlier stage of development, many immediate benefits can be derived by learning from and imitating the practices of forerunner economies as suggested by Lin's theory of latent comparative advantages (Lin, 2012). However, these low-hanging fruits may be depleted, and some economies may need to reach high-hanging fruits with much effort or less marginal benefits. Eventually, an economy may need to grow its own fruits that taste differently from those grown by others and these may taste even better because that economy does not have to compete directly with others.

The above point is related to the concept of the "catch-up paradox" introduced by Lee (2019). The paradox states that "a firm cannot catch up if all it does is to keep catching up" where the former "catch up" means closing the gap between the firm and its target, while the latter "catching-up" means imitating the targets. This makes sense considering that if the latecomer keeps following the same path taken by the forerunners, it cannot easily catch up or overtake them. In other words, the inferior cannot beat the superior if the former fights using the same weapons or strategies. In the old fable, David beat Goliath by using a different weapon instead of engaging in physical contact. Another analogy can be made by referring to Xenon's paradox, which is also introduced in Lee (2019). This paradox relays how Achilles cannot overtake a turtle in a marathon by referring to the gradual exhaustion of the catch-up effect, which is observed as the latecomer moves closer to the target. Therefore, the latecomer must find an alternative path to liberate itself from the exhaustion of the catch-up effect.

The latecomer may also try to take a shortcut. However, this shortcut may become crowded when it becomes known to everyone, thus jamming the latecomer's road and preventing it from reaching the goal. This phenomenon is similar to the so-called adding-up problem (Spence, 2012; Lee and Ramanayake, 2018), in which latecomer economies try to export the same or similar products, thereby flooding the market and ending up with record-low prices. As an alternative, these economies may take detours that may be longer but less crowded than the main road, thereby allowing them to move fast if they have innovation capabilities meaning good driving skills.

The second reason latecomers attempt to leapfrog relates to the barrier of IPR protection by the incumbents against the possible imitation and imitative behaviour by the latecomers (Lee, 2019). Under the auspices of the World Trade Organization (WTO), free trade has been promoted as a vehicle for world economic development. The WTO also regulates and provides guidelines for IPRs through the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement, which is the most extensive multilateral agreement for the global harmonization of IPRs by setting out minimum standards for protection across member countries. One of the impacts of TRIPS is that the level of IPR protection in developing countries has increased, thereby reducing the gap in the level of IPR protection between developed and developing countries by 2005. The impacts of the expansion and enforcement of global IPRs on export growth might differ because developed and developing countries are at different stages of economic development. Specifically, many exporting firms in developing countries tend to incur high costs when they adopt TRIPS obligations, and the strict enforcement of IPR laws in developed countries may curb imports from developing countries because the latter's exports are negatively affected when they are too imitative in nature or are invented around existing products.

According to Shin et al. (2016), the U.S. International Trade Commission (US ITC) has witnessed a fourfold increase in IPR-related disputes against foreign imports over the past two decades and interestingly, a higher number of U.S. firms has complained about IPR violations than about unfair dumping, thus highlighting the increasing significance of IPRs as a measure of trade protection. In fact, the entry of firms from the Republic of Korea into the U.S. market has been marred by patent disputes between U.S. and Korean firms since the mid-1980s. One of the most noteworthy cases is the ban on Samsung's computer chip exports imposed by the US ITC for violating the patent rights of Texas Instruments.[4] A leading high-tech firm from China, Huawei, also had a serious patent dispute with Cisco in 2011, which explains the weak performance of Huawei's main product (telecommunication switches) in the U.S. market.

Although Samsung and Huawei are now huge multinationals with many resources to deal with such disputes, resolving disputes may be a matter of life and death for SMEs as some examples from the Republic of Korea show.[5] If SMEs are entangled in IPR lawsuits, the litigation usually hurts them in a number of ways and not only in terms of sales. Patent licensing fees and marketing channels may be lost during extended litigations. Given these risks, most SMEs are particularly concerned about patent lawsuits, especially during the stage in which they start developing a new technology. In one survey, SMEs in the Republic of Korea's semiconductor equipment sector stated that while the localization of intermediate materials and goods is not difficult (their feasibility is estimated as being "very high" (40.9 per cent) and "high" (59.1 per)), they claimed that "IPR-related legal disputes" (64.3 per cent) represent the biggest obstacle to localization.[6]

The implications of such incidents is that the possibly negative impact of IPR protection levels in the North may be greater for developing countries that are rapidly catching up than for low-income countries with very low technological capabilities, weak export performance or exports that are arranged by inter-firm trade in the form of contract manufacturing and FDIs. This reasoning has been confirmed by the extensive econometric analysis in Shin et al. (2016), who found that as an importing country's IPR level increases, the net marginal effect of technological innovation on exports decreases, especially in the case of exports by countries with technological levels that are currently in the process of catching up. This finding implies that strong IPR protection in the North may act as an obstacle to exports from the South, i.e. for countries currently catching up in terms of their level of technology. In this sense, IPR protection is identified as a source of the middle-income trap (MIT).

Given the fact that IPR protection in incumbent economies and firms has acted as a barrier against the technological catching up by latecomers, this obstacle can be overcome by the latecomer not following the same technological trajectory as the incumbent to avoid IPR disputes, but to create a new path, take a detour or try to leapfrog. In general, this means that the latecomer must eventually make a transition from imitation to innovation. An interesting case in this respect is Huawei, a leading IT company in China.

[4] For details, see Lee and Kim (2010).
[5] These SME cases are taken from Kim and Lee (2009).
[6] A survey conducted by the Center for Corporate Competitiveness of Seoul National University in 2004 (Y. Kim, 2006).

One study used patent citation data to investigate the catching up of Huawei in China with Ericsson in Sweden, and found that Huawei relied on Ericsson as a knowledge source in its early stages of development, and subsequently reduced its reliance and increased its self-citation ratio to become more independent.[7] The investigation of mutual citations (direct dependence), common citations (indirect reliance) and self-citations reveals that Huawei has caught up with or even overtaken Ericsson by taking a different path. Moreover, unlike Ericsson, Huawei developed its technologies by building on recent technologies, resulting in a patent portfolio with short citation lags (which means that its technologies have a short cycle). Huawei also relied heavily on scientific knowledge (so-called non-patent literature), which is a public good free from IPR disputes with the incumbents. The citations in non-patent literature and the patent portfolio with short citation lags imply that Huawei has carried out extensive basic research and maintained up-to-date technologies to accomplish technological catch up, thereby avoiding another patent dispute with incumbent firms.

Overall, the examination of successful catch ups (or cases of overtaking) in East Asia suggests that exploring a technological path that differs from that taken by forerunners presents a possible and viable catch-up strategy for latecomers and, in this sense, a "necessary" condition to overtake the incumbent. This strategy, however, is not a sufficient condition to overtake the incumbent as it involves a higher risk than advancing along a straight yet probably jammed road and may end up in failure or encounter accidents along the way. We examine the issue of risks involved in leapfrogging in the next section.

3 One pre-condition and two risks of leapfrogging

3.1 Precondition for leapfrogging

As discussed in the introduction, leapfrogging is like "flying on a balloon when the conventional ladder used to catch up has been kicked away". One of the preconditions for flying exists, which is that technological capabilities must be built up. Without such capabilities, one may fall to the ground instead of flying into sky. However, it is quite difficult to build up such capabilities as they differ considerably from production capabilities. Thus, although the consolidation of technological capabilities has long been suggested by many as being a crucial component of economic catching up, guidelines for this process are lacking. Lee (2019) suggests three detours when building up such capabilities.

[7] The study of this leading IT company from China is taken from Oh et al. (2016).

Latecomer economies must take detours because of the presence of two failures and one barrier: failure of both firm capability and of size and IPR protection from incumbents in the North. The failure of firm capability refers to the intrinsic difficulty of building up innovation capabilities in developing countries. This type of failure drastically differs from conventional market failure for which R&D subsidies help achieve optimal (or increased) R&D. However, this linkage from subsidies to more R&D is only valid under the hidden assumption that firms are already capable of conducting R&D. Otherwise, i.e. if they lack such capability, nothing will happen, even if incentives or subsidies are increased. A similar criticism applies to the notion that a stronger IPR protection leads to further innovation, which is only true under the assumption that the firm is already equipped with innovation capabilities. Size failure refers to the lack of large businesses in developing countries that are currently dominated by SMEs, which are considered inadequate to lead a country towards a high-income status. The existence of these "two failures and one barrier" has necessitated latecomer economies to explore a new path or detour to build up their innovation capabilities instead of replicating practices employed by advanced economies.

