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Published in:
Industrial and Corporate Change

DOI (link to publication from Publisher):
10.1093/ICC/DTAA038

Publication date:
2020

Document Version
Early version, also known as pre-print

Citation for published version (APA):
Landini, F., Lema, R., & Malerba, F. (2020). Demand-led catch-up: a history-friendly model of latecomer development in the global green economy. *Industrial and Corporate Change*, *29*(5), 1297–1318. https://doi.org/10.1093/ICC/DTAA038

Landini, Fabio, Lema, Rasmus, & Malerba, Franco. (2020): 'Demand-led catch-up: a history-friendly model of latecomer development in the global green economy'. *Industrial and Corporate Change*, *29*(5), 1297–1318.
https://doi.org/10.1093/icc/dtaa038

Demand-Led Catch-Up: A History-Friendly Model of Latecomer Development in the Global Green Economy

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Abstract

This article examines the role played by demand in catching up and in leadership changes in green industries, motivated by the belief that demand-led catch-up is a prevalent pathway in such industries. The paper first examines stylised cases of sectoral green catch-up by China in which the local market and domestic demand played an important role before the sector started expanding globally. In particular, the focus is on three industries: wind, biomass and hydropower. Then it uses a history-friendly model to study the effects of a major increase in domestic demand (a 'demand window') in a green industry. The baseline simulation first examines the effects of a demand window in promoting learning and capability building by latecomers and in triggering a catch-up process. Then, the counterfactual simulations show that (a) a technological discontinuity which takes place after the demand window could reduce the effectiveness of the demand window in the catch-up process; (b) the specific timing of the demand window could significantly alter the dynamic patterns of catch-up; (c) protectionism is a necessary condition for the demand window to have its effect; and (d) regimes of slow capability accumulation could turn out to be beneficial for the latecomer when a technological discontinuity follows the demand window. These results can help policymakers in identifying key conditions related to demand-led catch-up strategies.

Keywords: catch-up, windows of opportunity, demand, energy, green, sustainability, sectoral system, industry evolution, history-friendly models

JEL Code: L10; O10; O20; O30; Q20; Q40

1 Introduction

In recent decades, the emergence of a ‘Green Techno-Economic Paradigm’ (Freeman, 1992) has characterised the world economy. As Mazzucato and Perez (2015) mentioned, a green redirection and transformation of the economy is becoming the next big technological and market opportunity, with innumerable actions and activities already under way in the private sector and in public policy. The literature on the relationship between the ‘green turn’ in the global economy and corporate and national economic development is extensive, but it has mainly focused on advanced economies. Recently, rising powers such as China and India, as well as other emerging economies, have extended the analysis about green growth also to latecomer countries. In this respect the discussion has moved beyond jobs and new venture creation and is now focused also on the development of new global comparative advantages in green industries, along with the creation of innovative and internationally competitive domestic firms promoted through ‘green industrial policy’ (Rodrik, 2014).

Thus, the discussion on China, India and other emerging economies has shifted to catch-up and leapfrogging in green sectors. Several factors can be identified at the base of the process of catch-up and change in industrial leadership in green sectors: they may be related to the emergence of windows of opportunity in some of the basic elements of green sectoral systems (Lema et al., 2020). In this respect, it is useful to draw on the work of Lee and Malerba (2017), who distinguish between three distinct windows which might open during an industry’s development. These are (a) major changes in technology, (b) changes in the size and nature of market demand and (c) changes in institutions and public policy. While considering all three windows, in this paper we mainly focus on drastic changes in domestic demand (called ‘demand windows’), eventually supported by public policies. In general, the changing role, relevance and nature of domestic demand is important in influencing the evolution of industries, the rate of technological change and the development of capabilities (Malerba et al., 2007; Mowery and Rosenberg, 1993).Green innovation research focused on advanced economies has often highlighted the importance of demand pull and lead markets (Beise and Rennings, 2005; Wüstenhagen and Bilharz, 2006). In this paper, we move the analysis to the economic catch-up of emerging economic leaders and latecomer countries and claim that domestic demand-led catch-up has been a particularly prevalent pathway in the green industries of these countries. We also show that deliberated and directed policies such as incentives to consumers and users, public procurement and the building of advanced infrastructure policies have facilitated the working of domestic demand in affecting catch-up.

Based on stylised evidence regarding the role of domestic demand derived from the cases of three sectors (i.e. wind, biomass and hydropower), this paper uses a history-friendly model of catching up to study the effect of the opening of a demand window. It does so by exploring the role of domestic demand in the catch-up process in a rigorous and analytical way. The basic structure of the model is not new: it derives from previous contributions to study industrial catch-up in different contexts (see Landini et al., 2017; Landini and Malerba, 2017). The novelty in this case is that the model is used to investigate a completely different issue, namely the role of domestic demand in favouring (and eventually hampering) catching up. The history-friendly model is calibrated to replicate the cases of wind energy, biomass and hydropower in broad terms. While in the past history-friendly models have been criticised for being tailored to a specific industry, their application to different industries (as done in this paper) increases the extent to which results from the model can be generalised. In this paper, the model allows to conduct some experiments that explore the relationship between demand and technological windows, and the effects of the timing of the introduction of the different demand and technological discontinuities.

