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How Does Urban Rail Development in China and India Enable Technological Upgrading?

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Abstract

The socioeconomic wellbeing of urban areas depends on a well-functioning transportation system that makes it easier for people to access goods and services. Whereas most urban areas in emerging economies are expanding in size and human population, high motorisation and inadequate public transport services have resulted in congestion, traffic accidents and increasing transport-related greenhouse gas (GHG) emissions. Urban rail development can help address the current transportation problem because trains can move a large number of people at high speed, provide reliable services, contribute to lower GHGs and have a low accident rate. However, urban rail is expensive and requires many technical and technological capabilities often unavailable in emerging economies because they are technology latecomers. This paper examines how two emerging economies, China and India, have adopted industrial policies to develop local capabilities for urban rail technology. The paper shows how the Chinese government has moved from purchasing urban rail technology from multinational companies (MNCs) to the current situation where it has developed local capabilities, owns rail technology patents and competes with the same MNCs on the international market. The paper also demonstrates how India is gradually improving the local manufacturing of rail subsystems as opposed to importation. Overall, the paper suggests a pathway to industrial policy adoption that demonstrates how emerging economies can catch up with urban rail technology development to address their local transportation needs.

Keywords: China, India, industrial policy, multinational company, technology indigenisation, technology transfer, urban rail

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Abbreviations

BEL	Bharat Electronics Limited (China)
BEML	Bharat Earth Movers Limited (India)
BJTU	Beijing Jiaotong University
CARS	Chinese Academy of Railway Services
CASCO	China Alstom Signal and Communication
CBTC	communication-based train control
CNR	China North Railway Company
CRCC	China Railway Construction Corporation
CREC	China Railway Engineering Company
CRRC	China Railway Rolling Stock Company
CSR	China South Railway Company
DMRC	Delhi Metro Rail Corporation
EMU	electric motor unit
FDI	foreign direct investment
GHG	greenhouse gas
GOI	Government of India
ICF	integral coach factory
ICT	information and communications technology
IT	information technology
JICA	Japanese International Cooperation Agency
JV	joint venture
MNC	mulitnational company
MoHUA	Ministry of Housing and Urban Affairs (India), previously MoUD
NAIR	National Academy of Indian Railways
NDRC	National Development and Reform Commission (China)
NITI Aayog	National Institute for Transforming India
R&D	research and development
SATCO	Shanghai Alstom Transport Company
SATEE	Shanghai Alstom Transport Electric Equipment
SEI	Strategic Emerging Initiative (China)
SWJT	Southwest Jiaotong University (China)

1 Introduction

Most urban areas in emerging economies are expanding in size and human population, resulting in increased demand for transportation and mobility services. The socio-economic wellbeing of urban areas depends on a well-functioning transportation system that makes it easier for people to access goods and services. However the urban areas of most emerging economies are characterised by high motorisation and inadequate public transportation resulting in traffic congestion, accidents and increasing greenhouse gas emissions (GHGs) (Pojani & Stead, 2017). There is an urgent need to develop sustainable mass transit systems to provide the growing urban population with efficient mobility services and address the current socio-economic and environmental problems associated with the transportation system in emerging economies. Urban rail (metro, tram, monorail, suburban) can be an essential component of the solution.

Urban rail has many advantages: Trains can move many people at high speed, provide reliable services because of their physical segregation from traffic, lower GHGs when the energy source is renewable, and have a low accident rate. There has been a consistent increase in urban rail lines in emerging economies over the past decade (IEA [International Energy Agency], 2022; UITP [International Association for Public Transport], 2019) because of the need to transport the growing urban population efficiently. In 2018, 907.1 km of metro lines were constructed in emerging economies representing 94.5 per cent of global new metro lines (UITP, 2019). But urban rail is capital intensive. For instance, the infrastructure cost of implementing light rail is about three times more expensive than a bus of similar passenger capacity (ITDP [Institute for Transportation and Development Policy], 2017). Another major challenge for emerging economies when introducing urban rail is the technical capabilities required for the rolling stock, infrastructure, and IT (information technology) solutions. Because most emerging economies are technology latecomers, they do not possess these essential capabilities.

Emerging economies can either import all or most of the components and services required for an urban rail system, or try to develop local capabilities through pro-active industrial policy to gradually increase value-added and domestic employment. But the latter is not easy as the leaders in rail technology are unwilling to share their intellectual property. The option of domestically developing rail technology may translate into inferior products and service quality, and higher transportation costs.

This paper examines how technology latecomer economies can build the required urban rail capabilities locally while ensuring good service quality and affordable prices for users. The paper relies on secondary data to explore the objective stated above. It adopts a case study approach to understand the context, processes, causes and outcomes (Flyvbjerg, 2011). Two countries have been selected for the case study (mainland) China and India. These countries have the first- and second-largest markets for urban rail development and have adopted industrial policies to indigenise rail technology. China has successfully managed the transition from importation to almost completely national manufacturing and services of most urban rail technology. Local Chinese firms have developed urban rail technology, own patents, and currently compete in the international market with firms that have traditionally manufactured urban rail technology. India is pursuing an explicit “Make in India” strategy to increase local manufacturing and offers one of the most dynamic markets for urban rail development. India has already shifted from complete dependence on importation of urban rail technology and is on the verge of achieving 100 per cent local manufacturing for some rail subsystems, yet technological core capabilities are still highly concentrated in the Indian subsidiaries of foreign-invested rather than Indian firms. Comparing these different approaches pursued by China and India will thus provide useful lessons for other emerging economies that seek to indigenise urban rail implementation through an industrial policy to address their transportation problems.

Section 2 introduces rail transportation systems focusing on types of urban rail, the components of rail systems, and the technical barriers to its adoption to demonstrate the level of expertise required for rail technology indigenisation. Understanding rail technology requirements is necessary to appreciate the components that must come together for trains to function, the level of technical complexity, and entry barriers to assess the opportunities for indigenisation of the various components. Section 3 briefly discusses the concept of industrial policy and provides information on how it can be designed for technology indigenisation. Section 4 describes the steps China is taking to develop local capabilities. How India is implementing urban rail transportation is then described in Section 5. Section 6 concludes by highlighting the lessons from the experiences of China and India, the study's limitations, and an outlook for policymakers in other emerging economies.

2 Rail transportation systems

Rail transportation is suitable for transporting goods (freight) and people. But, because rail tracks are fixed and do not primarily offer last-mile services, they are not the preferred transport service for goods within urban areas. Rail transport in this report solely refers to passenger transport unless specified.

2.1 Types of urban rail transport

Although there are different types of urban rail transport, they can be broadly categorised based on passenger capacity, speed and number of tracks. Within this categorisation, there are four main types.

Suburban rail

Suburban rail transport covers medium to long distances with a maximum speed of 150 km/h. It mainly connects urban centres with surrounding areas for work and school purposes. This allows people in the suburbs to commute via mass transit to the urban centre, where most jobs and services are located. Suburban trains usually have a higher comfort level than other urban trains because of the relatively long route. The transport capacity of the trains can vary between 250 and 1,500 passengers and can reach about 60,000 passengers/hour/direction depending on the frequency of services, speed and number of vehicles. The trucks are usually double to achieve sufficient track capacity and to reduce travel time (Pyrgidis, 2016).

Metro rail

Metro rail refers to high-frequency services within the city with standing passenger options and wide doors for rapid boarding and exit. They are mainly designed as underground and elevated networks. There are two types of metro rail transport, namely light and heavy. While the heavy metro is appropriate for conveying a larger number of people (about 45,000 passengers/hour/direction), the light metro is characterised by lower capacity (about 35,000 passengers/hour/direction) and a shorter distance between intermediate stops. For that reason, the heavy metro may have more vehicles per train and train length than the light metro. The light metro can be considered as a compromise between the heavy metro and the tram. Metros have a maximum speed of 50 to 90 km/h depending on the location and distance to the next station in the city. Metros often operate on double tracks.

Trams

Trams or tramways are transport systems, often at street level and offering less capacity (about 15,000 passengers/hour/direction) than metros. They usually serve distances between 5 and

20 km with commercial speeds of about 15 to 25 km/h. They use double tracks constructed with either grooved rails embedded in the pavement or conventional flat bottom rails.

Monorail

Monorails, also called Skytrains, are electrified light rails. They move via rubber-tyred wheels on an elevated beam which serves as the guideway. Thus, this rail has one track, not two like other rail types. Monorails can develop a maximum speed of 60 to 90 km/h and are mainly offered for short-distance transportation services to circumvent land scarcity in congested cities and mountainous landscapes. Because monorails are elevated, they are also beneficial for leisure places due to the panoramic view they allow (Pyrgidis, 2016). Magnetic levitation (Maglev) is a type of monorail technology. With Maglev, the coaches of the rail float on a four-inch cushion above the track using the Meissner effect of superconducting magnets (Clark & Cooke, 2015; Mahmoud, 2018). Maglevs can attain higher speeds than other monorails.

2.2 Components of rail transport systems

All rail transport components can be grouped into three main components from a transport-system point of view: these are rolling stock, the railway infrastructure, and railway operations. These components come together to enable rail transportation services. This subsection generally describes the components that enable rail transportation and their complexity.