The first detour promotes imitative innovation under a loose IPR regime in the form of petit patents and trademarks instead of promoting and strengthening regular patent rights. The second detour focusses on global value chains (GVCs), specifically a non-linear sequence of the first increased, then reduced and increased GVC. In contrast to Baldwin (2016), who states that increased GVC participation is preferable, Lee (2019) and Lee, Szapiro and Mao (2018) warn against such a linear view. Instead, they propose a GVC-related detour in which an economy should initially learn by participating in a GVC but later reduce its reliance on these chains at a certain point by building increased domestic value chains in sequential entries into high-end segments. Otherwise, the latecomers might remain in low value-added segments, which is a middle-income trap (MIT) symptom. Only after this intermediate stage of building a certain level of domestic value chains can re-integration into the GVC be recommended. The third detour entails specializing first in short-cycle technology-based sectors and products (i.e. ITs) and only at a later stage, in long-cycle sectors and segments (i.e. pharmaceuticals). Long-cycle technologies implies that previous knowledge remains useful and is important for a long period of time. Such technologies act as an entry barrier against latecomers, although they denote high profitability and thus have desirable attributes. Therefore, latecomers are advised to target short-cycle technologies for which entry barriers are low but growth prospects are good due to high innovation frequency that often disrupts the dominance of the incumbent.

In other words, the pre-condition for leapfrogging is to correct the capability failure by providing latecomers with learning opportunities so they can enhance their innovation capabilities. One starting point for a latecomer firm to build up innovation capabilities is to establish its own in-house R&D centre. Independent R&D efforts are necessary because foreign firms become increasingly reluctant to grant technology licenses to emerging latecomer firms, especially when the latter attempts to enter higher value-added or profitability markets dominated by advanced countries. By establishing in-house R&D laboratories, firms can explore diverse channels of learning and access foreign knowledge beyond simple licensing. Accessing foreign knowledge and testing new modes of learning are crucial because isolated in-house R&D efforts are often insufficient to build internal R&D capabilities. A diverse set of alternative modes of learning is available, including co-development contracts with foreign R&D specialist firms and/or with public R&D institutes, mastering the existing literature, establishing overseas R&D outposts and initiating international mergers and acquisitions (M&As).[8] For example, since the early 1990s, a small number of firms in the Republic of Korea began establishing overseas R&D posts to obtain easy and fast access to foreign technologies that cannot be easily acquired through licensing.

Only after building a certain level of technological capabilities during the detours do latecomer firms get ready to take the risk of attempting to leapfrog.

3.2 The two risks involved in leapfrogging

An early paper (Lee et al., 2015) identifies the following two risks associated with leapfrogging. The first risk is choosing the appropriate technologies out of several possible emerging technologies. The second risk is how to create the initial market after the technology for producing the new goods has been selected.

In the early stage of a new technological paradigm, alternative technologies tend to be available, among which one dominant or successful technology eventually emerges in later stages. If the catching-up country invests in the wrong technologies, the country will fail to gain returns from its investments. Moreover, even after the catching-up country becomes successful after having chosen the right technology, it still needs to be successful against other competitors from advanced economies. The two risks and how to mitigate them are discussed in the following section, using the example of the classical case of leapfrogging in the Republic of Korea's TV manufacturer (Lee et al., 2005) and in the country's cell phone production (Lee and Lim, 2001).

[8] For details on these diverse learning modes, see Chapter 3 Section 2 of Lee (2019).

The risk of choice over alternative technologies

When the Republic of Korea’s TV manufacturers decided to enter the high-definition (HD) TV technology segment, they faced tough choices regarding technology standards. Initially, they were heavily influenced by the Japanese leaders in analogue HD TV. A group of Japanese firms arrived in the Republic of Korea during the 1988 Seoul Olympic Games and staged a promotional tour of their achievements in analogue HD TV. Recognizing that HD TV would be the next generation hot consumer item with tremendous technological and market potential, the Government of the Republic of Korea established the Committee for Co-development of HD TV in 1989 with the participation 17 institutions comprising private firms, GRIs (government research institutes) and universities.

One year after the Republic of Korea initiated the project, GI in the United States, a leading firm in digital TV technology, staged a historic demonstration in 1990 of the possibilities of digital TV. The Republic of Korea’s team consequently decided to target digital HD TV instead of the Japanese developed analogue HD TV. The U.S. standard had not yet been determined at that time. One interesting strategy of the Korean consortium was the decision to develop several alternative standards simultaneously, with different private companies assigned to monitor and follow different standards. This strategy can be described as a ‘parallel mover’ strategy in comparison with the first mover strategy. Immediately after the so-called ‘grand coalition’ had agreed on a common standard for digital TV, the Korean firms became first movers in terms of producing the first digital TVs compatible with the common standard in the U.S. markets.

In terms of access to foreign knowledge, Korean firms closely monitored the technological activities of GI and other leading firms in the United States. As early as September 1989, Samsung established an R&D team for digital TV and a U.S. branch (AML: Advanced Media Lab) in Princeton, New Jersey. LG acquired a share of 15 per cent of Zenith, a U.S. company whose core technology was in digital TV, as early as 1990. LG eventually acquired 100 per cent of Zenith’s equity shares and was able to use the patented technology without worrying about patent violations.

Another case of leapfrogging by the Korean consortium was cell phones, which was a private–public collaboration. At the time Korean firms and the government authorities considered entering this segment, the leader was the U.S firm Motorola, and the analogue system was dominant in the United States, while the TDMA-based GSM system was the dominant in Europe. The authorities of the Republic of Korea (i.e. the Ministry of Information and Telecommunication) focussed on an alternative initiated by Qualcomm, namely code division multiple access (CDMA) technology characterized by higher efficiency in frequency utilization and higher quality and security in voice transmission. Thus, despite the considerable uncertainty associated with the development of the world's first CDMA system as well as strong reservations expressed by telephone service providers and private manufacturers (e.g. Samsung and LG), the Ministry and the Electronics and Telecommunication Research Institute (ETRI) decided to spearhead CDMA by forging an R&D alliance with Qualcomm. One of the main reasons for this decision was the consideration that if the Republic of Korea simply followed the already established standards, the gap between the country and its forerunners would never close and catching up would take even longer. Thus, the Republic of Korea chose a shorter but riskier path.

The Korean government designated the development of the CDMA system as a national R&D project as early as 1989. In 1991, a contract to introduce the core technology and develop the system together with the U.S.-based Qualcomm was concluded. The Ministry declared that CDMA was to become the national standard in telecommunications in 1993. Given the high frequency of innovation and the high fluidity of the telecommunications industry, latecomers were afraid to take the risk of investment in R&D. The expected profits and other related gains from first-mover advantages served as a strong motivator, and the high risks were shared with the government-led R&D consortium and the knowledge alliance with Qualcomm. The ETRI also contributed to reducing technological uncertainty by providing accurate and up-to-date information on technology trends and by identifying appropriate R&D targets that were more promising than the alternatives.

The risk of finding the initial market

To mitigate the second risk associated with the existence of initial markets, the importance of standards must be emphasized, which is a critical factor for product innovations to be successful on the market, in particular digital technologies. An isolated development of information or other emerging technologies without paying attention to the issue of standards might lead to a failure of the entire project. In standard setting, collaboration and establishing partnerships with competitors or suppliers of complementary products is important. Who creates product innovations and who breaks in and sells to the market first is also important, as the size of the market determines the success or failure of one standard over another. In this competition for standard setting and market creation, the government can play a role in facilitating the adoption of specific standards and thereby influence the formation of markets at the right time.

Implications: public-private R&D consortia and the incumbent trap

The cases of digital TV and mobile phones in the Republic of Korea demonstrate how the emerging new technological paradigm can serve as a window of opportunity for catching-up firms.[9] A long list of success stories of the public-private R&D consortium, from digital telephone switches to memory chips (D-RAM), wireless phones (CDMA), and finally digital TV in the Republic of Korea confirms the positive role of the government and the GRIs in the technological catching-up of latecomer firms. The private firms that participated in the public-private consortium acknowledged the important function of the government in providing legitimacy to these large projects which private firms would not be able to execute on their own. The consortium pooled together domestic resources from various sources, especially universities. The contribution of public research laboratories was also critical in performing the role of 'technology supervisor', interpreting and monitoring state-of-the art trends of R&D activities in foreign countries.

The reasons why Japanese digital TV manufacturers became laggard compared to those from the Republic of Korea can be discussed against the backdrop of the concept of the incumbent trap. Japan had been locked into 'analogue' HD TV since the late 1980s when it created the first HD TV system. Although the Japanese government attempted to shift to digital TV in 1994, the effort was stifled by firms that had invested heavily into analogue HD TV. This early start and lock-in by Japanese manufacturing firms demonstrates the disadvantages and risk of being a technological pioneer, exemplifying the so-called innovator's dilemma proposed by Christensen (1997). Japan was the forerunner in terms of HD TV initiatives, but it followed the trajectory of analogue technology. However, Japan's success turned into failure when the United States and other countries accepted digital TV as their new standard, and when latecomers decided to follow this trajectory. This case clearly demonstrates that a shift in technological paradigm can actually punish the leader while serving as a window of opportunity for latecomers who use complementary assets to exploit a new technological opportunity.