The major findings of the experiments are that a) a technological discontinuity that occurs after the demand window reduces the effectiveness of the catch-up process; b) the timing of the demand window significantly alters the dynamic patterns of catch-up; and c) protectionism is a necessary condition for the demand window to have its effect. An additional intriguing finding is that regimes of slow capability accumulation turn out to be beneficial when a technological discontinuity takes place because the slow pace of capability accumulation reduces the lock-in effect and allows latecomers to take advantage of the larger internal demand due to the demand window.

The paper is organised as follows. A discussion on catch-up by latecomer countries and of the role of domestic demand in this process, with insights from renewable energy in China, is provided in Section 2. In Section 3, a history-friendly model of catch-up is used to examine the role of demand in fostering catch-up by latecomers. Section 4 follows with experiments in which changes in some of the factors that affect the catch-up process are presented. Section 5 discusses the main findings and, finally, Section 7 concludes the paper.

2 Demand-led catch-up and leadership change in green industries

2.1 Catch-up and demand windows

In this paper we use the term catch-up with reference to the attainment of significant worldwide market shares in a given industry. The pathways for attaining such increases in market shares reflect the fact that latecomer countries and firms accumulate over time advanced technological, organisational and market capabilities. This view of catch-up does not imply that latecomers necessarily follow the footsteps of the pioneers and take similar pathways along specified stages of development. On the contrary, it has been shown that catch-up could imply a variety of different trajectories and pathways, depending on the nature and combination of different factors (Lee and Malerba, 2017).

To understand how catch-up and leapfrogging occur, it is useful to examine industries as sectoral systems (Malerba, 2002) and to pay attention to discontinuities and ruptures in the evolution of a sectoral system in terms of 'windows of opportunity'. For catch-up and leapfrogging to be effective, however, the opening of a window must be coupled with a response by domestic firms and by the sectoral system of the catching-up country (Lee and Malerba, 2017). The response by domestic firms of the latecomer country depends on their level of capabilities and their learning processes, while the response by the sectoral system depends on the level of education, the features of the university and public research systems, the role of an active public policy and the presence of appropriate institutions and financial organisations. While the role of technological windows and of institutional windows has been extensively examined in the literature (see, for example, Perez and Soete, 1988; Malerba and Nelson, 2011), the demand window has received less attention so far. A demand window, and in particular domestic demand, may be present for several reasons. One is the classic reason that significant or increasing domestic demand in an emerging economy gives domestic firms the possibility to enter an industry, to grow and to accumulate capabilities because it is constituted by low-end markets that require low-price products not addressed by multinational corporations. Consequently, by focusing on this demand, catching-up firms obtain economies of scale in production, learn by doing, develop technological and marketing capabilities, and grow in size. In addition, in several cases, local demand is composed by groups of local users who need products tailored to specific needs that cannot be addressed by (or are not attractive enough to) multinational corporations. In this way, latecomer firms can survive, learn and grow. The examples discussed by Malerba et al. (2017) are cases in point. In a sense, the peculiarities and differences of local demand with respect to global demand create a test bed and a shelter for new latecomer firms, which allow them to enter the domestic market, learn and grow, because they do not face intense competition from multinational corporations. In this sense, local demand can start a virtuous cycle of learning, capability building and growth that eventually leads the catch-up firms to market dominance.

Trajectories driven by local demand can differ significantly from those driven by exports and associated with 'learning by exporting' (see, for example, Salomon and Shaver, 2005). The literature on global value chains has shown that insertion into such chains can provide opportunities for fast upgrading for firms in developing countries, but only up to a point. Further upgrading requires, in fact, the development of design, innovation and marketing capabilities (Gereffi, 1999; Humphrey and Schmitz, 2002). Local markets might provide a superior avenue for acquisition of those capabilities required for industrial leadership (Lee et al., 2018; Lema et al., 2019; Navas-Alemán, 2011).

Another major factor related to the role of domestic demand is the home-made effect (Diodato et al., 2018). Often a bias in consumers' choices exists because consumers infer quality from the products' country of origin (Dinnie, 2004), in particular for differentiated durable and luxury consumer goods for which quality is imperfectly observable before purchase (Godey et al., 2012). A case in point is indeed the catch-up dynamics in the wine industry, where in recent years some producers (in emerging countries, such as Chile, and in developed countries, such as Australia) have managed to take a sizeable share of the world market. These producers certainly had to learn how to make good wine. However, they also made a huge effort to get consumers to acknowledge that their bottles could compare to those from Italy or France (Morrison and Rabellotti, 2017).

As far as innovation is concerned, it must be noted that extensive literature has documented that innovations can be stimulated in response to demand (Mowery and Rosenberg, 1993). A large or growing demand provides incentives for firms to invest in research and development (R&D) expenditures, therefore increasing the probability of introducing innovations. Moreover, demand itself can be a source of innovation. There are various ways in which this may take place. First, the learning and product innovations of domestic producers are significantly shaped by the interaction between producers and users (Lundvall, 1985, 1992; von Hippel, 1976). The feedback and information provided by users often prove a significant source of innovative ideas for producers or suggest ways to improve existing products, often leading to real co-invention between producers and users. In addition, users themselves may be the sources of innovation. Domestic lead users may innovate on their own to develop solutions for their specific needs before the bulk of the marketplace even recognises the same needs (von Hippel, 1986). Experimental users (Malerba et al., 2007) may be willing to try emerging technologies and to attribute intrinsic merit to a product simply because it embodies a new technology. User entrepreneurs may end up producing and commercialising products or services that they have first developed for their own use (Hienerth, 2006; Shah and Tripsas, 2007), while user industry spinouts from firms in the user industry may apply their downstream contextual knowledge to new products and services in an upstream industry (Adams et al., 2015). In all these cases, domestic demand and domestic users strengthen the capabilities and the roster of firms in the domestic industry.