2.2.1 Rolling stock

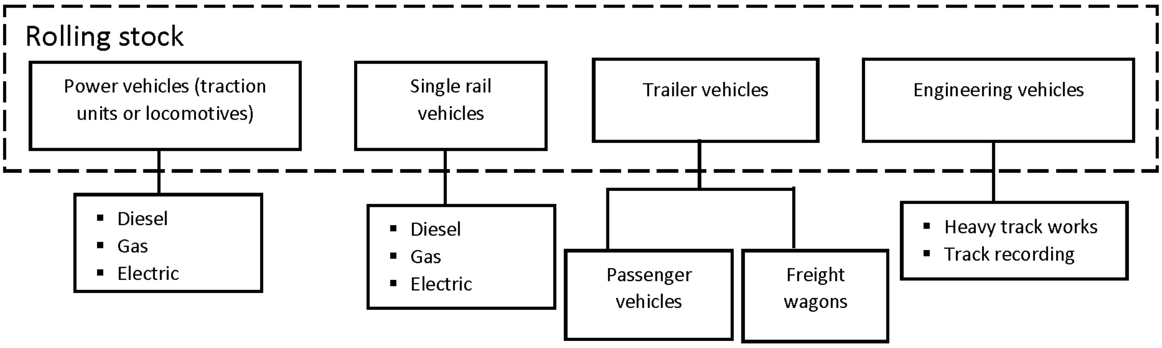
"Rolling stock" is the term used for all railway vehicles. The railway vehicles may be power vehicles, single rail vehicles, trailers, or engineering vehicles (see Figure 1). The power vehicles are self-propelled and may be used for hauling trailer vehicles, transporting several passengers or for shunting purposes. Power vehicles used for hauling are called locomotives.

Locomotives may be steam-, diesel-, gas-, or electric-powered, depending on the traction power, but most urban rails are electric-powered, whereas some may be diesel-powered. Some suburban trains may have locomotive sections to haul trailer vehicles. The single rail vehicles may be diesel-, gas- or electric-powered. Trams, monorails, and metros are mostly single rail vehicles powered by electricity. Most urban trains are connected single rail vehicles depending on the required passenger capacity. The number of connected rail vehicle units distinguishes a heavy metro from a light metro.

Whereas steam technology is old and not used anymore because of its inefficiency, onboard storage technology such as hydrogen and battery or a fuel-cell will become the future technology for rail transport because of the low greenhouse emissions and mobile usage (Hein & Ott, 2018). The alternative propulsion technologies are useful for urban rail services because of the relatively short distances and lower speed compared to long-distance rail transportation.

The trailer vehicles are either for passenger or freight purposes. The engineering vehicles carry out track panel installations and various track inspections and maintenance work. The locomotive is an essential part of the rolling stock since it powers the movement of the trailer vehicles. The design and engineering of the locomotive and single vehicles require high expertise because they embody the main traction motor and propulsion equipment that power the movement of trains.

Figure 1: Types of rolling stock



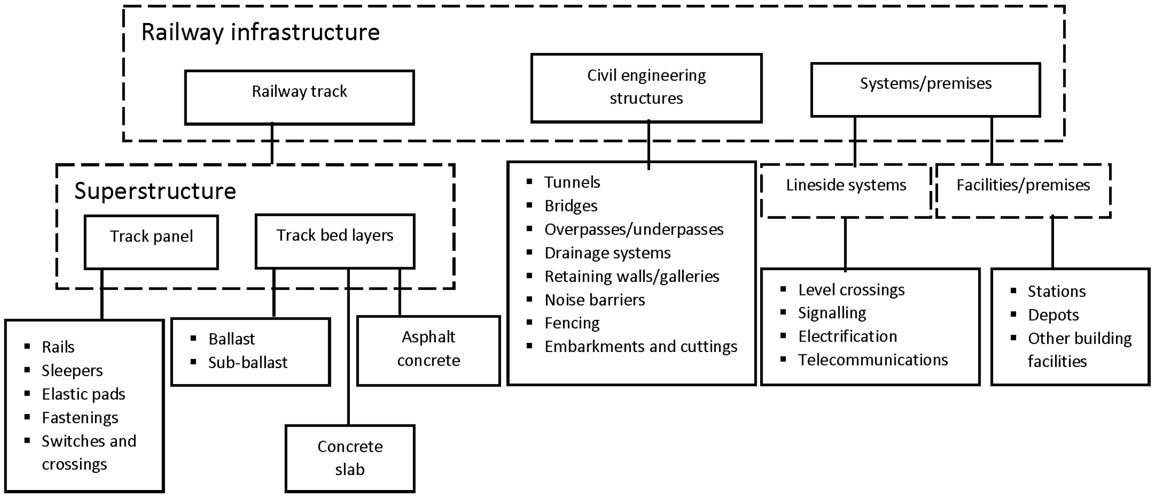
Source: Authors, adapted from Pyrgidis (2016)

2.2.2 Railway infrastructure

Urban railway infrastructure can be built below and above ground. Railway infrastructure generally consists of three main components that ensure a safe railway traffic: the railway track; all the civil engineering structures; and the systems and premises (Pyrgidis, 2016). The railway tracks are long, large structures designed to support the movement of heavy rolling stock on soft ground. As shown in Figure 2, the railway track comprises different sub-components. The components of the railway tracks are of varying stiffness that transfers the static and dynamic traffic loads to the foundation. The track bed layers located at the lower part of the superstructure are of different types. The selection is based on cost savings and low maintenance requirements advantages. For example, a ballasted track may be used in above-ground areas where low train speeds are required. In contrast, the non-ballasted track such as concrete slabs and asphalt concrete may be preferred for underground track sections where maintenance requirements are restricted and stability and durability are required.

The civil engineering structures ensure that external objects do not obstruct rail transport services and ensure low noise in urban areas. These comprise of underground tunnels, bridges, overpasses and underpasses, drainage systems, noise barriers, and fences. The operation of a railway requires infrastructure systems such as level crossings and electrification, signalling and telecommunication systems collectively referred to as lineside systems. These lineside systems ensure traction power supply, telecommunications, and train control to avoid accidents. The railways need infrastructure such as stations to protect passengers from inclement weather, depots and warehouses to keep coaches for repairs, and administration buildings for management and operational services.

Figure 2: Components and subcomponents of railway infrastructure

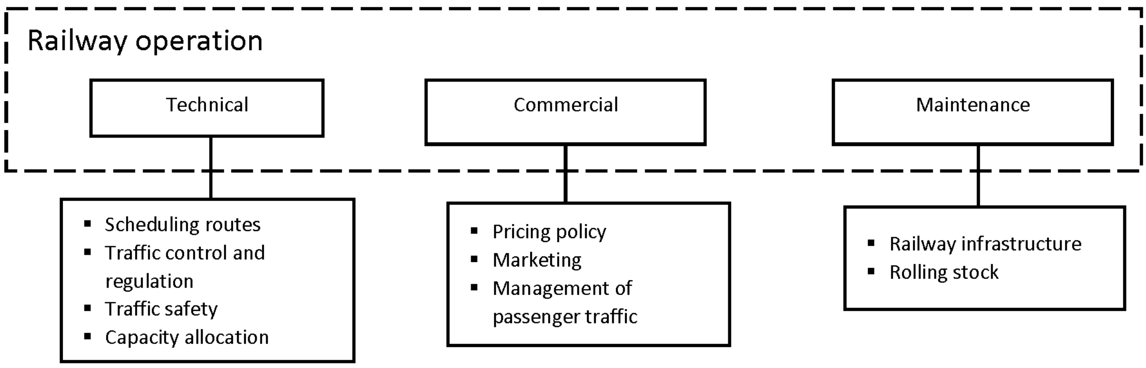


Source: Authors, adapted from Pyrgidis (2016)

2.2.3 Railway operation

The railway operation brings together the infrastructure and rolling stock to ensure movement from origin to destination and the service's commercial benefit. The commercial component ensures that rail services generate enough revenue to cover the expenditure and profit for reinvestments for improving the service. The technical component enables safe and reliable services and the maintenance component addresses issues that may affect the safety and reliable services. Without the assurance of safety and reliable services, a lower number of passengers may result in higher costs and the collapse of the service.