4 Three windows of opportunity for leapfrogging

The preceding sections described how latecomers successfully leapfrogged ahead of the forerunners, leaping over them. Leapfrogging is highly likely to succeed if it occurs during a shift in paradigm or generation or during exogenous moments of disruption, which early Schumpeterians, such as Perez and Soete (1988) coined "windows of opportunity." A window of opportunity is a moment in time in which the entry barriers for latecomers recede. Latecomers

[9] These implications are also explained in Lee et al. (2005).

tend to experience difficulties because of entry barriers that exist in many product areas, and because they have to compete with the incumbents to be able to enter and occupy product space. Thus, in our dynamics of economic catch up, the role of leapfrogging is similar to "flying on a balloon when the conventional ladder used to catch up has been kicked away." As we can only fly balloons under favourable weather conditions, economic leapfrogging is only successful when exogenous windows of opportunity are available.

The concept of leapfrogging has also been applied within the theoretical framework referred to as "catch-up cycles" developed by Lee and Malerba (2017), which covers successive changes in industrial leadership. Many industries have witnessed changes in industrial leadership more than once by the successive catching up of late entrants. The incumbent often fails to maintain its superiority in production or market shares, and a latecomer eventually catches up with the incumbent. The latecomer gains leadership but eventually loses it to another latecomer. In addition to the lead article by Lee and Malerba (2017), sectoral studies have been carried out to explain these phenomena and have been collected in a special issue on catch-up cycles published in Research Policy. The cases studies examine various industries, such as cell phones, the memory-chip segment of semiconductors, cameras, steel, mid-sized jets and wine.

The framework of catch-up cycles is related to, but different from, the notion that Vernon's (1966) product life cycle theory. The latter theory cannot explain the phenomenon of leadership changes because it only focusses on the location change of factories from advanced to developing countries, and leadership is assumed to remain within the firms from advanced countries. The catch-up cycle concept is based on Schumpeterian notions of innovation systems applied at the sector level and on the evolution of these systems over time.[10] Such systems may be affected by several discontinuities. These discontinuities are called windows of opportunity and refer to the role of the rise of new techno-economic paradigms in generating leapfrogging. These windows of opportunity can be extended to additional dimensions that correspond to the building blocks of a sectoral system, such as changes in demand conditions or in the government's regulations and policies.

Three types of windows of opportunity may be opened for late entrants to take advantage of. One is the rise of a new techno-economic paradigm that tends to threaten the advantage of existing first movers or incumbents who were involved in capital investments into the old technologies. When a new paradigm emerges, latecomers and incumbents find themselves at the same starting line with the new technology. Incumbents may fall behind by clinging to old technology, which

[10] For the concept of the national systems of innovation, see Freeman (1987), Lundvall (1992), Nelson (1993), and for the SSI, see Malerba (2002, 2004) and Malerba (2005).

initially catapulted them into a dominant position. The propensity of incumbents to remain in the old paradigm for a prolonged time makes sense considering their heavy investments into the old technology and their superiority. Incumbents want to fully recover their investment costs. Depending on the situation, instead of making a full scale techno-economic paradigm shift, a mini-paradigm, a new generation of technologies or a new trajectory can represent such a window of opportunity.

The second type of window of opportunity is derived from the secondary components of SSI (i.e. demand conditions or market regimes), that is, a business cycle and/or abrupt change in market demand, including the rise of new consumers. Mathews (2005) asserts that business cycles create opportunities for challengers to rouse the industry as downturns play a cleansing role. Weak players are thus often forced into bankruptcy, and resources are released at low prices and acquired by challenger firms seeking to enter the industry. These demand changes can be intrinsic to the industry but exogenous to the firms (e.g. the short-term cyclical behaviour of prices in the IT industry, such as memory chips and panels).

The third type of window of opportunity can be opened by the government. This opportunity usually creates an asymmetric environment for incumbents and entrants through a range of regulations and support measures for entrants. Latecomers can utilize such asymmetries to offset initial cost differences associated with late entry.

Although the three types of windows of opportunity are assumed to be events that are often exogenous to latecomer firms, they need to recognize and take advantage of these open windows if they are to realize their potential. In other words, together with the notion of windows of opportunity, the catch-up cycle framework also uses the concept of "responses" by firms and the systems at the sectoral or national levels. A few firms from emerging countries and the sectoral system supporting them may respond to the opening of windows and successfully catch up or rise in the local or global market. Current leaders from a given country may fall behind due to a lack of effective response by the firm and sectoral system, as is the case of the "incumbent trap", leading to misalignments with the new window. The gist of the theory is that diverse combinations of windows of opportunity and the responses of firms by latecomers and incumbents determine the pattern of successive catch ups that most likely emerge in a given sector.

Two industry cases

One or more windows may open in a single sector during its evolution. Some examples from different sectors are presented here, starting with a case study from the steel industry. The **steel** industry has witnessed two leadership changes (Lee and Ki, 2017). The first change was from the U.S. to Japan in the late 1970s and early 1980s, and the second from Nippon Steel in Japan to POSCO in the Republic of Korea during the late 1990s.

The leadership shift from the U.S. to Japan in the steel industry entailed technological and institutional windows of opportunity, but not the demand window. Japanese firms immediately adopted the Austrian innovation of the basic oxygen furnace method (BOF), which they further improved through follow-on innovations (Yonekura, 1994). The Japanese government was also involved by coordinating the collective licensing of BOF for significantly reduced royalty fees (Nakamura and Ohashi, 2012). By contrast, U.S. firms fell into an incumbent trap by continuing to stick to the existing methods (OHF).

The downturn in the global steel industry provided a window of opportunity for POSCO, a latecomer Korean steel company. POSCO first initiated a gradual catch up process from the low-end segment, adopting a path-following strategy of importing mature technologies from Japan, and consequently switched to the stage-skipping strategy to forge ahead by adopting up-to-date technology and capitalizing on downturns. The demand window in this case was significant because POSCO purchased state-of-the-art technologies at considerably lower costs as a result of the global recession in the 1980s (D'Costa, 1999). POSCO also benefited from the institutional window that was present because the government participated in indicative planning for the growth of steel-consuming sectors, such as the shipbuilding and automobile sector. Eventually, POSCO outperformed its "teacher" firm, Nippon Steel of Japan in the late 1990s.

The case of POSCO demonstrates that not an upturn but a downturn in the business cycle can be a window of opportunity that allows latecomers to purchase and install state-of-the-art technologies at lower costs because of the downturn. The role of downturns was also noted in the case of semi-conductors in a study of Shin (2017), which found that Japanese firms (in the 1980s as late entrants following U.S. firms) and later Korean firms (in the 1990s as late entrants following Japanese firms) invested heavily during the downturns, while the incumbent firms were more cautious in terms of investing.

It is also worth looking at the case of cell phones. Giachetti and Marchi (2017) found that leadership changes in the cell phone industry occurred twice, with an interval of 14 years. The first change occurred in 1998, when Nokia and its digital cell phones dethroned Motorola, which had invented analogue cell phones. The second leadership change took place in 2012, during the transition from regular cell phones to smartphones, when Samsung, together with Apple, dethroned Nokia in terms of market shares.

In both cases of leadership change, technological progress opened the most significant window of opportunity for firms in the cell phone industry. The emergence of digital technology was the window of opportunity in the transition from Motorola to Nokia, while the change from regular phones to smartphones was the significant window of opportunity in the transition from Nokia to Samsung. Unlike previous mobile operating systems, such as the Symbian of Nokia, the Android OS of Google was custom-built to support the touch interface that gained popularity among consumers. The first mobile phone vendor that incorporated the Android OS was Samsung. The demand window was considerably important during the first change in leadership from Motorola to Nokia because the number of individual phone users increased instead of the number of business users; moreover, the institutional window in the form of exclusive support from the EU for digital GSM standards compared with the U.S., which supported multiple standards. In the transition from Nokia to Samsung, the role of demand and the institutional window were unclear during the stage of forging ahead in 2000, whereas the entry and gradual catching up of Samsung in the 2G era in the 1990s was facilitated by the regulatory intervention of the Korean government, which established the CDMA as the exclusive standard in the Republic of Korea's market.[11]

In general, the stories of catching up in several industries (Lee, 2019) suggest that although the path-following strategy based on initial factor-cost advantages may promote a gradual catching up of late entrants in terms of market shares, a sharp rise of their market share is more likely to occur with a shift in technologies or demand conditions (particularly downturns). These shifts are facilitated by variants of leapfrogging, either path creation or stage skipping by latecomers. Decisive investments in opening new windows irreversibly changes the leadership of the industry, resulting in a forging ahead, which pushes the old incumbent to the back of the line. Windows are always likely to open because generations of technologies and business cycles change frequently. Therefore, leadership changes and catching up by latecomers will very likely occur repeatedly. A leader will decline not only as a result of the rise of latecomers but also due to "falling into the incumbent trap". That is, leaders tend to be complacent with their current success and therefore pay less attention to the emerging technological or market paradigm, including new types of consumers.