It must be noted that in several cases a demand window is complemented by public policy. In fact the public procurement of new technologies and products can drastically increase domestic demand. This policy has proven to be quite effective to support the growth of domestic demand in the face of tough international competition and to stimulate innovation by domestic firms (Edler and Georghiou, 2007; Edquist and Zabala-Iturriagagoitia, 2012). In addition, policies favouring adoption can support demand. In the case of green technologies, because of their public good nature, governments worldwide have introduced a range of demand-side measures to promote technology adoption and diffusion and to make green investment attractive (Altenburg and Engelmeier, 2013). Feed-in tariffs are also widely used to subsidise technologies which are not yet cost-competitive with non-green alternatives. Finally, tendering systems for long-term supply contracts, mandatory purchasing requirements, tax rebates and preferential access to energy grids can be used.

In the next section, we will present the cases of three Chinese green sectors (wind energy, hydropower and biomass energy) in which demand has facilitated catch-up by Chinese firms.

2.2 Demand windows in Chinese green sectors

The purpose of this section is to illustrate the role of demand windows in the development of three green sectors in China. In a later section, we discuss further how the demand windows interacted with other factors to determine the specificity of the trajectories in the sectors.

A. Wind industry. Although the *wind industry* in China dates back to the 1980s when experimentation projects brought in by European firms (mainly German and Danish) started to take place, it was not until the mid-2000s that the industry really started to grow. From 2003 on, domestic demand for wind turbines took off with the Wind Power Concession Programme. It was, however, with the renewable energy law of 2005 that the domestic industry really developed (Nahm, 2017). According to Dai et al. (2020) and Kirkegaard (2017), the growth of wind energy in China is a direct result of this law, which created demand-side stimuli for local firms. The policy basket included two types of demand creation: the mandatory purchasing of wind energy by utilities (from 2008) and a feed-in tariff (from 2009) for market creation. In addition, the law provided support for R&D and active facilitation of university–industry linkages, and the policy basket included local content requirements which were in effect from 2005 to 2009.

By 2017, China had a total cumulative installed wind production capacity of 188 GW out of the of the world's cumulative total of 540 GW (GWEC 2018). The rapid deployment of wind energy was almost exclusively undertaken by local firms. Although there were no Chinese firms in the global top 10 (market shares) in 2000, in 2018, half of the top 10 firms were Chinese, with a combined global market share of more than 30 per cent (Haakonsson et al., 2020).

B. Biomass industry. Historically, the most important *biomass*-producing countries were all located in Europe and North America: therefore, leading firms from advanced economies dominated this industry (Hansen et al., 2016). However, in 2005, the first renewable energy law in China became a turning point in the global industry (Hansen and Hansen, 2020). Like in the wind sector, this law included a generous feed-in tariff for biomass power plants and a bold target of 24 GW installed capacity for biomass energy by 2020, offering significant incentives for investments in biomass projects.

In the biomass industry, demand-side subsidies are extremely important and a key condition for biomass firms' competitiveness (Christensen, 2015). Indeed, state intervention in the form of feed-in tariffs resulted in a period of rapid sectoral growth (Binz et al., 2017). The initial demand-side stimulus subsidy of RMB 0.25 per kWh was adjusted upwards with an additional premium of RMB 0.10 when it became apparent that domestic firms were unable to make a profitable business (Christensen, 2015).

Overall, this demand-led industrial development strategy proved highly effective. While there was no biomass-generating capacity in China prior to the renewable energy law in 2005, ten years later, more than 5 GW had been installed, bringing the country to par with the traditional lead markets in Germany and the UK (Hansen and Hansen, 2020).

C. Hydropower industry. The development of the Chinese *hydropower* industry is a case of initial domestic demand creation, learning in the sectoral innovation system and subsequent overseas expansion in export markets (see Zhou et al., 2019).[1] Unlike wind energy and biomass, this sector developed prior to the renewable energy law, as the initial source of demand reflected the overall need for electricity to fuel China's rapidly growing economy during the industrialisation of modern China. It was during the 1970s and 1980s that the modern hydropower industry began its embryonic stage with funding from the National Planning Economy Committee, the World Bank and the Asian Development Bank, all supporting domestic demand creation.

Domestically, the 2000 to 2005 period was an inflection point in China, where the rate of growth increased to overtake the USA and the EU as the largest global market (Earth Policy Institute, 2020). At the same time, in the early 2000s, the World Bank and most other sources of loans from Western countries decided to abandon financial investments in hydropower due to criticisms related to social and environmental effects. This created a gap in supply and funding that Chinese Engineering, Procurement and Construction (EPC) firms and supply chain firms filled in collaboration with the China Export-Import Bank. Initially, investments were mainly located in emerging markets, but over time, the business expanded to Europe and other advanced economies (Han and Webber, 2020; Liu and Dunford, 2016).

Before 2010, Europe was the clear market leader with 61.2 per cent (USD 19.65 billion) of the internationally traded market for hydropower projects, whereas China was a comparatively small player with 10.2 per cent of the market. However, in the second period (2011–2018), China became the leader with 44.8 per cent (USD 20.33 billion) of the market, and Europe declined in both absolute and relative terms (FDI Intelligence, 2018).