Figure 3: Railway operational activities



Source: Authors, adapted from Pyrgidis (2016)

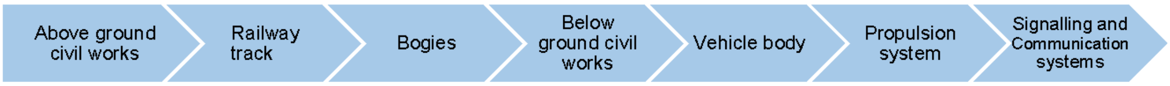
2.3 Technical barriers to urban rail implementation

The components of rail systems described above show the diverse subcomponents that must come together to ensure implementation and operational services. Expertise in architecture, transportation engineering, power supply systems, structural mechanics, soil mechanics, ICT (information and communications technology), urban planning and design, electrical and electronic engineering, rolling stock technologies, and more are required. But the technical expertise required for various components and sub-components has undergone an evolutionary process in its development. The firms that have invested in research and development (R&D)

have enabled rail technology to evolve in speed, safety, efficiency and comfort for passengers. Most of these firms are located in countries with a long history of rail transport services, such as Germany, Japan, France, the United States, and the United Kingdom (SCI Verkehr, 2018). Thus, the specialised expertise for rail transport has been developed by international rail firms over a long period in particular regions of the world. Multinational companies (MNCs) such as Alstom, Bombardier Transportation,[1] Siemens Mobility, Kawasaki Railcar Manufacturing, and Construcciones y Auxiliar de Ferrocarriles (CAF) have accumulated advanced capabilities in most subsystems of modern rail technology systems. Other MNCs such as ABB and Mitsubishi Electric specialise in rail technology subsystems such as propulsion systems for the rolling stock and signalling systems.

Different rail technology subsystems are required for urban rails to function (see Figure 4). Whereas some subsystems, such as railway tracks, do not require highly sophisticated technological capabilities, they require higher volumes. In contrast, propulsion/traction and signalling and communication subsystems generally require high technological capabilities than other subsystems. Nevertheless, all the subsystems require a high level of technological precision. They are essential for the overall performance of urban rail transportation implementation and operational services. The subsystems requiring more sophisticated technology keep improving to ensure enhanced commuters' safety, comfort, and reliability.

Figure 4: Technical barriers to increasing urban rail technology subsystems



Source: Authors

The following sub-section discusses three components – rolling stock; signalling and communications; and infrastructure – based on the subsystems shown in Figure 4. The propulsion system, bogies and vehicle body make up the rolling stock, whereas civil works below and above ground, including facilities and premises, electrification and the railway track, make up the infrastructure component. Thus, the capabilities required for urban rail technology indigenisation based on the subsystems can be broadly categorised as rolling stock, signalling and communications, and infrastructure.

The rolling stock

The rolling stock for urban rail transportation consists mostly of two or more connected single vehicles. The rolling stock consists of two distinct parts: the vehicle body (the part where passengers sit or stand) and the bogies (that support the car body and provide traction and braking). The vehicle body usually has a zone for the electrical equipment and a zone for communications to control the operation of the rolling stock, which also serves as the driver's location. The body contains the main structural frame that transmits traction and dynamic forces, the central power plant units and various units for movement of the wheels, monitoring and managing the performance (Spiryagin et al., 2016). The vehicle body includes several components for the control of traction transmission, braking, cooling, ventilation, and safety devices. The bogies contain the wheels that move on the tracks, a traction motor built within it, brake parts, and other small components that ensure the train's movement is safe and comfortable.

1 Alstom acquired Bombardier Transportation in 2021. Since then, all assets of Bombardier Transportation are owned by Alstom. Bombardier Transportation is however continuously used in this paper to depict the activities of the firm prior to Alstom's acquisition.

The rolling stock has specific systems that require electric power to function. These systems include air-conditioning, lighting, battery chargers, monitoring, door control, onboard signalling and communication equipment. In addition to the auxiliary electric power, the train monitoring systems collect, record and present information on the functions of the train for efficient operation and maintenance. The monitoring systems perform several support functions, including ensuring doors open and close properly, the brakes function accordingly, test-run measurements, and recording of faults. These systems require high skills and years of R&D.

The energy generated when an electric train is slowing down can be transformed into electricity (regenerative power) that can be fed into the grid for other trains. Electric-powered trains have extra technology requirements as they require lineside infrastructure to transmit the electricity for traction purposes. Recently, train personnel and passengers expect improved ventilation, air-conditioning systems, information and entertainment systems, and power sockets for laptops and phones on trains requiring more technological innovations to keep up with these demands. These further require onboard electric and electronic devices to meet the demand, which means that the rolling stock designs must keep improving beyond speed and safety.

The weight of rolling stock has increased over the years due to the demand for onboard equipment for heating and air conditioning. Heavy rolling stock increases damage to the rail tracks, increasing infrastructure maintenance costs. The heavy weight also increases the energy required to operate the trains and requires higher traction and braking systems (Mistry & Johnson, 2020). This means that R&D for lightweight materials for rolling stock design and manufacturing has become essential.

Signalling and communication systems

Trains cannot run safely without signalling systems. The purpose of signalling systems is to ensure the safe movement of trains on the rail track by locking movable track elements, checking the clearance of track sections, locking out conflicting movements, and generally controlling train movements to keep them safely apart (Pachl, 2020). Thus, signalling and communication systems ensure separation between trains and control points of movement for trains to get to their destination safely. There are different types of signalling, and the methods differ for each country.

Because the distance needed for trains to come to a complete halt after brakes are applied is more protracted than road vehicles, only one train can occupy a specific section of the rail track for safety purposes. A section of the rail occupied by a train is called a block. Signals in rail transport enable information on the position of a train for it to stop, slow down, or proceed with its movement. Signals have evolved from signallers raising optics and pulling levers to lineside electrical signalling and the contemporary communication-based train control (CBTC). CBTC uses telecommunications between the train and track equipment for traffic management and control. It ensures efficient and safe movement while enabling an increased train line capacity by reducing the time interval between trains travelling on the same line. The modern signalling technology enables real-time train-to-train and train-to-network communication and infrastructure components for autonomous driving technology (Clark, 2012; Hein & Ott, 2018).

Therefore, signalling and communication systems have become a high technology-based area for ensuring the safety of trains. The high technology enables many trains to operate in blocks at safe distances from each other to convey more people on the same rail line. Signalling and communication are even more essential for urban rails because they move over short distances with numerous stops. Thus, urban rail transport technology ensures frequent movement when signals and communication are automated for train detection systems. For a long time, international firms in countries that have operated trains for a longer period have developed the capacity for signalling using modern technology to ensure the safe and efficient movement of trains. It is difficult for new firms that have not gone through the evolution of rail signalling and communication subsystems to develop the technology for commercial purposes. Thus, it has become a significant drawback for emerging economies that do not already have local firms with signalling technology. Over the years, purchasing signalling and communication systems from MNCs have been the primary means of ensuring urban rail service safety for most emerging economies.

Infrastructure

Because the advantages of electric-powered trains exceed those of diesel-powered trains, most of the recent urban trains are electric-powered. But electric trains come with the construction of additional electric infrastructure. Electric-powered trains require either third-rail or overhead transmission systems (also known as a catenary system) as part of the lineside systems to provide electrical power for the movement of the rolling stock. Power components such as transformers, rectifiers, inverters and switching circuits must be constructed to provide power to the traction system of the rolling stock. These involve expertise in power supply and electronics systems specific to rail traction.

The civil engineering requirements within urban areas for rail transportation are enormous. Underground tunnels, drainage systems, overpasses and others may be difficult to construct if the expertise does not already exist. Civil works such as tunnelling and laying electric cables for electric trains may not require very highly specialised skills, but experience in successfully executing such projects ensures safety and value for money. Civil works may require several instances of high expertise for underground construction, which is very useful for densely populated areas.

Digital infrastructure has recently enabled efficient transportation through pre-board booking and payment. Cumbersome payment systems may turn away potential passengers, whereas easy payment systems are associated with modernity. Digital payment systems reduce the level of payment theft. Moreover, introducing urban rails requires an easy payment system linked to other transport systems to enable transfers and to increase passenger usage of mass public transportation. The many infrastructure requirements for urban rail, mainly metros, contribute to the long duration of their construction.

3 Industrial policy pathways for latecomer countries

Markets sometimes fail to adapt to changes for comparative advantage or to efficiently allocate resources. Therefore, governments can step in and stimulate firms to undertake investment decisions in another direction, do more of the same, or implement plans at a higher speed (Groenewegen, 2000). Industrial policy is where governments intervene in markets to influence the structure of their national economy. While governments may redirect resources to certain areas of the economy for a positive structural change, this can have a negative effect. There are instances where government interventions through industrial policy have both failed or succeeded (Aiginger & Rodrik, 2020; Etzkowitz & Brisolla, 1999). The limitations of governments to effectively implement industrial policies have been the main reason for industrial policy failures. Some countries that have rich natural resources have failed to implement industrial policy due to overreliance on the resources. Other factors that have affected successful implementation include political conflicts, and failure to transition to a more fully diversified economy (Aiginger & Rodrik, 2020). Numerous industrial policy failures have led to the situation where it has been virtually banned from official economic discourse in some countries. This, in turn, led to the ideology that the best industrial policy is *no* industrial policy and the recommendation that policymakers should enact “horizontal” policies that favour all industries equally, rather than “vertical” policies that discriminate explicitly by favouring some industries.