[11] See Lee and Lim (2001).

5 Leapfrogging in the 4th Industrial Revolution and Sustainable Development

5.1 Leapfrogging in the Fourth Industrial Revolution

With the arrival of the 4th Industrial Revolution (4IR) first mentioned by Schwab (2016) at the 2016 World Economic Forum, the question and challenge today is whether the next generation of latecomer economies can also use manufacturing as a path to prosperity. The 4IR refers to the new waves of innovations consisting of several technologies such as 3D-printing, IoT (Internet of Things), AI (artificial intelligence), smart cars, big data and on-demand economy (sharing economy), and can further include smart health, renewable energy and VR (virtual reality) technologies.

In other words, the existing mode of economic catch up faces many challenges with the arrival of the 4IR in several aspects (Lee et al., 2019). First, the 4IR is re-writing the rules of manufacturing. As the cost of automation plummets, low-cost labour is a less effective strategy to attract manufacturing investments. Second, with the 4IR, we are potentially witnessing the beginning of a trend towards re-shoring of manufacturing back to developed countries (e.g. Apple and Adidas). Third, some expect global supply chains will become flatter and more regional or national to reduce delivery times and to make manufacturing more responsive to local preferences and local demand conditions. This potentially reduces the level of economies of scale required to produce for the whole world.

The response of latecomer economies to these challenges will determine their eventual economic fortune. Those capable of developing innovations can take advantage of the 4IR as a new window of opportunity (Perez and Soete, 1988) while those unable to do so will fall behind (destruction) and get stuck in the low-income or middle-income trap (Lee, 2013). In Schumpeterian economics, the 4IR can also be perceived as the arrival of the new techno-economic paradigm, and could thus also be a window of opportunity for latecomers to leapfrog. At present, the majority of 4IR technologies tend to be initiated not by latecomers but by advanced economies, and the response of latecomer economies has been slow or has taken place on a smaller scale (ILO, 2016a). To the extent that this is true, the 4IR seems to be a counter-attack by incumbent countries against the recent catching up of latecomers, in particular against those in East Asia. In other words, the incumbents and latecomers are not standing at the same start line; the former have already departed from that line, leaving the latter behind once again.

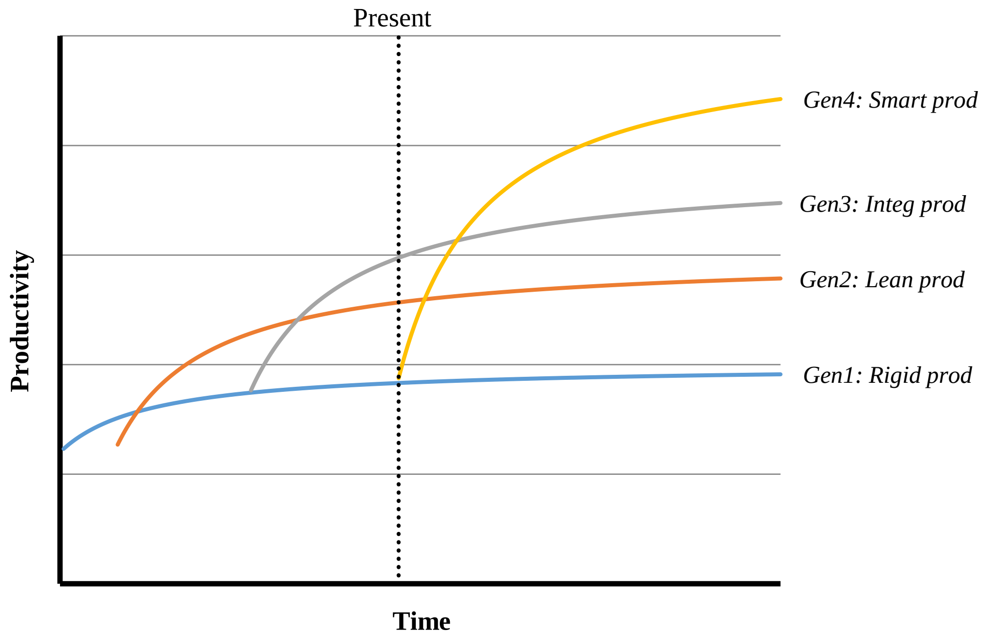
Despite this assessment, it still seems necessary to explore the possibilities of the 4IR becoming a window of opportunity for latecomer economies and how they can prepare for the 4IR so as to not get stuck in the development trap. In general, we do not think that it is too late to take action, but that there is still some time left to respond and to take strategic action. Ideally, while the 3IR was a window of opportunity for first tier Asian economies, there is a possibility for 4IR to assume this role for the next tier latecomer economies.

Another dimension of the window of opportunity associated with the 4IR are start-ups and young SMEs versus incumbent firms in emerging economies. In other words, the 4IR can represent a new window of opportunity for start-ups and young SMEs more so than for incumbent firms in emerging economies in the sense that the latter are more likely to be locked in, or to be complacent with existing technologies or business models or to display inertia-type of behaviour and take a lukewarm attitude towards new technologies. By contrast, new firms have no or less sunk investments in old or exiting modes of technologies and business models and are thus more inclined to try or to switch to new technologies and business models.

Given that the scope of 4IR is very broad and that many of the related technological revolutions do not take place in developing countries, a flexible definition of the 4IR can be adopted. In this context, the concepts of Industry 3.0 (automation) and Industry 4.0 (smart factory) are more relevant for countries with a manufacturing base. In fact, typical factories in developing countries are at the stage of Industry 2.0 or at the mass production stage, and thus even automation (Industry 3.0) is not very advanced, let alone the transformation to a smart factory or Industry 4.0 (ILO, 2016a and ILO, 2016b). In general, the 4IR is expected to expedite the transition from mass production (Industry 2.0) to automation or the leapfrogging to the smart factory system (Industry 4.0).

This idea of leapfrogging in the 4IR era is illustrated in Figure 2. The four generations in the figure can either refer to Industry 1.0 to Industry 4.0 or to rigid production, lean production, integration production and smart production, respectively, which are discussed in Ferraz, et al (2019). Following the logic discussed in Figure 1, a latecomer’s industry can jump from either rigid or lean production to the last generation of smart production.

Figure 2: Leapfrogging in the 4IR



Source: Adaption of a figure from Ferraz et al. (2019)

Notes: Generations 1 to 4 refer to rigid production, lean production, integration production and smart production, respectively (Joao Ferraz et al., 2019), or Industry 1.0, 2.0, 3.0, and 4.0, respectively.

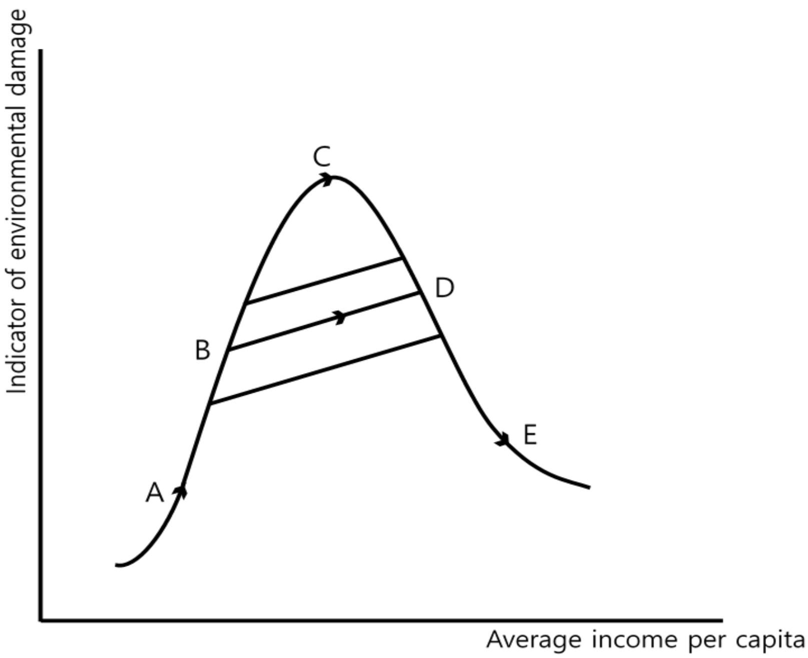
Even if we take the option of leapfrogging, it must be carefully managed because it comes with both potentials and risks (Lee et al., 2005). As discussed in the preceding section, the primary risk is the choice of appropriate technologies or standards. For instance, in the case of 5G, we are observing the emergence of multiple standards. While firms in the Republic of Korea and the U.S. are ready to launch the first worldwide 5G services and the accompanying cell phones, differences in the specifications of standards exist. While Korean firms, including Samsung and LG, are preparing to produce full-scale 5G-compatible phones, Verizon and Motorola plan to launch LTE phones that can be used with 5G module chips. By contrast, Chinese firms, like Huawei, will reportedly opt for a different standard, the so-called 5G Advanced, which is supposed to be a further improved version of the 5G products first released in 2019. The possibility of diverse 5G standards might affect firms' choices which plan to launch new products or services associated with 5G, such as health-related wearables, autonomous driving solutions and products, drones and other IoT-based products and services in smart factory systems.