2.3 A dynamic view of demand-led catching up in green sectors

These three trajectories of catch-up in wind, biomass and hydro have been all influenced significantly by the timing and sequence of internal demand-side polices. However, demand-led catch-up is likely to unfold differently depending on a range of different factors and the way in which they come together in distinct sequences and complementarities. There is

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[1] While hydro is 'green' in the sense of providing low-carbon energy, there are often other environmental impacts, including effects on local environmental ecosystems. Similarly, other green energy industries might have environmental implications, such as use of rare earth metals in wind turbines or of farmland for bioenergy. Of course, there are trade-offs involved in the deployment of most green energy technologies.

therefore the need to explore in a consistent and rigorous way the specific mechanisms at the base of such positive role of demand, and at the same time to maintain a dynamic approach, which is required when catch-up processes are analysed.

To advance hypotheses about the nature of such possible demand-led trajectories, the next sections (Sections 3 and 4) use a history-friendly model informed by the cases discussed in this section. History-friendly models are evolutionary models that aim to capture the evolutionary process of industrial dynamics and to illustrate the mechanisms proposed by the verbal 'appreciative theory' based on the empirical analysis of an industry (Malerba, Nelson, Orsenigo and Winter, 2016). They are simulation models based on the reconstruction of the key factors explaining the dynamics of an industry and have been applied to many industries. For a more general discussion, see Malerba et al. (2016). For this paper, we rely on a previous model of industrial catch-up discussed by Landini et al. (2017) and Landini and Malerba (2017).

Differently from these previous history-friendly models, we explicitly focus on the effects of demand windows and their interactions with other drivers of catch-up such as technological discontinuities, policy interventions and learning patterns. In the following sections, we present a brief outline of the model. For a detailed and formal description, see the Appendix.

3 A history-friendly model of demand-led catch-up in green industries

3.1 Overview

We consider an industry with two main components: the market space and the technology space. The former is a characterisation of consumers' preferences for the products and their characteristics. Consumers can be both individuals and private or public firms (e.g. electricity suppliers). The technology space is a characterisation of the innovation opportunities available to firms within a given technological paradigm (Dosi, 1982). Firms can take advantage of such opportunities via R&D activities (Freeman, 1979). Both the market space and the technology space are subject to discontinuities. In the former they are the result of government interventions, which increase the consumer base in a given country. In the latter, they follow the emergence of a new technological paradigm, which enables new (and superior) technological alternatives to be pursued. In both cases, discontinuities open windows of opportunity for catch-up.

The link between the market space and the technology space is established by firms' activities. Firms search the technology space to improve the techniques used in production and sell products in the market. Firms are heterogeneous both in terms of the techniques they discover and the capabilities they accumulate.

Firms and consumers can belong to one out of two competing countries. Firms of each country have access to the same technology space and can serve two distinct markets: the national market and the foreign market. At the beginning of the simulation, the industry is born only in one country. We call the latter the incumbent. After some period, an embryonic industry is born also in the other country, which we call the latecomer. Once the industry is born in both countries, firms compete internationally to gain market shares. The country whose firms serve the largest portion of the market is called the 'leader country'.

In the following paragraphs we describe each component of the model in more detail.

3.2 Technology space

The technology space consists of an ordered vector of techniques. Firms search the technology space to find new techniques. Each technique is distinguished by a specific 'merit' and can be used to develop one product (single-product firm). The merit reflects how good the technique is given the current technological conditions. We keep the definition of technical merit general enough to encompass different types of innovation, such as product, process and organisational innovations (e.g. change of business model). Techniques are distributed according to a beta cumulative distribution function, whose shape reflect different types of technology, e.g. increasing versus decreasing returns. Previous works showed that these types of returns lead to different industry-level characteristics in terms of concentration and entry barriers, which significantly affects the catch-up dynamics (Landini and Malerba, 2017). In this paper, to be consistent with the cases of biomass, hydropower and wind, we consider a technology with increasing returns.

When the industry is born, the technology space is bounded by an initial technical frontier. This frontier corresponds to the best technique that can be chosen given the initial technological paradigm. Following a technological discontinuity, this frontier can shift allowing firms to search an expanded technology space (see below).

3.3 Market activities

Firms are born with the propensity to serve the national market first. To serve the foreign market, they face a sunk cost that can be paid only once a sufficiently large amount of financial resources are accumulated in an ‘export account’ (see below). In addition, firms that serve their national market enjoy an advantage over foreign firms in the form of public subsidies that cover part of the price paid by national consumers. Finally, we assume that when serving the foreign market, firms are subject to export tariffs.

The probability that the product of a firm is sold in the market depends on three components: the merit of the technique used in production, the capabilities of the firm and the price, together with the public subsidies and export tariffs discussed previously. To lend some credibility to the model, we can imagine merit to capture technical and objective features of a given product (e.g. speed and reliability of installed plants) and capabilities as managerial and organisational routines related to how the product is produced, marketed and distributed (e.g. management practices). The former is the result of the activities that firms carry out to explore the technological space; the latter is a firm-specific trait that can improve over time. The combination of merit and capabilities determines the perceived quality of the product. Demand is vertically fragmented (Shaked and Sutton, 1982) thus, depending on the quality thresholds of consumers, distinct market segments exist. Firms can access a given market segment only if their product satisfies the minimum quality threshold of that segment. It follows that the greater the perceived quality of the product, the larger the number of market segments that can be accessed and thus the greater the market share that can be achieved. At the same time, the likelihood for a product to be purchased within a given market segment depends negatively on its price, positively on the public subsidies a firm receives and negatively on the export tariffs to which a firm is subjected.