But in reality, all nations use industrial policy. Some nations are more successful than others, and while some nations are more open about using industrial policy, others are less open about its adoption (Ciuriak & Curtis, 2013). Indeed, the "Asian tigers" South Korea, Singapore and Taiwan have openly adopted industrial policies since the 1960s while later the Chinese government utilised it for its economic development. The adoption of industrial policy has become common and open since the global credit crunch of 2008 to 2009 (Andreoni, Chang, & Scazzieri, 2018; Ciuriak & Curtis, 2013). There are numerous benefits to industrial policy. Firstly, it serves as a tool to protect jobs and stimulate local demand. Secondly, it can be used to push for cleaner technologies and a more efficient energy use for green economy purposes. Although there is no proof that implementing industrial policy would ensure the transformation of the productive structure that would lead to sustained economic growth, the quest for economic development without an explicit industrial policy has lower possibilities for success (Moreno-Brid, 2013).

Thus, the critical question is not *whether* to adopt an industrial policy but *how* to adopt an industrial policy, given the potential disruptive political and technological change (Aiginger & Rodrik, 2020). How industrial policy can be successfully implemented in emerging economies must be different from methods used in developed economies because the former are burdened with public sector limitations and other factors mentioned above that militate against implementation. Altenburg & Lütkenhorst (2015) identified seven key lessons on how industrial policies could be successfully implemented in latecomer economies. These lessons are:

- Political leaders must have the firm will to implement national transformational projects aimed at diversifying the economy and developing new competitive advantages in higher value activities.
- The transformational projects need to build on existing or anticipated comparative advantages and define upgrading pathways.
- The transformational projects need to balance economic, social and environmental objectives.
- The industrial policy should be devised as a collaborative process of experimental learning involving stakeholders and ensuring feedback loops between learning, implementation, and impact measurement.
- The focus of the industrial policy should be on supporting innovative ideas and encouraging experimentation.
- The policy should strengthen the linkages between firms and segments of the business community.
- The policy should promote and gradually increase international and regional trade and investment links.

The industrial policies of technology latecomer countries needs to be different from developed countries. The MNCs of developed countries have already developed modern technology after many years of R&D and it is therefore not prudent for latecomer countries to "reinvent the wheel" as this would take them many years while the existing technology continues to improve. Rather, technology latecomer countries could put mechanisms in place to access the technology and capabilities already established by MNCs. Thus, latecomer industrial policy should focus on attracting FDI (foreign direct investment) in a way that leads to indigenous capability accumulation. However, it is relevant to ensure that the incoming MNCs do not undermine or eliminate indigenous firms and their technology learning capabilities.

Given the complexity of urban rail subsystems and the technical requirements, emerging economies could follow a gradual process to overcome the technical and technological barriers. Urban rail technology indigenisation policy instruments for technology latecomer economies could start from the point where (a) countries import almost everything from MNCs and tender low technical requirements to local firms.

The policy instruments could then take different forms to ensure local manufacturing and technology indigenisation through (b) MNCs are encouraged to manufacture locally; (c) MNCs enter into joint ventures (JVs) and partnerships with local firms; (d) local manufacturers produce under licensing or technology transfer agreements with MNCs; and (e) local firms manufacture rail subsystems with own intellectual property.

In (a) the manufacturing is done elsewhere and installed in the technology-receiving country. This does not enable local technology development beyond repairing skills. Most emerging and low-income countries implement urban rail technology development through this mechanism. In (b), the technology-receiving country adopts local manufacturing mandates to pull international firms to manufacture locally. A percentage local manufacturing quota may be adopted. The quota may vary depending on local technical capabilities for a particular subsystem in the country. This policy instrument aims to ensure an eventual 100 per cent local manufacturing with local skills and know-how in the country.

The next stage, (c), focuses on policies aimed at joint ventures and partnerships between local firms and MNCs with potential for technology transfer and collaborative R&D. The flow of the technology is mainly from the MNC to the local firm with limited interaction on R&D. This form of technology transfer follows what Lema & Lema (2012) describe as unconventional technology transfer.

In (d), there is a direct technology transfer where substantial interactions and collaborative R&D exchanges exist. The local firm may learn how to manufacture a subsystem from an international firm and then manufacture the same with the intellectual property license of the MNC. Another approach is where a local firm acquires a firm that already has capabilities for a subsystem and automatically has access to the technology. This unconventional technology transfer requires significant expenditure and high absorptive capabilities from the technology-receiving firm (Lema & Lema, 2012). In (e), the industrial policy favours local firms to manufacture with their intellectual property. The development of local intellectual property could be from high investments in R&D of local firms at (c) or (d). It could also be from local firms new to that market but with technological expertise in other related subsystems.

4 Urban rail development in China

4.1 Expansion of urban rail implementation

The Chinese government expects to migrate 20 million people to urban areas annually by 2035 (Woetzel et al., 2009). China is deliberately concentrating people in urban areas to maximise the benefits of urban expansion. There are already six cities with a population over 10 million; 12 cities with a population of between 5 and 10 million; 21 cities with a population of between 3 and 5 million; and 164 cities with a population of between 1 and 3 million (Bao, 2018). Overall, China expects to have 221 cities with a population above 1 million by 2035. This increasing urbanisation has implications for transportation and mobility. In recent times, the Chinese government has focused on urban rail development as a primary means of addressing the current and future demand for transport. As a result, since the beginning of the 13th Five-year Development Plan (2016-2020), 100 cities have formulated plans for urban rail transit (Bao, 2018).

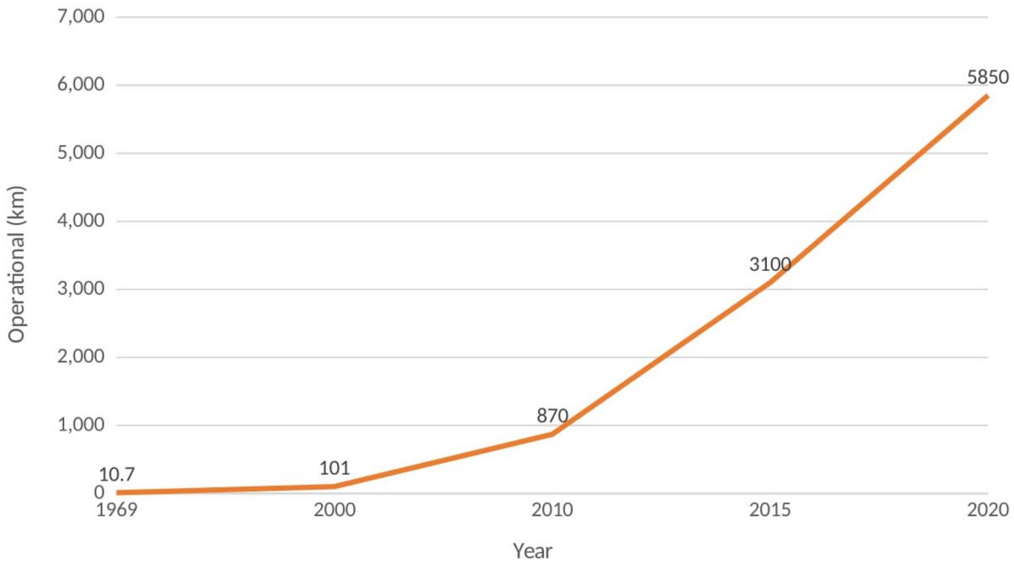
Urban rail development in mainland China has gone through a tortuous journey before an explosive growth in implementation since 2010. Urban rail development can be categorised into three stages. The first stage started with the opening of a 10.7 km metro line in 1969 in Beijing. Tianjin, Guangzhou, and Shanghai followed the metro construction in the 1980s and 1990s (Ding & Xu, 2017; Klinge, Xuelian, & Kuizhong, 2020). The technology for the rolling stock, signalling and automatic ticketing were primarily imported. Subsequently, trains were seen as a symbol of modernisation. Therefore many regions and cities submitted metro proposals to the central government for approval. But because of the high cost of importing rail technology, maintenance and the long construction period, the government suspended all metro projects except ongoing projects in Beijing, Guangzhou and Shanghai in 1995 (Q. Liu, 2020).

Towards the end of 1997, the National Development and Reformation Commission (NDRC), responsible for coordinating development projects, permitted metro implementation. This time, the policy pushed for the localisation of rail technology in China after studying the rail implementation plans submitted by the cities. An obligatory minimum percentage of local manufacturing of rail sub-components was introduced. This marked the beginning of the second stage of rail development in China. The national plan led to cooperation between MNCs and local firms to achieve the localisation strategy (Q. Liu, 2020). As a result, Alstom formed a joint venture called Shanghai Alstom Transport Electric Equipment (SATEE) with the Shanghai Electric Group in 1999 to mainly produce traction equipment. The same year, Alstom and the Shanghai Rail Traffic Equipment Development formed SATCO for manufacturing and maintaining rolling stock (Alstom, 2016). The Chinese firms that participated in the joint ventures either belonged to the China South Rail Company (CSR) or the China North Rail Company (CNR).

Besides the local manufacturing mandate and the push for joint ventures, the Ministry of Railways opted to open up to the leaders in rail technology in a quid-pro-quo agreement. Thus, they offered the entire Chinese rail market to four rail technology giants (Alstom, Bombardier, Siemens Mobility, and Kawasaki Heavy Industries) in exchange for high-speed and metro rail technology transfer in 2004 (C. Li, 2014; Lin, Qin, & Xie, 2021). As a result of these policies, the track length of operating lines increased from 101 km in 2000 (concentrated in four cities) to 870 km in 2010 (in 10 cities) (Salzberg, Mehndiratta, & Liu, 2012).