An ILO study also illustrates both the opportunities and threats of robotics and automation. It finds that robot-based automation is basically "human centric", occurring in the form of collaborative robots or "cobots", able to perform repetitive, high precision and difficult tasks, and such automation assists workers rather than to replace them (ILO, 2016a). Thus, the ILO's report determined that people still exceed the capabilities of robots in overall assembly, perception, flexibility, dexterity and adaptation to new duties, which means human workers are (for now) more cost effective. However, the threats should not be underestimated because predicted uptakes in 3D printing, the displacement of lower skilled packaging and assembling jobs is possible.

5.2 Leapfrogging for sustainable development

Another impetus for leapfrogging can be discussed in terms of the global consensus on sustainable development. In this regard, leapfrogging can serve as an effective way of shifting to an environment-friendly, sustainable mode of development (Lee, 2019). Figure 3 presents the Environmental Kuznets Curve, where the degree of environmental damage is measured along the vertical axis, the horizontal axis represents per capita income. According to this curve, increasing environmental damage is expected with the initial rise of per capita income. The environmental damage can be mitigated after a certain point of growth in the income level. Given this path of the forerunner economies, if all current latecomer economies continue to follow the path of the existing economic model of growth, the global goal of reducing carbon emissions will be impossible and the environmental impact will be substantial. A better alternative would be to skip an intermediate stage, such as Point C, by jumping or leapfrogging directly to Point D from point B. With a proper composition of economic activities and the use of better technologies, such leapfrogging becomes possible.[12]

Figure 3: Leapfrogging and the Environmental Kuznets Curve



Source: Redrawn by the author following the graph in Jackson and Roberts, 2000: copied from Figure 7-1 of Lee (2019)

[12] This remark was also made in Lee and Mathews (2013; 2018).

If advanced countries' path is blocked by "carbon lock-in" (excessive dependence on fossil fuels), then latecomer countries can bypass such blockages by leapfrogging to cleaner and greener technologies. Mathews (2017; 2018) refers to this alternative as "green development," based on the green industrial system free from fossil fuels and extensive resource throughput. In fact, a green window of opportunity has been opened up with the rise of various renewable energy technologies such as the production of solar panels, wind turbines, new smart grid devices, electric vehicles, recharging stations, etc.

Thus, in light of this green window of opportunity, late latecomers (economies other than those East Asian economies that have already achieved significant strides in terms of catching up) are in a good position to attempt to leapfrog into an environment-friendly trajectory of development. Such leapfrogging requires the pre-existence or building up of a certain level of capabilities.

In what follows, we discuss several examples of leapfrogging by latecomer economies to further explore the possibility of leapfrogging as a key latecomer development strategy for the 21st century.

5.3 Cases of leapfrogging in latecomer economies

In a specific context and under certain conditions, such as the availability of foreign assistance, access to knowledge and/or funding, latecomers can attempt to leapfrog into newly emerging industries, such as renewable energy or a broad spectrum of technologies associated with the 4IR. In what follows, we discuss several cases of leapfrogging in latecomer economies.

Two cases from China

Solar thermal technology is an alternative source of energy in the search for low carbon energy solutions. However, its diffusion has been slow or ineffective. By contrast, China has achieved notable success, especially in rural areas, more so than in urban areas (Zhou et al., 2012).[13] Solar thermal technology in China was developed as early as the 1980s, as a result of the R&D project carried out by the Tsinghua University as part of China's national R&D initiatives. After the university disclosed the vacuum tube patent so that the technology could be easily transferred to the manufacturing sector, the scale of production increased significantly. The interesting aspect of this story of market expansion is that it did not succeed in urban areas due to the mismatch with the existing urban architecture but succeeded in rural areas. In other words, compared to gas and electric thermal systems which are already installed in cities, solar thermal systems that only function for six months out of the year are not attractive for urban residents. By contrast, solar

[13] This case is taken from Lee and Mathews (2013; 2018).

thermal systems in the rural market are successful because rural buildings tend to have a more simple structure which can be rebuilt by the individual owners who care more about the structure's practical utility and less about appearance. Most importantly, compared to no hot water at all, six months of hot water supply is highly attractive for residents living in rural areas.

The case of solar thermal energy in China indicates that rural areas have bypassed the stage of gas- or electricity-based heating and leapfrogged into the stage of solar thermal-based heating. It also indicates that not only the supply side (technology), but also a relative match or mismatch with the demand side can represent a source of leapfrogging. Solar water heaters imply a huge disruption of the lifestyle of wealthy or urban residents as they know it, whereas under-developed areas did not have such a high degree of lock-in which made them more receptive towards alternative energy systems.

A case directly involving 4IR technologies can be mentioned here as well, which can be considered a case of broadly-defined leapfrogging, namely the case of Deep Glint, which is one of the leading intelligent IoT technology companies located in Beijing, China. It was founded by Zhao Yong in April 2013, who used to be a senior researcher at Google's research institute and was one of the key members of the R&D team for Google Glass.[14] Deep Glint was started as a high-tech camera and advanced security system company using computer vision to help monitor crowds. Currently, the company uses advanced AI (artificial intelligence) technology to create products and services at low cost and it can thus be deployed on a large scale. In 2018, Deep Glint belonged to the top 30 list of Chinese artificial intelligence (quasi) unicorns and to the top 100 Most Emerging Growth Enterprises list. It is a very technology-intensive company, with an increasing number of patents; by the end of 2018, Deep Glint had obtained 13 invention patents, five utility model patents, three design patents and ten software copyrights.

Given its original focus on face recognition technologies, its future growth seems to be in autonomous driving which requires AI-based technology to monitor a large number of moving objects. This may be the reason why this company received an equity investment from Hyundai Motor Company. So far, it has completed the first two stages (A and B) of venture capital funding with the amount of investment for each stage amounting to over CNY 18 million.[15] Before the company received private investments, it was supported by several Chinse government

[14] The basic information about this company is from the company website, http://www.deepglint.com/aboutus.
[15] Source: https://www.crunchbase.com/organization/deep-glint#section-funding-rounds and https://pulsenews.co.kr/view.php?year=2019&no=151329.

programmes, such as the Torch Program and the Start Entrepreneur Program, which targeted, among others, the AI industry.

Using IoT technologies for fish farming in Indonesia

Founded in 2013, eFishery is one of the first "fishtech" start-ups in Indonesia. It provides an Internet of Things (IoT) solution for fish and shrimp farming businesses. According to eFishery, feeding costs account for around 80 per cent of total fish farming expenses but feeding is inefficiently carried out by unskilled labour with no control or supervision.[16] Thus, eFishery created a device that enables automated feeding of stock in fish farms, which results in reducing feeding costs, better feed performance, fish growth, water quality and eventually a multiplication of the profits of fish and shrimp farmers. On average, the company's smart feeding device helps reduce the amount of feed used by farmers by around 21 per cent.[17]

eFishery's device consists of hardware and software, including several sensors to monitor fish movements and ripples in the ponds. In this sense, it is a manufacturing company. If the sensors detect certain motions, the feeders identify that the fish are hungry and agitated, and dispense food accordingly. Farmers can watch the entire process in real time on their smartphones and even adapt the system to their needs. The device also collects information on fish behaviour and farm production patterns, which eFishery utilizes to improve its products and to create more solutions for the aquaculture industry.