The total market share of a firm is the sum of the market shares across all segments that the firm serves (both at home and abroad). A country’s market share is the sum of the market shares of all the firms of that country.

3.4 Price, profit and industry dynamics

Firms set prices according to a mark-up rule. The size of the mark-up depends on the elasticity of demand (negatively) and the firm’s market power (positively), i.e. the firm’s market share. The firm's total profit is computed as the sum of the profits obtained in the two countries.

Firm entry and exit depend on performance. In every period, there is a positive probability that a cohort of new firms enters the industry in any given country. New entrants search the technology space and if they find a suitable technique they serve the market. Firms that at the end of any period have a total market share lower than a positive exit threshold go bankrupt and exit the industry. This exit threshold is assumed to be the same for both countries.

The total number of consumers in the two countries changes over time following a logistic path. These changes are due to causes not explicitly modelled, such as technology adoption and diffusion of new products.

3.5 Innovation activities

Technical change occurs through the innovation activities carried out by firms. The latter are modelled as follows. In each period, firms invest a fixed fraction of the profit earned in the previous period in an R&D account, which is used to finance innovation activities. The remaining part of the profits is invested in an export account, which is used to finance export (i.e. to cover the sunk cost associated with foreign market entry, see above).

Innovation activities consist of searching procedures within the technical landscape. In each period, firms have the chance to extract a number of techniques proportional to the amount of resources invested in the R&D account. Once a new technique is discovered, it receives a patent, and no other firm in the industry can use it. If more than one new technique is found in the same period, firms adopt the one with the highest merit.

Although the technology space is common to all countries, the process of searching is not. In particular, we assume that country-specific organisations and institutions contribute to spread information, which affect the pace and direction of searching (Mazzoleni and Nelson, 2007). Firms that have the opportunity to innovate within a given paradigm do not know their actual position in the technology space and randomly search the portion of the space that is available (given the technical frontier). If no firm in the country has chosen any of the techniques associated with the given paradigm, then search is driven by a uniform distribution. Once a new technique is found, however, all firms of that country start searching using a beta cumulative distribution whose shape changes depending on the quality of the new techniques discovered in the country. The larger the latter's average merit, the higher the probability that good techniques (i.e. techniques that are close to the frontier) are drawn. This endogenous change in the shape of the beta cumulative distribution introduces a country-level effect on the search dynamics: depending on the firms that survive in any given country, the rate at which the technical frontier is approached will differ. As a result, the technology accumulated over time by each country will differ, and the accumulation process will be driven by country-specific factors, such as the size of the domestic market (which affects the amount of resources that can be invested in R&D) and the design of innovation systems (which affects learning; see below).

3.6 Discontinuities

Industry evolution is marked by demand and technology discontinuities. At certain periods, for reasons not explicitly modelled (think, for instance, of government decisions and/or innovations taking place in other sectors of the economy), a new set of consumers and/or a new technological paradigm emerges. Demand discontinuities allow firms to expand their operation, enlarging their economic returns. Technology discontinuities shift the technological frontier. Firms adopting the new technology have access to an expanded technical landscape and thus have the chance to extract techniques with greater technical merit.

The probability that the firm of a given country perceives the existence of the new technology depends on two components: individual capabilities (positively) and the country's performance while using the old technology (negatively). The first component operates at the firm level and captures the role of learning by doing and absorptive capacity in favouring the understanding of new technologies (Cohen and Levinthal, 1990). The second component operates instead at the country level and captures the effects of technological complementarities and path dependency in delaying the perception new technologies (Perez and Soete, 1988; Malerba, 2002).

If a firm perceives the existence of the new technology, the choice to adopt depends on the comparison of two components: the negative impact of the new technology on the capabilities accumulated by the firm within the old paradigm (capability loss, i.e. cost of technology adoption) and the expected gain in terms of technical merit that the new technology offers (technical gain). Whenever the capability loss is smaller (greater) than the expected technical gain, the firm chooses (not) to adopt.

3.7 Learning

Firms are born with a given set of heterogeneous capabilities. Capabilities accumulate over time following a learning path that combines both increasing returns and long-run saturation. The latter, reflects the fact that, being developed within a given technological paradigm, capabilities tend to run into diminishing returns as the innovative potential of a given technology gets exhausted. At the same time, firms' learning benefits from systemic interactions with other firms, as well as from the support by country-specific organisations and institutions (Lundvall, 1992). Therefore, the higher the average level of capabilities in the country, the faster learning. This in turn implies that, although in the long run the capabilities of both countries will converge, the speed at which such convergence proceeds will differ.

4 Simulating variations in catch-up trajectories

The above model does not allow for analytical, closed-form solutions. Therefore, we rely on simulations to analyse its behaviour. We proceed in two steps. First, we calibrate the model to generate a stylised episode of demand-led catch-up, such as the ones observed in the Chinese green sectors discussed above. Second, we carry out theory-driven counterfactual experiments. In particular, we ask whether the identified pattern of catch-up could have been different had some key parameters taken alternative values.

It is important to note that the dynamic patterns shown below are emergent properties of the model. To eliminate across-run variability due to stochastic components, we perform extensive Monte Carlo analyses. Consequently, all results refer to cross-run averages over 600 replications.