These policies ensured that international firms locally manufactured rolling stocks through joint ventures. At the same time, local capacity for rail technology subsystems increased, resulting in a reduced cost of rail implementation in China (Q. Liu, 2020). Subsequently, the rate of approval of new rail proposals and the extension of existing systems increased, ushering in the third stage of urban rail implementation boom. As a result, the metro rail lines increased to 3,100 km in 25 cities by 2015 (S. Li, 2018), and then in 2020, 30 cities had metros with 5,850 km (Urban Transport Magazine, 2021) (see Figure 5). Statista (2022), however, reported 7,354 km of metro in China. Since 2016, the length of newly operational metro lines per year has exceeded 500 km.

Figure 5: Metro rail expansion in China from 1969 to 2020



Source: Authors

4.2 Policies and implementation strategy

The construction of the first metro in Beijing was influenced by military considerations and not by mobility. The development was based on Soviet technology. However, the subsequent metro construction was based on mobility considerations with an emphasis on urban population and the cost of implementation (Loo & Li, 2006). When China began its market reforms in the late 1970s, urban population and personal incomes began to increase (Kamal-Chaoui, Leman, & Rufei, 2009). The concomitant result of increased demand for transportation and mobility led to increased motorisation as people moved to suburban areas without the requisite public transportation to match the demand.

The 10th Five-year Development Plan (2001-2005) placed cities and town-based urbanisation as one of the key policy thrusts. The 11th Five-year Development Plan (2006-2010) further promoted the urbanisation process through a balanced development of cities and towns regardless of size (Kamal-Chaoui et al., 2009). Although road development was the focus of urban transportation, the Chinese transportation plans and policies since 2002 have included medium- and long-term rail network development. In 2007, the Chinese government laid out the goal of building a comprehensive transport network for the medium- and long-term based on modern transportation technology (China Academy of Transportation Sciences, 2021). Urban rail development is intended to reduce congestion, provide efficient transportation, attract development, address air pollution, and ensure low transport-related GHGs in China; cities are at liberty to develop their own plans so far as they fit the national strategy (World Bank, 2010).

China has a long history of industrial policy. The industrial policy has been expressed through the five year planning cycles and a centrally planned economy coordinated through the National Development and Reform Commission (NDRC) (Kenderdine, 2017). In 2006, the Strategic Emerging Initiative (SEI) policy – a ten-year industrial plan – then specifically sought to upgrade advanced technologies to secure the position of technology-intensive local industries. Those industries were expected to make up 8 per cent of the Chinese economy in 2015 and 15 per cent in 2020 (ISDP [Institute for Security & Development Policy], 2018). As part of the SEI, "public and private research and development initiatives were to support Chinese companies to develop cutting-edge technologies in key sectors, accumulate intellectual property and gain access to foreign intellectual property in exchange for access to the Chinese market research and development" (ISDP, 2018).

In 2015, the Made in China 2025 industrial policy was adopted to further the SEI. One of the ten outputs of this policy is to advance the local manufacturing of rail and rail equipment by upgrading Chinese firms' manufacturing capabilities and growing them into a more technology-intensive powerhouse (ISDP, 2018; Kenderdine, 2017). The Made in China 2025 policy was linked to the 13th development plan and the current 14th development plan.

4.3 Rail technology indigenisation

Rolling stock

The policy for urban rail technology development in China is directly linked to a quest for long-distance rail. During the first phase of rail development in China (1969-1997), the high demand for rail transportation led to several experiments with indigenous electric-powered long-distance trains. The rolling stock locally manufactured during this period to the early 2000s was considered to have technological deficiencies and, therefore, not moved into mass production (Chen & Haynes, 2016). Despite the lack of commercial success at this stage, local institutions and firms had developed some capabilities for rolling stock manufacturing and other essential rail technology through continuous R&D (Chen & Haynes, 2016). China needed to navigate between relying entirely on inefficient but the relatively cheaper local production of rail technology or the purchase of efficient but expensive modern technology. Relying on local technology meant that China would produce trains with outdated technology, missing out on speed, reliability, low GHG emissions and the other benefits of modern rail.

As stated earlier, the Chinese government opted for purchasing modern rail technology by pushing for percentage mandates on local manufacturing and joint ventures between Chinese and international firms (see Table 1) (Bombardier Transportation, 2008; Loo & Li, 2006). Joint ventures were the main means by which the international firms could enter the Chinese market because not more than 30 per cent of the project cost could be imported using foreign exchange (Loo & Li, 2006). The joint ventures formed between Alstom, Bombardier, and the Chinese firms locally manufacture and provide rolling stock throughout China. In 2021, Alstom acquired Bombardier and took over its joint ventures in China (see Appendix 1). Alstom now has 11 joint venture manufacturing facilities across China and reports to have manufactured 7,194 metro, 536 monorail, and 191 tram vehicles in China (Alstom, 2022). The JVs are reported to be carrying out maintenance services for 2,252 metro vehicles.

Table 1: Selected rolling stock joint ventures in China

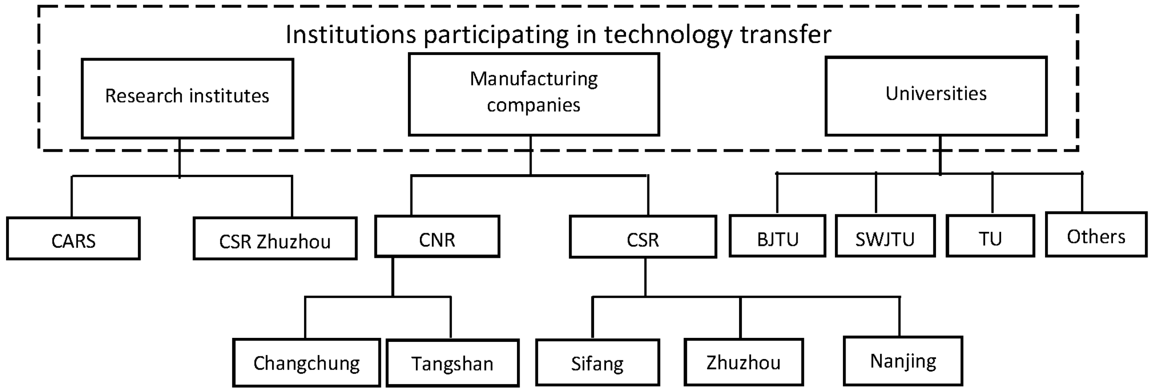
Name of joint ventures	Rail technology	Year established
Changchun Bombardier Railway vehicles Company Ltd. (CBRC) (Bombardier + CSR Changchun Railway vehicles Co. Ltd.)	Rolling stock manufacturing (also approved as Designated Localisation Enterprise)	1997
Bombardier Sifang Power (Qingdao) Transportation Ltd. (Bombardier + CSR Sifang Locomotive and Rolling stock Co. Ltd.)	Rolling stock manufacturing	1998
Shanghai Alstom Transport Electric Equipment (SATEE) (Alstom + Shanghai Electric Group)	Traction equipment supply	1999
SATCO (Alstom + Shanghai Rail Traffic Equipment Dev. Com. Ltd.)	Manufacturing and maintenance of rolling stock	1999
Bombardier CPC Propulsion System Company Ltd. (Bombardier Power ltd + Changzhou Railcar Propulsion Engineering and R&D Center)	Production, marketing and maintenance of propulsion equipment	2003
Bombardier NUG Propulsion System (Bombardier Transportation + New United Rail Transit Tech)	Manufacturing and maintenance of propulsion equipment	2003

Source: Authors

In addition to the joint ventures, the Chinese government initiated an explicit technology transfer with four major rolling stock companies – Alstom, Bombardier, Kawasaki Heavy Industries, and Siemens Mobility – in exchange for access to the Chinese market. According to Lin et al. (2021), the technology transfer had the following components:

- Joint design of train modes based on foreign prototypes but with adaptation to the local Chinese conditions
- Access to the blueprints
- Instructions on manufacturing procedures
- Training of engineers.

Figure 6: Organisational structure of technology transfer-receiving institutions in China



Source: Authors, adapted from Chen & Haynes (2016)

To assimilate the rolling stock technology, the task of R&D and manufacturing of nine critical subsystems was given to the local institutions mentioned in Figure 6. These technologies included electric motor units (EMU), bogies, traction control, traction transformers, converters, traction motors, braking systems, network control systems and EMU system integration (Chen & Haynes, 2016). Local institutions such as Zhuzhou Electric Locomotive Research Institute and the Chinese Academy of Railway Services (CARS) Rolling Stock Institute researched traction systems, network control systems, and braking systems. At the same time, CSR Nanjing Rolling Stock Manufacturing developed braking systems.