It took several months for eFishery's business to flourish. The company ranked first in two Indonesian start-up competitions. At a price of USD 975 per piece, eFishery sold 140 units in only seven months between February and September 2014, with a total revenue exceeding USD 100,000.[18] In 2015, the company had sold its product to over 17,000 fish and shrimp farms.[19] Its profits in 2018 were 261 times higher than in the 2016–2018 period. These initial successes helped the company raise USD 5.2 million in total funding to date.[20]

eFishery could have a major impact on Indonesia's aquaculture industry. The company's product can help enhance the lives of more than 3.3 million Indonesian fish farmers (FAO, 2018). With 3.3 million fishponds and 2.7 million fish farms, Indonesia's aquaculture machinery is a million dollar industry, i.e. the huge impact of eFishery has not yet been registered. The company's

[16] eFishery's website at https://efishery.com/en/home/; also https://www.techinasia.com/this-startup-is-building-smartphone-powered-fishtech-for-indonesias-commercial-aqualife
[17] https://www.techinasia.com/indonesia-startup-efishery-funding-news
[18] https://www.techinasia.com/this-startup-is-building-smartphone-powered-fishtech-for-indonesias-commercial-aqualife
[19] https://www.techinasia.com/indonesia-startup-efishery-funding-news
[20] https://www.techinasia.com/indonesian-aquaculture-startup-efishery-nets-4m-funding

products are currently being used in thousands of farms in 16 provinces and 67 cities/districts in Indonesia, from Maluku to North Sumatera. The company has also received orders from Singapore, India, Thailand, China, Brazil, and some countries in Africa, and is operating pilot projects in Bangladesh and Viet Nam as well. The future aim of eFishery is to become a platform that connects the entire ecosystem of fish and shrimp farming, creating a more accountable and profitable industry across the region.

Biofuels in Brazil [21]

Brazil has been able to build an urban private transport system based largely on home-grown and processed ethanol and (now) biodiesel. Brazil developed its bioethanol programme in the 1980s by utilizing its own domestic resources (sugar cane plantations fed by rainfall without the need for irrigation) and technology. Through the National Alcohol Programme dating back to the military dictatorship of the 1970s, a market for ethanol was mandated as a means to save oil imports. Domestic producers as well as local suppliers of equipment (such as Dedini) were supported, thus creating an entire value chain on the supply side. On the demand side, there was initial resistance because cars had to be either ethanol-adapted or conventional, and consumers who switched to ethanol-only vehicles in the 1980s paid the price when the global price of oil fell and ethanol became non-competitive. In the 2000s, Brazil’s ethanol programme was revived with strong government support for the national oil company Petrobras, and with the demand-side innovation (developed in Brazil) of flex-fuel vehicles, which could run on ethanol, gasoline or any combination of the two.

The success of Brazil’s bioethanol programme (now being replicated for biodiesel) is not a conventional story of the import of products, followed by the import of equipment and insertion in global value chains in order to access technology. Rather, Brazil was already a sugar producer at the world frontier in terms of technology and a world leader in terms of costs – and was able to carry these initial advantages over to the production of ethanol. Technology for ethanol production was initially imported and rapidly domesticated (leading to the establishment of domestic equipment suppliers such as Dedini) and then rapidly diffused through the R&D efforts of the national R&D institution, EMBRAPA. This was the body (equivalent to ITRI in Taiwan ROC) that monitored global technological developments, and utilized advanced technological methods to research Brazil’s sources of comparative advantage, e.g. soils suitable for sugar cane cultivation revealed by satellite surveillance. But these advantages inherent in Brazil would have been reduced to naught had it not been for strong government support in mandating a steadily

[21] This case is originally from Lee and Mathews (2013; 2018).

increasing market share for domestically produced ethanol, and the role of the national oil company Petrobras in acting as the primary distributor of ethanol through pipelines and terminals and fuel outlets across the country. Now Brazil is building an entire value chain for production of first-generation ethanol as well as creating companies to usher in the second generation (in competition as well as collaboration with U.S. and European firms).

Cases from Africa

Several cases of leapfrogging exist in Africa as well.[22] One notable example is the M-Pesa in Kenya, which serves as an efficient and convenient mobile banking and payment system for Africans without access to offline banking.[23] M-Pesa's creators were looking for a way to apply their mobile payment system to resolve other problems. They established another company M-Kopa Solar to provide solar energy to rural households in Africa. M-Kopa Solar uses three readily available technologies, namely solar generation and low-energy LED lights, mobile payments similar to M-Pesa and the SIM cards embedded in the M-Kopa control unit. The innovation introduced by M-Kopa is packaging these technologies and combining them with a mobile payment system, thereby providing solar energy products at affordable prices. M-Kopa is an effective off-the-grid solar system for Africa, with poor land-based infrastructure and frequently erratic electricity supply. M-Kopa enables children in rural area to study after school and relieve residents from the burden of fetching firewood and burning kerosene late into the night. M-Kopa has leapfrogged out of kerosene-based lighting, bypassing grid-based electricity and into off-grid renewable energies. This system is an innovation not only in technological terms but also in terms of business models adapted to African conditions.

Another example of leapfrogging from Africa is the use of solar power in desert grasslands in rural areas in Jigawa, Nigeria (Lee and Mathews, 2013). This semi-desert area has no water supply. The traditional option was to open wells with ropes and buckets, hand pumps or government-supplied diesel-powered pumps that were operational until they broke down or until villagers ran out of money and could no longer afford the expensive diesel. This problem was resolved using solar-powered pumps designed to run maintenance-free for at least 8 to 10 years.

Another example is the O&L Group in Namibia (Lee et al., 2014). This company started in retail and brewery and later diversified into dairy and solar energy. O&L expanded quickly with government support (against a South African company's effort to sabotage the company by price dumping) with sales reaching approximately 4 per cent of Namibia's GDP. O&L plans to the

[22]. These cases are also presented in Chapter 7 of Lee (2019).
[23] Information on M-Pesa and M-Kopa was taken from Shapshak (2016).

energy business, including the wind power industry, because Namibia imports electricity from South Africa and Angola. However, the company must first resolve the hurdle of a government-imposed grid monopoly.

India: Country-level stage-skipping[24]

The economics literature differentiates between China's manufacturing-led growth and its service-led growth.[25] China's impressive catch-up since the 1980s is viewed as a 'classical' case of catching up, as its evolution was accompanied by typical structural changes, with the share of the primary sector shrinking over time, and the secondary and tertiary sectors increasing. India's case is unusual because the increase in the share of the service sector corresponds closely with the decrease in agriculture, whereas the share of the secondary sector remains almost flat.[26] In fact, India's service sector has grown steadily since the 1980s, with its GDP share exceeding 50 per cent. Some economists believe that the growth of India's service sector might be an example of premature tertiarization typical in developing countries, in which low-paying service jobs are generally generated in the urban informal sector. Although this may be partly true in India, it is not representative of India's entire service sector. India's IT service industry has generated high-paying jobs and upgraded into higher value-added segments of the value chain.

Another impressive indicator of India's success is its rising share of service exports in relation to total exports. This share reached 35 per cent in the mid-2000s in India and attained over 50 per. cent in the 2010s, one of the highest in the world, surpassing even that of advanced economies. By contrast, the export share of China's service sector remained at around 10 per cent in the 2000s. Therefore, if India follows the proven success path of export-led growth, it is likely to do so through service exports (tertiary sector) and not through manufacturing (secondary) or agriculture (primary sector) exports, as in other developing countries.

Growth in most industrialized countries in the world has been fuelled by manufacturing, with the service sector increasing only after the stage of manufacturing-based growth ends. This pattern has been explained in terms of the service sector's income elasticity, or the service sector as an intermediate input to manufacturing. However, in India, the service sector advanced without passing through the usual growth stage in the manufacturing sector (Ok et al., 2014). Thus, India seems to have leapfrogged in terms of industrial structure because the service sector developed

[24] This case of India is a summary based on Chapter 8 of Lee (2013).
[25] For instance, see Winters and Yusuf (2007).
[26] According to Figure 8-1 of Lee (2013), the contribution of China's manufacturing sector to total GDP has steadily increased, attaining 30 per cent by the 2000s and accounting for the sharp decrease in the agriculture sector's contribution to GDP. By contrast, the GDP of India's manufacturing sector has never exceeded 20 per cent, with its size remaining constant at around 15 per cent for over two decades.

before the manufacturing sector accounted for a significant share of the economy. Under Modi's leadership, India is trying to promote manufacturing as well. In this sense, India took a detour via leapfrogging; India bypassed the stage of manufacturing-led growth but leapfrogged into service-led growth and then returned to promote manufacturing.

It should be noted that this service-led growth has been dominated by the three giants, Infosys, Tata Consultancy Services (TCS) and Wipro. These Indian firms have undergone the three stages of upgrading: body shopping, offshoring and global delivery model (GDM), which are similar to the manufacturing stages of OEM, ODM and OBM, respectively (Lee et al., 2014). Among these three giants, the case of Wipro is a model example of leapfrogging. This company was established as an agro-business company that produced and sold vegetable oil products (Hamm, 2007). With its entry into the personal computer era, Wipro engaged in assembling and selling personal computers as well. Shortly thereafter, the firm addressed its weak competitiveness against foreign products and switched to PC maintenance and repair service. The Y2K panic around the year 2000 brought a decisive boost to Wipro's business, turning the firm into a global IT service company listed in the New York Stock Exchange. Wipro's historical development illustrates the company's leapfrogging into IT service, bypassing the stage of IT manufacturing.