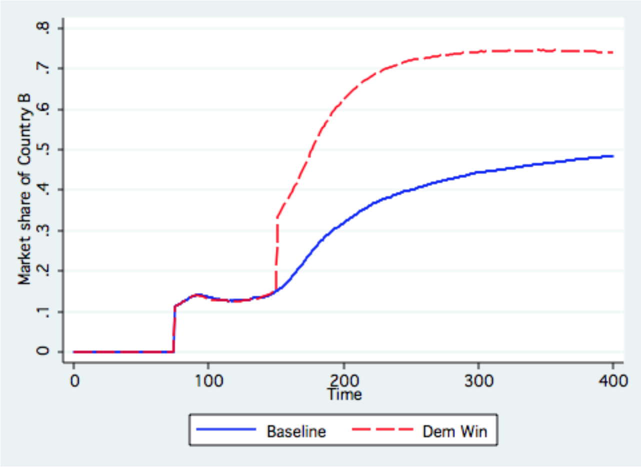
4.1 Baseline and history-friendly runs

In our two-country setting, we assume the incumbent to represent the rest of the world, the latecomer being China. We generally refer to the former as Country A and the latter as Country B. The timing of the simulation is as follows. Firms of Country A (A-firms) are the first ones to enter the industry. After 75 periods (one period corresponds to approximately one month), some firms of Country B (B-firms) enter the industry too. The creation of indigenous firms in the latecomer country is driven by the emergence of some local demand, which itself derives from an expansion of Country B's consumer needs. In addition, B-firms benefit from lower cost of production. At the same time, however, the latecomer firms face an initial gap in terms of capabilities with respect to the incumbents, because they are younger and less experienced. Moreover, the market size of Country B is relatively small at its inception due to the embryonic nature of early industrial experimentations (see above). All of these factors combined make it difficult for catch-up to occur.

Starting from this setting, public and private supports to local demand creation in Country B enlarge the consumer base of Country B by five times, creating a discontinuity in demand (*demand-based window*). After this sudden increase, the demand of Country B continues to expand following the same logistic path, with the result that at the end of the period, the size of the market is five times the size it would have achieved had the window not opened. Under a wide range of parameter settings, such discontinuity will create a window of opportunity for the latecomer. In our history-friendly simulations, we set parameters to generate a case of clear leadership change driven by demand. It is important to note that, as in most history-friendly models, our main objective is not to exactly replicate the observed market shares, which would be impossible given the simplified setting with only two competing countries. Rather, our focus is on the dynamic pattern of competition between countries that leads the incumbent to become the industry leader after the discontinuity. For more details about the methodology of history-friendly simulations, see Malerba et al. (2016).

Figure 1 reports the evolution of Country B's market shares (the market share of Country A being the complement to one). To assist the reader, we show results for the history-friendly runs alongside a hypothetical baseline scenario where no discontinuity in demand opens. At the time of entrance (period 75), Country B controls less than 15 per cent of the market. This share remains nearly constant until period 150. Then, as soon as the demand discontinuity opens, Country B's market share quickly rises above 30 per cent and then steadily expands. By the end of the simulation, Country B is by far the industry leader, a position that would not have been achieved in the alternative baseline scenario.

Figure 1: Baseline scenario and demand window scenario in Country B (market shares)

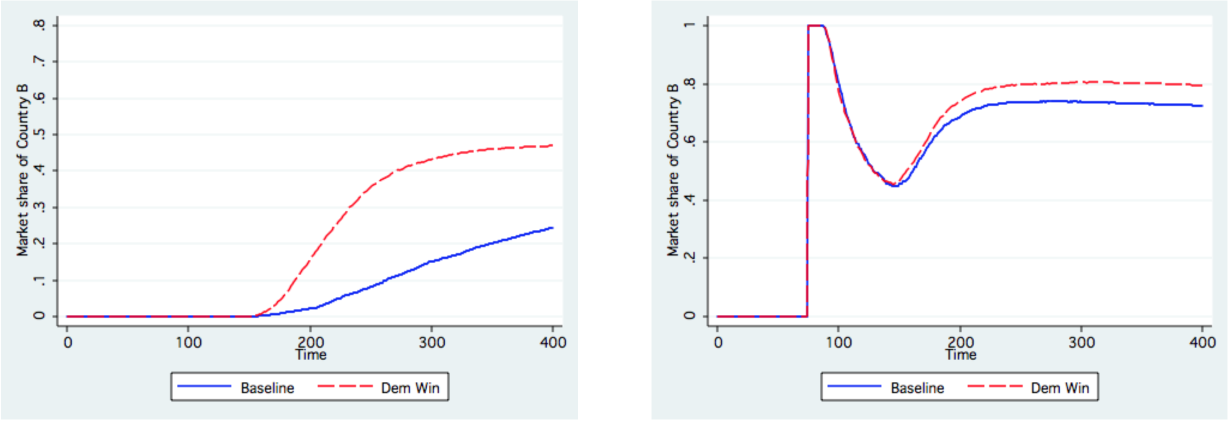


Interestingly, the market dynamics at the global level reflect similar trends within countries. In this respect, panels a) and b) of Figure 2 report the market shares of Country B in Countries A and B, respectively. After the demand discontinuity, Country B's market share rises significantly in both submarkets, suggesting that the overall performance is not only driven by a 'home country bias' effect. The expansion of the local demand allows B-firms to become more competitive and to enlarge their consumer base, even in Country A.