Alstom received 60 orders for high-speed train manufacturing as part of the technology transfer scheme. Among the 60 orders, Chinese engineers were allowed to observe the design and manufacture of three trains in France; six orders were imported as parts and later assembled by Chinese engineers under guidance from the foreign partners. The rest of the 51 orders were manufactured by gradually replacing the foreign parts with domestically produced parts, facilitating the absorption of the transferred technologies (Chen & Haynes, 2016; Lin et al., 2021).

Besides receiving rolling stock technology from the four companies that manufacture all rolling stock subsystems, the local Chinese firms further partnered with MNCs such as ABB, Mitsubishi Electric, and Hitachi for the technology transfer of rolling stock subsystems (Lin et al., 2021). The latter MNCs specialise in rolling stock subsystems such as traction motors, braking systems and series pantographs. In general, the two leading manufacturing companies with facilities all over China, the China South Rail (CSR) and China North Rail (CNR), rapidly absorbed the rail technology and made substantial indigenous innovations (C. Li, 2014). CSR and CNR were merged in 2015 to form the China Railway Rolling Stock Company (CRRC). CRRC is now the largest manufacturer of rolling stock globally owing to its R&D policy of "effectively digesting, absorbing and recreating imported technology, committing itself to mastering critical know-how and elevating its self-determination and originality" (CRRC [China Railway Rolling Stock Company], 2022). Table 2 shows selected urban rail projects of the CRRC technology transfer-receiving firms from MNCs. The CRRC manufacturing facility in Tangshan is a significant local metro rolling stock manufacturer for the Chinese market.

Table 2: Selected urban rail projects of technology transfer-receiving firms in China from MNCs

CRRC company	Type of urban rail rolling stock	Selected projects
Qingdao Sifang Co. Ltd	Metro	Beijing metro (2013) Singapore (2013)
Changchun Railway Co. Ltd	Metro, tram	Hong Kong metro (2012)
Tangshan Co. Ltd	Metro, tram, maglev	Maglev for Beijing (2016) Shijiazuay (2016)
Sifang Co. Ltd	Tram and metro core parts	
Zhuzhou Co. Ltd	Metro	Wuhan metro (2017) Changshan metro (2017)
Nanjing Puzhen Co. Ltd	Core parts	

Source: Authors

While most of the rolling stock manufacturing firms in China are state-owned, BYD is a private firm that has recently been involved in rolling stock manufacturing in China. BYD was established in 1995 as a battery technology developer. It then ventured into electric vehicle manufacturing because of its expertise in battery technology and became a world-renowned electric vehicle company. In 2012, the company decided to invest in monorail R&D, foreseeing the large future market in China and other parts of the world. BYD currently own patents for monorail and is the largest provider of monorail rolling stock in China since it produced the monorail at a fifth of the manufacturing cost and a third of the construction time for metros in 2017 for the city of Yinchuan (Clover, 2017). BYD is becoming a major manufacturer of monorails around the world as it has ongoing projects in Brazil, Egypt, Morocco and the Philippines (Huang, 2018).

Recently, the CRCC launched an autonomous metro in Shenzen with its self-driving train having a maximum speed of 80 km/h. The train is supported by an inbuilt multi-dimensional safety detection system which aids the train in precisely checking the rail conditions and provides information on obstacles more precisely than humans. The CRRC Datong and the State Power Investment have developed China’s first hydrogen fuel-cell hybrid locomotive. The hydrogen-fuelled locomotive has a maximum speed of 80 km/h, can operate continuously for 24 hours, and would be used for shunting, fetching and delivery services (CRRC, 2021).

The CRRC has also been exporting rail technology to cities in Africa and the United States. In 2017, the CRRC won three bids for metro rolling stock provision in the cities of Chicago, Boston and Los Angeles. The CRRC bid for the Los Angeles metro in 2017 was reported to be the highest rated technical offer and the lowest price while offering the most robust local employment programme, and the highest local manufacturing component of 60 per cent (Reuters, 2017).

Signalling and communications

Before rolling stock joint ventures in China commenced in the late 1990s, Alstom and the Chinese Railway Signal and Communication Corporation had formed a joint venture in 1986 called CASCO. CASCO currently provides signalling services to metros across Chinese cities. TST is another joint venture providing signalling services in China since 2011. TST is a joint venture between Thales SEC Transport (a French MNC) and Shanghai Electric. In 2020, the TSTCBTC 2.0 locally developed in China received China’s Urban Rail Certification, the first CBTC to be granted it (Thales, 2020). In 2021, TSTCBTC 2.0 recorded 86 seconds average turnback time of trains operating on Shanghai metro line 5. This lower turnback time would allow a higher frequency of train services, shorter headway, and make the overall metro system energy efficient.

Bombardier Transport began providing signalling and communication services to urban rails in 2008 with its CBTC which is adapted for high-frequency scheduling. Bombardier provided services to Shenzhen metro line 3, Beijing international airport, Tianjin metro lines 3 and 4, and other cities without forming a joint venture with a Chinese firm (Bombardier Transportation, 2011). However, Bombardier formed a joint venture with a private Chinese firm – New United Group – in 2015 to continue the provision of signalling services in China (Hammond, 2015) (see Table 3).

Table 3: Selected joint ventures with CBTC signalling technology in China

Name of joint venture	Year established	Selected projects
CASCO (Alstom + Chinese Railway Signal and Communication Corporation)	1986	Beijing metro line 6 Chengdu metro line 9
TST (Thales SEC Transport + Shanghai Electric)	2011	Shanghai metro line 5 & 14 Qingdao metro line 8
Bombardier NUG Signalling Solutions (Bombardier Transportation + New United Group)	2015	Changzhou metro line 1 Wuhu monorail line 1 Shenzen airport

Source: Authors

Although the three joint ventures (now only two since Alstom has acquired Bombardier Transportation) provide many signalling services in China, there are also new local firms providing signalling and communication subsystems. The Chinese telecommunication company Huawei is involved in providing urban rail communication support. Their services allow multiple uses, such as train control, dispatching, and video surveillance (Shanshan, 2018). Two other core services from Huawei that ensure safety and efficient travel are the cloud-based traffic control integrated automation system, and the urban rail data communication system.

In cooperation with the China Railway Academy of Science and Technology, Guangzhou metro developed a new CBTC for which field trials were conducted in 2010. The developed CBTC only became operational when the Guangzhou metro line 7 was opened in 2016 (H. Liu, 2020). The CRRC Zhuzhou Institute released a locally developed CBTC signalling system in 2019. The signalling system was adopted for the Changsha metro line 4 (CRRC, 2019). Another Chinese company that provides urban rail control systems and solutions is HollySis. HollySis was founded in 1993 and has been involved in rail control systems in China, including automated driverless rail systems. Beijing Traffic Control Technology Company (Beijing TCT) has also been involved in signalling and control systems provision for the Beijing metro. In 2011 (Beijing TCT) collaborated with Wind River Technologies (an international technology firm based in California) to develop communication-based train control (CBTC) for some of the metro lines in Beijing (Miller, 2011). The cooperation between the two firms involved multiple parties from the government, research, academia and industry in China.

Infrastructure

Local Chinese firms have been responsible for infrastructure development for urban rail. China Railway Engineering Company Limited (CREC) is a local Chinese engineering and construction firm with more than 100 years of construction history. It has a long history under different names. In 1950, it was two separate firms called General Bureau of Construction and General Bureau of Capital Construction. It became CREC in 1989 and later in 2007 was listed on both the Shanghai and Hong Kong stock exchanges. CREC has been responsible for three-fifths of China’s urban rail transit infrastructure projects. CREC was responsible for the construction of the first metros in China, that is, the Beijing metro line 1 (1969), the Tianjin metro line 1 (1980) and the Shanghai metro in 1993 (CREC [China Railway Engineering Company], 2019). CREC had these capabilities because of the long history of construction in China, collaborating with Soviet firms in the 1950s to 1960s and thereafter with western firms.

The China Railway Construction Corporation Limited (CRCC) is another local firm involved in urban rail civil works for both underground and above ground. The CRCC constructs rail tracks and other civil works in China and many countries outside China. CRCC has 19,072 patents for construction in general (CRCC [China Railway Construction Corporation], 2022). The firm was set up in 1948 under the name Rail Engineering Corporation.