6 Enabling policies and prospect for leapfrogging

6.1 Enabling conditions and policies

The enabling conditions and policies for leapfrogging can be discussed in terms of the NIS (national innovation system). Specifically, the implementation of leapfrogging strategies should first start from considering the one precondition and two risks of leapfrogging discussed in Section 4. In other words, a latecomer economy should first build up a certain level of capabilities in production technologies, if not innovation capabilities. As discussed in Section 4, the Republic of Korea's case of leapfrogging into digital TV ahead of Japan was possible because Korean companies had experience producing analogue TVs.

The necessity to build a certain level of technological capabilities does not necessarily mean engaging in isolated national R&D efforts. If these national R&D efforts are to lead to leapfrogging, they should be accompanied by gaining access to the global knowledge base, without which leapfrogging and catching up is almost impossible or very risky, as the latecomer firms cannot generate radically new technologies themselves. The products that result from leapfrogging are often a combination of the latecomer's production capability based on the seed technology of the forerunner firms. Although the latecomer firms' products are new, they were only able to develop them by applying the foreign sourced science and seed technology to the specific development target.

Thus, the possibility of leapfrogging calls for a modification of the theories of technological development (Lee et al., 2015). According to the stage theories of technological development, the latecomer country moves from the ‘internalization stage’ to the ‘generation stage’ to produce ‘new knowledge’**.** This sequential mode of learning has to be modified, specifically in terms of the changes in the channels of knowledge access. While in the past or in the path-following catching up scenario, the main channels were licensing or FDI, the current cases of path-creating or path-leading catching up during the paradigm shift period demonstrate the significance of new channels such as co-development with, and acquisition of, foreign firms or university start-ups as well as collaboration based on complementary assets owned by latecomer firms. Horizontal collaboration with universities, public research organizations or forerunner firms is only possible when the latecomer firms have something to give in return. While absorption capacity was emphasized in the former story of technology transfer via licensing or FDI, now complementary assets that have been created with speedy R&D activities and investments in production seem to have taken a lead role in the new ways of accessing knowledge.

Another important factor is the management of risks involved in leapfrogging. The primary risk of leapfrogging is choosing the right technology among several alternatives. In this regard, cooperation with public R&D institutions, universities and other entities is crucial as such R&D consortia can reduce the risk by pooling knowledge together. These collaborating entities may critically contribute by keeping “technology watch” by interpreting and monitoring state-of-the art trends in R&D activities in foreign countries (Lee et al., 2015). For example, in the case of Korean leapfrogging into mobile phones or digital TV, it was the ETRI (a government research institute) that identified small firms like Qualcomm as a suitable R&D partner to develop digital cellular phone systems, and KITECH and ETRI carried out R&D activities and coordinated the consortium of research projects in digital TV.

Despite the possibility of mitigating the risk by making the right choice among emerging technologies, the issue whether sensible targeting is possible has always been a controversial issue. In the arguments against targeting, design failure is often confused with targeting failure (Lee, 2017). One example is the case of South Africa, which developed its own electric car called ‘Joule’. According to Swart (2015), the South African government provided the initial funding and established a state-owned start-up called Optimal Energy in 2005. The company initially succeeded and had developed four roadworthy prototypes by December 2010. However, the company closed down in June 2012 despite its technological success. The government, a major shareholder, decided to halt the funding required to start the large-scale production of the electric cars due to uncertainties in marketing success. The failure of 'Joule' cars was caused by the lack of involvement of private companies willing to take over the role in volume production and sales. Existing foreign multi-national companies and local auto companies did not want this new 'disruptive innovator', a state-owned company, to grow as another rival that sells cars. The government should have established a public-private consortium with the plan that volume production would be carried out by private actors after the consortium had developed the prototype (Lee, 2017).

This South African case can thus be considered a 'design failure' rather than a 'targeting failure' (Lee, 2017). The reason that the leapfrogging process should involve private firms in terms of design is twofold: they know where market demand is, and they eventually run the show. Caution against government involvement often does not distinguish whether the sources of failure are due to targeting or design. The sources are often mixed together. While one might expect more cases of targeting failure, this is not always the case. Uncertainty diminishes when targeting is perceived in terms of identifying the potential or existing markets as long as the private sector with knowledge about those markets is involved. If not on the frontier, the targets may be obvious because a clear benchmark case often exists, and firms may consequently attempt to identify niches between existing firms and projects. Numerous public initiatives fail because of design or capability failure, where the latter refers to low execution capabilities.

While the above discussion focusses on avoiding design failure, targeting failure also poses a considerable risk. One way to minimize the possibility of targeting failure is to utilize the idea of entrepreneurial discovery (ED) suggested by the smart specialization framework (Foray, 2015). The process is as follows (Lee, 2017). First, policymakers should organize a public-private joint taskforce, which includes representatives from the private sector, and administer a survey to existing private firms and entrepreneurs on the nature of business items or technological areas where they see near-future potential, opportunities, risks and bottlenecks when entering or starting out in these future areas. The business areas to be identified by surveys are those areas where the private sector sees certain market potentials often associated with emerging technologies but with some technological, financial and other related environmental (regulation) uncertainties. Private firms may know better where the next market opportunities lie, but cannot be sure whether they will be able to develop the necessary and appropriate technologies and whether they will be able to raise the funds for such R&D and initial marketing. In other words, new business/technology areas with more certain market potential but uncertain technological, financial and regulatory uncertainty are targetable areas. Policy intervention promotes these identified areas by mobilizing public and private resources and competencies that correct market and coordination failures.

6.2 Prospect of leapfrogging-based development

The answer to the question whether the 4IR can either be a new window of opportunity for leapfrogging or a source of further risk for the latecomer is that it depends on the country's response and readiness, including industrial policy, digital literacy, skill and education level compared to wage rates, and domestic market size and position in GVCs (Lee et al., 2019). We can conceive of the following three groups of countries (Table 2).

Table 2: Possible responses to the 4IR by country group

	Group A	Group B	Group C
Main feature	National	FDI-based	Weak
	manufacturing base	manufacturing	manufacturing base
Examples	China, Rep. of Korea, Brazil	Malaysia, Thailand	Indonesia, India, Philippines
		Brazil, Mexico	Africa, Argentina
Promising	Leapfrogging into	Automation and	4IR-related
responses	smart factory	upgrading	service start-ups
Main initiator	Public-private partnership	MNC decision	Local entrepreneurs introducing business model innovations
Key enabling factors	Industrial policy providing funds and technologies	Local existence of skills and training institutions	Initial financing; venture capital
Risks	Waste of public funds	Relocation to	Entry by, & competition with
		cheaper wage sites	large foreign businesses

Source: Author

The first group of countries may correspond to the most promising scenario consistent with proper leapfrogging from Industry 2.0 (mass production) to Industry 4.0 (smart factory), bypassing the intermediate stage of Industry 3.0 (automation). This seems to be possible or happening in economies with a national manufacturing base that has reached a certain level, like China, the Republic of Korea or Brazil, supported by government commitment and societal consensus. The smart factory paradigm has also emerged as a solution by countries to maintain competitiveness by overcoming the problem of increasing wage rates or labour shortages in several economies, which is similar to the underlying motivation for Germany to initiate Industry 4.0. One mode of implementing an initiative towards smart factories (or automation) can take the form of a public-private partnership or collaboration, in conjunction with active industrial policies. Of course, the possible risk is the waste of public resources or state budget in case of the failure of these initiatives.

The second group of economies are those with an FDI-based manufacturing sector, like those in Southeast Asia or Latin America, where leapfrogging depends on the choice of parent MNC. In these economies, MNCs face various alternatives, such as relocation to other economies in search of cheaper wages and reshoring back to home countries. In this regard, some promising stories of FDI-based electronics industries in Penang, Malaysia and in the automotive sector in Thailand exist with some automation and upgrading into higher end segments, indicating that the key factor for success is the local institutions that enabled the training and upskilling of the local workforce, thereby compelling MNCs to remain in the area (Lee et al., 2019). The cases of the Penang electronics cluster and Thailand's automobile cluster are summarized in Box 1.

Box 1: Penang Electronics and Thai Auto Clusters

Export-oriented manufacturing has been a critical part of the Asian model of development. However, these manufacturing businesses are now encountering problems due to rising domestic wages although the products have remained in the low-end segment. Thus, certain Southeast Asian economies are showing signs of being stuck in the middle income trap. The arrival of the 4IR represents an additional source of challenge because it entails the possibility of re-shoring factories in the region back to the developed world as the cost of automation plummets, or low-cost labour becomes a less effective strategy to attract manufacturing investment.