Figure 2: Baseline and demand window scenario in Country A and Country B (market shares)

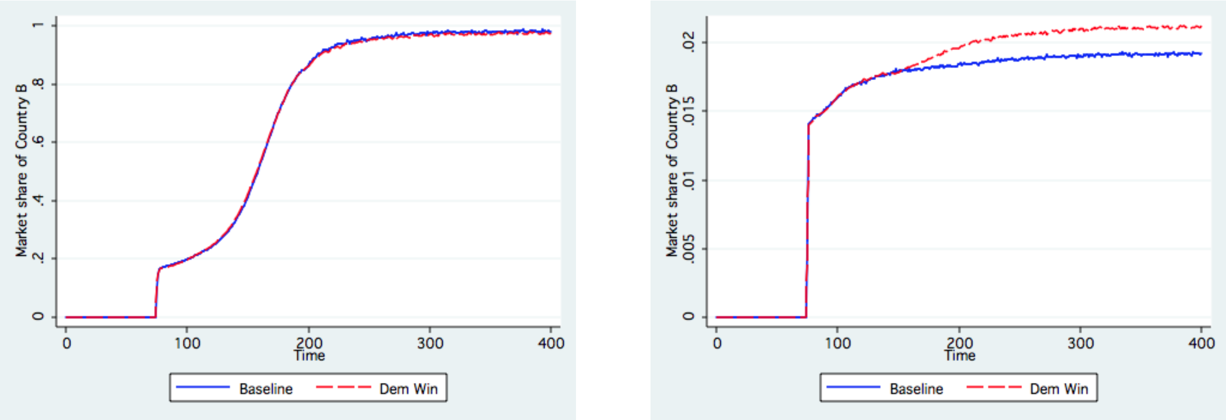
a) B's market share in Country A (incumbent)

b) B's market share in Country B (latecomer)



An interesting question is whether such improved competitiveness of B-firms is due to a learning effect (i.e. the increase in local demand allows firms to improve their market position and thus accumulate more capabilities) or a search effect (i.e. a larger consumer base allows firms to earn more profit and thus to invest more resources in R&D). To distinguish between these two effects, in Figure 3, we report the evolution of capabilities (panel a) and technical merit (panel b). The results suggest that the increased performance of Country B is driven primarily by a search effect.

Figure 3: Capabilities and technical merit baseline and demand window scenarios in Country B (market shares)


a) Average capabilities

b) Average technical merit

4.2 The four experiments

4.2.1 Experiment 1: Technology window after the demand window

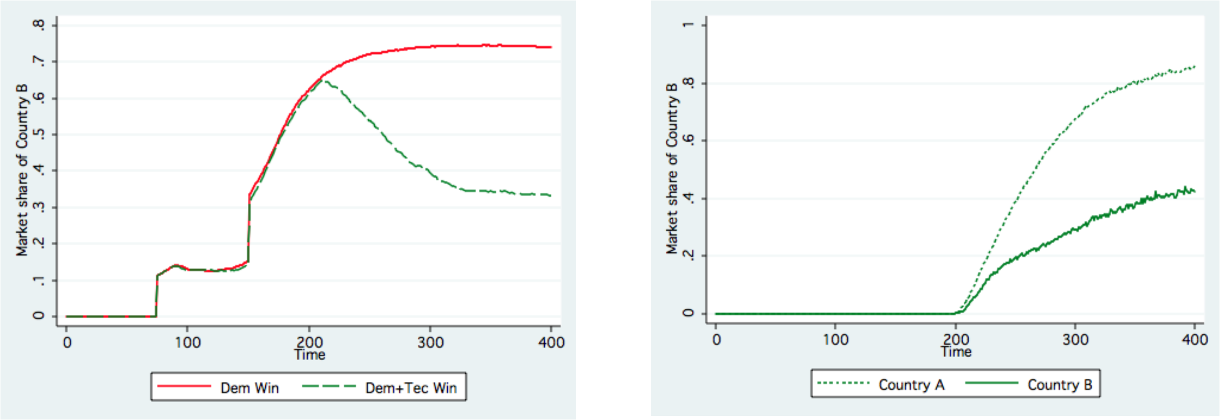
Because demand windows are proven to be important sources of successful catch-up, it is interesting to examine how they interact with other key determinants of industrial leadership change such as technological discontinuities. For this reason, the first experiment that we run introduces a technology window after the demand window. In particular, at period 200, a new technology emerges, creating a technological discontinuity (*technology-based window*). Initially, firms are born with a technology that enables searching over the first 40 per cent of the landscape. When the second-generation technology emerges, it allows firms to search the remaining 60 per cent of the landscape. The adoption of the new technology is therefore key to access a superior set of techniques, but it can be limited by the existence of technological lock-in.