5 Urban rail development in India

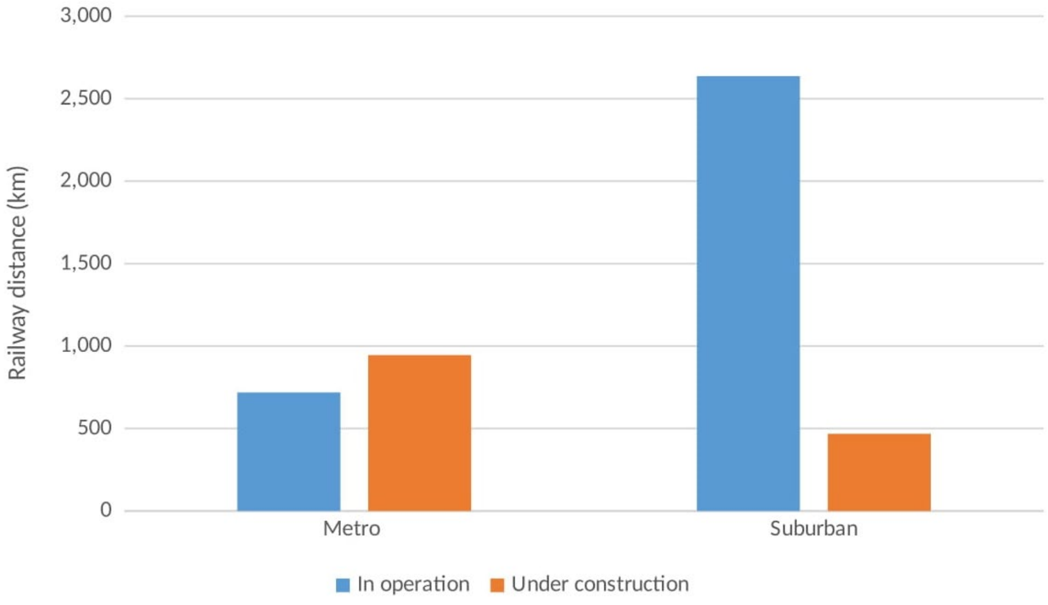
5.1 Expansion of urban rail implementation

India is rapidly urbanising. The Indian urban population in 2011 was 377.1 million representing 31 per cent of the general population. This is equal to a 3.1 per cent increase compared to the 2001 urban population (MoHUA [Ministry of Housing and Urban Affairs], 2019). There is a natural population growth because of a higher birth-to-death ratio and a high rural-urban migration trend. The trend will continue as urban growth is expected to contribute to 73 per cent of the total population increase by 2036 (NITI Aayog, 2021). The urban population is expected to increase to about 590 million by 2030 (Sankhe et al., 2010), requiring a rethink of urban policies, particularly transportation, because urban activities thrive on efficient mobility.

The Government of India’s (GOI) focus in the past was on road transportation favouring private car ownership as public investments in road transport have been higher than public transportation (Ministry of Urban Development, 2008; Verma, Harsha, & Subramanian, 2021). However, this is changing as promoting public transportation has become central to recent policies aimed at achieving sustainable transportation (Verma et al., 2021). In this context, many urban centres have developed plans for mass transit, such as rail-based transit systems, to meet the growing urban population. The national urban transport policies of 2006 and 2014 have bolstered the focus on public transportation. The “Make in India” initiative has further strengthened the shift to sustainable transportation, including improved public transportation and local manufacturing.

Public transportation began in colonial India with the horse-drawn tram in the 1870s. Since then, other modes of urban transportation have been implemented. Until recently, suburban trains and buses were the main means of public transportation in Indian urban agglomerations. Suburban trains were introduced to Mumbai in 1928, Chennai in 1931 and Kolkata in 1957 (IUT [Institute of Urban Transport (India)], 2013). The first metro (mainly underground) in India commenced operations in Kolkata in 1984 and another one (above ground) in Chennai later. The first phase of the metro was completed in 2007 in Delhi, covering 65 km. The second phase of the Delhi metro, covering 125 km, was completed in 2010. Subsequently, several cities have implemented urban rail to ensure efficient transportation for the growing urban population. Mishra (2019) reported that 17 cities had implemented metro rail besides Delhi and its suburban areas. These cities include Bangalore (42 km), Hyderabad (56 km), Kolkata (27 km), Chennai (45 km), Jaipur (9 km), Kochi (18 km), Lucknow (23 km), Mumbai (20 km), Ahmedabad (6.5 km) and Nagpur (13.5 km). In 2019, there were 718 km of operational metro rail in 14 cities, whereas 945 km are under construction in 18 cities. Some are extensions in the already mentioned cities (see Figure 7). Additionally, 2,637 km of suburban trains are in operation, while 468 are under construction. In 2014, a monorail length of 19.5 km commenced operations in Mumbai.

Figure 7: Metro and suburban trains in operation and under construction in India



Source: Authors

5.2 Policies and implementation strategy

The Ministry of Urban and Development (MoUD) now Ministry of Housing and Urban Affairs (MoHUA) published a national urban transport policy in 2006. The policy recognised the deteriorating and inadequate public transport services in urban India. It sought to push for reforms with transport technologies that ensure efficient mass mobility (MoUD [Ministry of Urban Development], 2006). In early 2014, the MHUA developed an update to the policy stressing the urgent need to provide and improve public transportation for the growing urban population and create a low emission pathway for the transport sector (MoUD, 2014).

Because urban rail is expected to address the transport demand of the growing urban population, the GOI has further developed a metro rail policy to shape the implementation of metros in Indian cities. The metro rail policy (GOI [Government of India], 2017) provides a framework for rail implementation, including justification, funding options and planning, to integrate with other forms of mass transportation services within urban areas. Urban transport is also a way for India to reduce GHG emissions by promoting varied forms of mass transportation that uses minimal fossil fuel-based energy sources (Verma et al., 2021).

The most significant policy yet is the Make in India initiative. The initiative seeks to facilitate investments, innovation, enhanced skill development, job creation and manufacturing (Mishra, 2019). It encourages indigenous manufacturing and production of goods. The Make in India initiative has technically replaced the five-year plans of the planning commission that have existed since India became independent in 1947. The National Institute for Transformation of India (NITI Aayorg) is the newly formed institution tasked with coordinating the national reforms in India. Infrastructure development is considered a significant part of growing the manufacturing sector in India (Mehta & Rajan, 2017).

The implementation of rail within the Make in India framework has been about the deliberate inclusion of indigenous firms in a phased manufacturing plan. The current plan seeks to increase the participation of Indian firms by 50 per cent in rolling stock, signalling and communications to 50 per cent by 2023 in a phased manner (Mishra, 2019). It further seeks to ensure that 80 per cent of civil works and 50 per cent of electrical items are procured locally. Since the initiative seeks to attract international finance and firms to manufacture in India as part of the package, a standard eligible criterion for procurement has been developed to ensure local firms do not lose out. This ensures that a minimum of 75 per cent tendered quantity of products with local capabilities are manufactured in India by international firms by establishing manufacturing facilities in India or partnering with local firms (Mishra, 2019). Furthermore, rail components such as rolling stock, signalling and communication systems, electrical and civil engineering systems are being standardised in India to facilitate the establishment of international firms that want to participate in providing rail infrastructure for the fast-urbanising economy.

5.3 Rail technology indigenisation

Rolling stock

The Indian Railways (2006) report elaborates on how the GOI procured Linke Hofmann Busch (LHB) coaches from Alstom-Germany on a technology transfer basis in the early 2000s to replace old rolling stock. The technology transfer involved training Indian personnel in manufacturing and repairing the coaches without the R&D component. This was thus a non-conventional technology transfer, as espoused by Lema & Lema (2012). The LHB coaches are mainly for intercity transport services. They are airconditioned, more comfortable and safer for passengers, as well as being faster than the previous coaches. The Indian state-owned rolling stock company, Integral Coach Factory (ICF), which was established in 1955, can currently manufacture about 2000 coaches per year based on the LHB technology in India. Other state-owned companies that manufacture the LHB for the Indian Railways are the Modern Coach Factory and the Rail Coach Factory.

The rolling stock for the first line of the Kolkata metro in 1984 was manufactured by ICF and Bharat Heavy Electricals Limited (BHEL), a local firm. Although ICF has been manufacturing metros for Kolkata, it does not have modern metro technology (MoUD, 2013) despite partnering with local and international firms such as Knorr-Bremse. During the first phase of the Delhi metro, BEML, an Indian government firm established in 1948, signed a technical collaboration agreement with Rotem (now Hyundai Rotem) to manufacture rolling stock for the Delhi Metro Rail Company (DMRC). BEML thus became the first indigenous firm to manufacture metro rolling stock with modern technology in India. But because BEML does not have capabilities to produce all modern metro technology subsystems, it has been collaborating with Hyundai Rotem which provides the propulsion subsystems. International firms such as Alstom and Bombardier have been involved in providing rolling stock in India. There is an instance in 2009 where metro coaches were airlifted from Bombardier's manufacturing facility in Germany to India to ensure they arrived early for commissioning (Indian Express, 2009).

As a result of plans to standardise rail technology and the requirement of 75 per cent tendered local production in India through the Make in India initiative, Bombardier and Alstom established manufacturing facilities in India to take advantage of the growing rolling stock market (see Table 4). Japanese companies providing rolling stock as part of the Japanese International Cooperation Agency (JICA) financial support are also required to manufacture at least 75 per cent of rolling stock in India through collaboration with Indian firms or by establishing independent manufacturing firms (Mishra, 2019). Recently, Indian firms such as BEML and Titagarh (a private firm) have been bidding for rolling stock manufacturing tenders because of their increased investment in their manufacturing capacity for rolling stock. For instance, BEML won a bid to produce 378 coaches for the Mumbai metro line (Mishra, 2019). The companies that participated in the bid included Bombardier-India, Alstom-India, China's CRRC, Hyundai Rotem, CAF and Titagarh. Besides Mumbai and Delhi, BEML has manufactured metros for Kolkata, Bangalore and Jaipur (BEML [Bharat Earth Movers Limited], 2019). Bombardier Transportation-India was reported to export metro coaches to Australia, Brazil, Saudi Arabia and Canada because it is relatively cheaper to produce in India (Industrial Automation, 2019).