In transitioning towards the 4IR era, multinational firms in the ASEAN countries have the four following options: 1) Remain in the region but adopt new automation technologies to stay competitive in terms of the cost of production; 2) Return to their home country by embracing full-scale 4IR-type radical innovation (e.g. Adidas); 3) Move to neighbouring low-wage countries in Asia, such as Myanmar; 4) Remain in the region but diversify by embracing new 4IR technologies in new businesses. In-depth case studies of the electronics cluster in Malaysia and the automotive cluster in Thailand suggest the possibility of upgrading into high-end segments and thus getting out of the middle income trap. In both cases, one key factor of the positive scenario were the local institutions that enabled the training and upskilling of the local workforce, in addition to their early start or long history going back to the 1960s or 1970s.

In Penang, such institutions include the PSCD (Penang Skill Development Centre), a non- profit institution that provides technical knowledge, training programmes for engineers, and the CREST which hosts multinationals and local firms, universities and research institutes. Established in 1969, the Penang Development Centre (PDC) was a state agency that helped the city significantly expand its industrial park development and employment creation, and cooperated with HP, Intel and Motorola. They founded PSDC together in 1989. Approximately 200 member companies of PSDC contribute to its technological knowledge base and enjoy the benefits of ensuring a stable supply of man power. PSDC also hosts a number of laboratories for shared services for its members. In 2016, PSDC trained and certified 7,048 individuals as skilled workers in the industrial park, a ratio of 35 workers per company in Penang. PSDC with its advanced industrial network plays a significant role in the process of developing competencies for I40 technologies. The agency is endowed with resources from the government to empower the workforce in Penang and elsewhere with knowledge that is useful for developing niches under Industry 4.0. Training programmes include I4.0: idea, architecture, demand and approach; embedded systems for IoT; cloud architectures & technologies; cybersecurity fundamentals for Industry 4.0; big data: methods and solutions; and the robot operating system.

In Thailand's automotive cluster, the corresponding institutions include the AHRDP, a joint collaboration between Thai and Japanese firms and public agencies to train workers and engineers in auto part manufacturing. The TAI has also been established, which is a sector-specific promotional and intermediary agency aiming at strengthening cooperation between key actors and at enhancing the industry's competitiveness. Nonetheless, realizing the 4IR's opportunity side is not automatic. The Thai automotive industry is facing the challenge of attracting new foreign investments in related electronic technologies and upgrading local suppliers to produce technologically sophisticated parts in generation cars, such as electric cars.

Source: Lee et al., 2019

The last group includes latecomer economies, where more promising areas and stories related to the 4IR seem to be taking place in service sectors or servicitized manufacturing sectors. Some examples include Indonesia, the Philippines, Argentina and several countries in Africa. For instance, Southeast Asia has recently witnessed a boom of start-ups, but all of the successful cases tend to be in services, e.g. mobility, e-commerce, games, mobile payments, travel, music and entertainment, and other app-based services.[27] Some of these, like Grabs, are very successful and large-scale, thus competing with global giants like Uber, and create many local jobs. Most importantly, they may have spillover effects on related manufacturing as well; for instance, GO-JEK is Indonesia's first unicorn which started as a motorbike and taxi-hailing app and then expanded to food delivery, groceries, massages and mobile payments.

It is quite plausible that success in services may have a boosting effect on local manufacturing, given the emerging trend of the blurring of boundaries between service and manufacturing. The case of companies like eFishery and DeepGlint discussed in Section 6 can be considered exemplary companies that are right at the border between manufacturing and solution providers; eFishery provides an Internet of Things (IoT) solution for the efficient feeding of fish and produces hardware for fish and shrimp farming businesses. DeepGlint produces a security camera and provides a face recognition system based on big data.

The possible risk these types of local start-ups face is the entry of and competition from large foreign businesses. These start-ups are advised to seek niches unless the government provides market protection against foreign firms; it is well-known that many IT start-ups and later giants in China (e.g. Baidu, Alibaba and Tencent) were able to grow due to asymmetric regulations against foreign firms, like Google, Amazon, Uber and Facebooks.

The case of Indian leapfrogging into IT services followed by the recent promotion of manufacturing discussed in the preceding section indicates the possibility of 'service first, manufacturing later' as a development strategy. India's service sector has become a viable export sector accounting for more than half of total exports, the highest ratio in the world. The earnings in convertible currency generated by such exports has become a basis for the promotion of India's manufacturing sector, which requires imports of capital goods in dollars. We do not have to discount this already occurring phenomenon by labelling it as premature deindustrialization. Some latecomer economies might have to follow this path of economic growth, given the high entry barrier in manufacturing compared to services.

[27] See the list of the top 15 start-ups in Southeast Asia at the https://www.techinasia.com/15-most-wellfunded-startups-southeast-asia.

One insight from promising cases of latecomer economies is that they do not have to be original inventors of new innovations; it often suffices to be follow-on innovators or even fast adopters with local twists, which have been classified as one variation of leapfrogging in Section 2 above. Leapfrogging is not only possible with technological innovations but also with business model innovations based on adoptions of foreign technological innovations. This has important implications for more laggard economies, e.g. some economies in Africa. The cases of leapfrogging in Africa discussed in the preceding section leaned towards adoption of new technologies rather than local innovations. However, adoption is the beginning or the stepping stone for learning and eventual innovation. Learning is not possible without adoption. Manufacturing firms in East Asia, such as Samsung and Hyundai Motors in the Republic of Korea, started with the adoption of foreign technology for production, learning by using, enhancing productivity by mastering production technologies, and finally acquiring design technology (Lee, 2005; 2013a). Recent examples can be found in the renewable energy markets of China, Brazil and India, involving the transition towards low-carbon economies. Options for LDCs in low-carbon technologies include wind, solar, biogas and geothermal energy sources. In this case, coordinated initiatives and incentives for early adopters are essential for reducing the risks associated with weak initial markets.

While the discussion above centres on the different types of economies facing distinct initial conditions, policy suggestions involving leapfrogging can also be made in terms of different types of firms with different levels of initial capabilities. In this regard we can divide firms of an economy into incumbents and start-ups; the former can be further classified into three firm types, namely leader, follower or laggard depending on their level of capabilities. We can then turn to the issue of which type of leapfrogging or other alternative might be suitable for which type of firm.

Relatively speaking, it can be argued that path-creating leapfrogging is more likely to occur among start-ups because they have made the least investments into the existing or former modes of technologies or business models. In other words, diverse technologies associated with the 4IR can be a source for product (or business model) innovation, more so than for process innovation, which is more relevant for incumbents. Even product innovations do not have to be entirely new or radical, they can be follow-on innovations or ‘adopt then improve’-type innovations.

Next, leader or follower type firms in emerging economies tend to have some experience and absorptive capacity and are thus likely to be in a position to try stage-skipping leapfrogging. Given their accumulated know-how and production experience, they can be considered as satisfying the pre-conditions for such leapfrogging, but they should be aware of the two risks involved in leapfrogging discussed in the preceding section (4.2). Given that they are incumbents, their leapfrogging is likely to not be inter-sectoral but intra-sectoral over different generations of technologies, for instance, from mass production to smart factories, bypassing the stage of traditional automation; or from lean production to smart production, bypassing the stage of integration production. Moreover, the nature of such innovation would be more process than product innovation.

Finally, laggard firms are advised not to try pre-mature leapfrogging but to first build an absorptive capacity and technological capabilities in their niche areas and thereby try to upgrade by moving into higher end segments of GVCs. In other words, they need to go through a stage of ‘several detours’ (Lee, 2019), which is a precondition for attempting to leapfrog. The detour can be from imitation to innovation by providing for relatively weak IPR protection to promote imitative R&D and the diffusion of innovations, as well as building a certain degree of domestic value chains while participating in GVCs (Lee, 2019).

Supportive policies may also differ across firm types. For instance, for start-ups venture capital (VC) funding including public-private joint VCs, may be more relevant, whereas for incumbents, conventional loans from commercial banks, subsidized loans from the public sector as well as conventional financing from equity markets are more relevant modes of financing.

Generally, new innovations in the 4IR and sustainable development require new forms of public policy and public-private partnerships. The 4IR’s comprehensiveness and across-the-board nature require policy response not by one specific government ministry but consultations and responses by multiple ministries and the coordination of the prime minister’s office. Furthermore, the responses must be timely because some negative impacts of the 4IR could arise earlier than expected, such as losses of certain assembly jobs and BPO jobs. The 4IR could also disrupt and reshape current GVCs, and new forms of insertion into new GVCs may not necessarily be at the level of firms but at the level of individuals. In this regard, education and training assume a decisive role, and integrating the labour market at the regional level and promoting start-ups of young entrepreneurs by spreading successful role models and cases would be desirable.

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