Bombardier-India also provides engineering services for the parent company in China, the United Kingdom, Switzerland and Germany.

Titagarh acquired an Italian rolling stock manufacturing firm, Firema Transporti in 2015. This makes Titagarh the only local Indian firm with high-end carbon steel, stainless steel and aluminium technology for the rolling stock vehicle body, which is one of the specialities of Firema. Titagarh has access to Firema's propulsion system technology and has produced metro coaches in India since 2019 (Titagarh, 2021).

Table 4: International and local urban rail rolling stock firms in India

International firms	Local firms
Alstom (manufacturing in India since 2013)	BEML (established in 1948)
Bombardier (manufacturing in India since 2008)*	ICF (established in 1955)
CAF (no local manufacturing yet)	Titagarh (established in 1997)
Hyundai-Rotem (long-term partner of BEML)	
CRRC (no local manufacturing yet)	

*Bombardier's manufacturing facilities are currently owned by Alstom after the takeover.

Source: Authors

Signalling and communication

Signalling and communication technology are essential components for trains' safe movement, especially in metros with frequent operations where services are scheduled minutes apart. Mishra (2019) reported that the Indian railways depend entirely on foreign firms for this critical technology. Mishra further stated that the DMRC, Bharat Electronics Limited (BEL), and the Centre for Development of Advanced Computing (CDAC) had taken the initiative to develop the technology locally. It is believed that the indigenisation of signalling technology would reduce metro rail project costs by about 15 per cent.

In September 2020, the DMRC released a press statement that it had indigenously developed a communication-based train control signalling technology for metro railways in India. This was through the joint effort of the BEL and CDAC. Because of this development, the DMRC is expected to adopt the locally developed signalling technology while upgrading metro lines that do not use the locally developed technology (The Times of India, 2020).

Infrastructure

The growth in urban rail transportation and the overall demand in rail transportation has resulted in increased infrastructure for tracks, civil engineering structures, systems, and premises. Additionally, India's target of 100 per cent electrification of all rail transport in the country is expected to spur the growth of local firms to undertake most of the electrification within the Make in India initiative.

Generally, both indigenous and international firms in India have been involved in rail infrastructure construction. Whereas some of the indigenous firms have been in existence since India's independence in 1947, some are young firms. For instance, the ABNCO group, a major rail electrification company, was founded in 1997. Tata Projects, formed in 1979 has been involved in infrastructure development for the Delhi metro. Recently, it was reported that Afcons Infrastructure (an indigenous Indian firm founded in 1959) had been awarded a contract for the Delhi metro phase 4 underground construction works which was contested by three other indigenous firms (Shah, 2022). Local capacity for rail infrastructure systems has generally increased in India, resulting in primarily Indian firms being engaged in urban rail infrastructure development.

6 Conclusions and policy lessons

This paper has examined how two technology latecomer economies – China and India – are developing local capabilities for indigenising urban rail technology. The cases demonstrate that both China and India have adopted industrial and urban policies that have led to the expansion of urban rail transit implementation and have improved local capabilities for various different rail technology subsystems. After many years of importing high-end rail technology of rolling stock and signalling and communication systems from MNCs, China and India have successfully attracted international firms to manufacture in their respective countries. The Chinese government has applied a comprehensive industrial policy package with clear localisation targets and R&D support to develop the required technological capabilities. It put pressure on MNCs to partner and share urban rail technology subsystems with local firms leading to assimilation and reingeneering of the acquired technology. Today, local firms are mastering rolling stock technology, although they still partner with MNCs for signalling and communication despite a few local developments for metro lines. Own R&D expenditures were critical for catching up technologically. BYD for example needed only five years to become a leading monorail manufacturer based on its earlier investments in R&D in batteries and other related technologies. CRRC has become a major exporter of rail technology including entire systems. India also pursued an active technology indigenisation strategy with ambitious local content requirements, but settled for having MNCs manufacturing in India without necessarily transferring core competencies to local firms. Also, it invested less in R&D. Technological learning did happen, but not at the same scale as in China. Local Indian firms also improved their manufacturing capabilities for some rolling stock technology subsystems but still rely on MNCs for critical subsystems such as propulsion technology. Indian metros depend on MNCs for signalling and communication despite a successful local development and testing of CBTC for the Delhi metro. In contrast to rolling stock and signalling technology, low-end technology subsystems such as civil works and railway tracks are mainly implemented by local firms.

The development of local capabilities and indigenisation of the high-end technology has followed a pattern that has been referred to as the “a-e” pathways mentioned in Section 3 through the adoption of different policies. This paper focused on how policies have been adopted in the case study countries to attract MNCs, ensure local manufacturing, and foster local capabilities to understand the indigenisation of urban rail technology.

The Indian case demonstrates that the introduction of local manufacturing mandates for urban rail subsystems has resulted in improved manufacturing capabilities on Indian territory, as India now exports rolling stock, but manufacturing and exports are controlled by MNC subsidiaries. The Chinese government’s requirement of not more than 30 per cent importation of urban rail project costs has facilitated the formation of joint ventures with existing state-owned firms. These examples show that local manufacturing requirements can be used to attract MNCs to manufacture rail subsystems locally.

Whereas joint ventures with MNCs have been a key policy for knowledge transfer in China, more voluntary partnerships emerged in India. The latter also allowed for some technological learning, without enabling Indian partners to accumulate the most critical core capabilities. This is demonstrated through the relationship between BEML of India and Hyundai Rotem of South Korea for rolling stock manufacturing. BEML has won some of the rolling stock bids and manufactures the vehicle body, but Hyundai Rotem provides the high-end technology propulsion systems because BEML lacks those capabilities.

Building on Lema and Lema (2012), we distinguish between the conventional (technology licensing, joint ventures, local content requirements) and the unconventional mechanisms of technology transfer (mergers & acquisitions, R&D collaborations, hiring of experts from foreign MNCs) that are increasingly employed as countries catch up technologically. We observed some of the latter in both China and India. The CRRCs acquisition of rolling stock technology has mainly been through mergers & acquisitions and R&D collaboration. The Chinese case shows that, with the right institutional arrangement and local R&D collaboration, the acquired technology can be re-engineered to the point of having own patents. But re-engineering such high-technology products is an uphill task that can fail.

In India, Titagarh has gained a competitive advantage over Indian competitors by appropriating lightweight vehicle body technology and other modern rolling stock technology through the acquisition of the Italian firm Firema.

The adoption of industrial policy by China and India for urban rail development shows that industrial policy can improve local technological capabilities for urban rail when combined with urban policies to improve public transport services. Altenburg (2011) had earlier emphasised that the countries that managed to catch up with traditionally industrialised and high-income countries are those whose governments proactively promoted structural change by encouraging the channelling of resources into promising and socially desirable activities. Thus, it is essential in emerging economies to unlock the structural change required for sustainable rail transportation to support the growing urban population. This enables a learning process that would not be attained without industrial policy.

An industrial policy that seeks to grow local firms' expertise and that provides incentives to attract MNCs to manufacture locally through joint ventures or partnerships may be a practical way to commence growth in local capabilities development. Thus, a shift from the complete purchase of urban rail technology to local manufacturing is beneficial in terms of skills acquisition, job creation and the lower cost of urban rail technology resulting in explosive growth for the benefit of the population through improved access to services and reduced transport-related GHG emissions.

Our analysis has relied on secondary data in the form of reports, published scientific and newspaper articles, and it is therefore limited in terms of primary data. In a next step, we intend to analyse patent data as a usuful proxy for technological capabilities. It is also limited to mainly English language published articles, meaning available secondary information, particularly in the case of China, is missing. Another limitation of the report is the choice of countries as a representative for emerging economies. Although China and India are notable in their adoption of industrial policy for urban rail transport, their population size and number of cities provide economic advantages unavailable to other emerging economies. Nevertheless, the cases provide insights into how urban policies aimed at public transit development through industrial policy can be used to develop local capabilities for technology subsystems. Moreover, emerging economies or technology latecomers without population advantages could use their regional population and demand for urban rail to leverage rail technology indigenisation other than as individual countries.

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Appendix 1

Alstom's rolling stock JVs in China after taking over Bombardier

Location and name	Product
Changchun (CBRC JV)	Manufacturing facility for metro vehicles
Changzhou (BNP JV)	Manufacturing facility for traction system
Changzhou (BNS JV)	Manufacturing facility for signalling system
Liuzhou JV	manufacturing facility for monorail
Qingdao (BST JV)	Manufacturing facility for metro vehicles
Qingdao (BTRES JV)	Manufacturing facility for bogies
Shanghai (SATEE JV)	Electric equipment manufacturing facility
Shanghai (SHBRT JV)	Metro maintenance service
Wuhu (PBTS JV)	Manufacturing facility for monorail
Xi'An JV	Electric equipment manufacturing facility

Source: Alstom (2022)