Figure 4 reports the results of Experiment 1. Panel a) shows the evolution of Country B's market share, while panel b) reports the rate of technology adoption in Country A and Country B. When the technological discontinuity opens (period 200), Country B is the market leader with more than 60 per cent of consumers. As a result, B-firms take some time before recognising the importance of the new technology. The rate of technology adoption is therefore slower in Country B than in Country A. It follows that the competitiveness of B-firms worsens, as does their market position. In a few periods, Country B's market share drops from above 60 per cent to below 40 per cent. By the end of the simulation, the market share of Country B is reduced to nearly 30 per cent. Because of the lock-in effect, the opening of the technology window cancels out all the advantages brought about by the earlier demand window, leading to a worse result in terms of catch-up (even compared with the baseline scenario where no window opens up; see above). From the policy point of view, the main message that can be derived from this experiment is that the combinations of different windows of opportunity is not always positive for catch-up and can sometimes have deleterious effects (for similar evidence about the relationship between demand-based and technology-based discontinuities in the setting of the Chinese telecommunication industry, see Li et al., 2019).

Figure 4: Demand window scenario vs. demand with technology window scenario (market shares)

a) Market share of Country B (latecomer)

a) Technology adoption of Country A (incumbent) and Country B (latecomer)

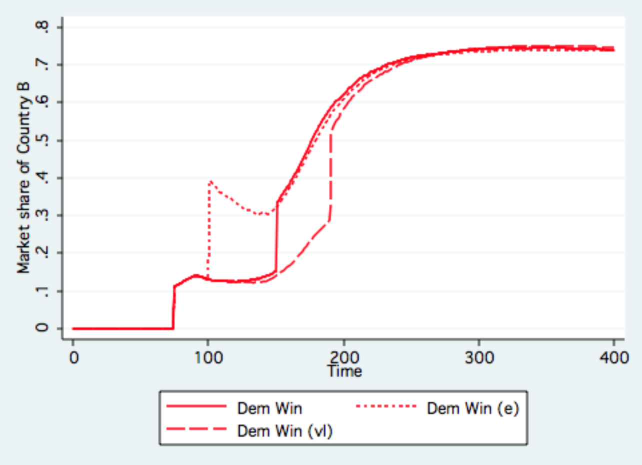


4.2.2 *Experiment 2: The timing of the demand window*

In addition to the interplay among windows of different natures, our model offers the opportunity to investigate another factor that plays an important role in a dynamic understanding of the catch-up process, namely the timing of the windows. In our second experiment, we thus shift the opening of the demand window back and forth to investigate whether the timing of the window affects the market dynamics. In particular, in the 'Early' scenario, the demand-based window opens at period 100 (i.e. only 25 periods after the entrance of Country B), whereas in the 'Late' scenario it opens at period 190.

Figure 5 reports the results of Experiment 2. Interestingly, neither the 'Early' nor the 'Late' scenario has a significant effect on the overall market outcome. In all scenarios, the market share of Country B converges to nearly 75 per cent by the end of the simulation. What is different, however, is the market dynamics right after the opening of the window. While in the case of 'Late' demand Country B's market share steadily rises, after the 'Early' demand there is an initial decline. When the demand window opens, B-firms that enter early do not have the time to accumulate capabilities and are therefore more vulnerable to the competitive pressure of A-firms. As a result, B-firms initially lose market share, falling from nearly 40 per cent in period 100 to nearly 30 per cent in period 150. As soon as learning becomes more effective, however, B-firms improve their competitiveness and, due to their cost advantage, can easily recover market shares.

Figure 5: Early vs. Late demand window in Country B (market share)



Overall, the results of this experiment reveal that, rather than affecting the final result in terms of market shares, the timing of demand windows can significantly change the dynamic patterns through which that result is achieved. When the opening occurs at a relatively early stage of the industry evolution, the latecomer country should take into account an initial period of significant disruption during which its total market share might actually decline.

4.2.3 Experiment 3: Removal of protectionism

One of the variables that played an important role in sustaining China's strategy of internal demand-led catch-up in green industries is protectionism. To single out its effect, we run a third experiment where, starting from our history-friendly parameterisation, we remove the fixed cost of export in both countries, making it easier for both countries to penetrate foreign markets. The resulting competitive dynamic should thus be interpreted as ensuing from the opening of an internal demand window in less protected world markets.

Figure 6 shows the evolution of Country B's market share in this scenario. We notice two main effects. Before the demand discontinuity opens, the market share of B-firms is lower than in the history-friendly run. This suggests that protectionism indeed favours the latecomer by shielding it from competitive A-firms. After the discontinuity, B-firms can take advantage of the larger indigenous demand, but at a lower rate compared to the history-friendly runs. The removal of protectionism indeed allows a larger number of A-firms to penetrate Country B and benefit from the extension of the consumer base. This interpretation is confirmed by the within-country market dynamics reported in Figure 7.

Figure 6: Demand window with low protectionism in Country B (market share)

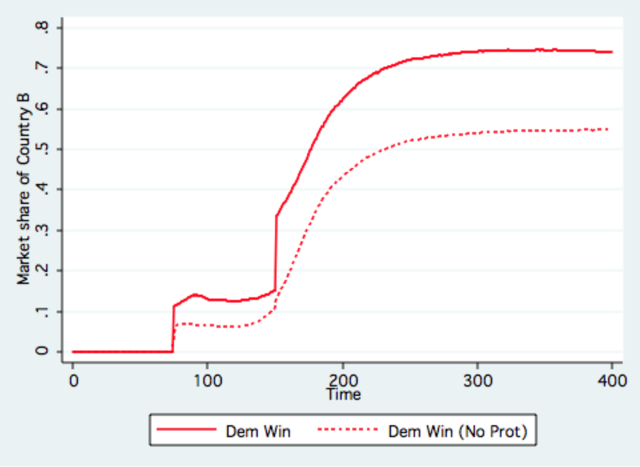
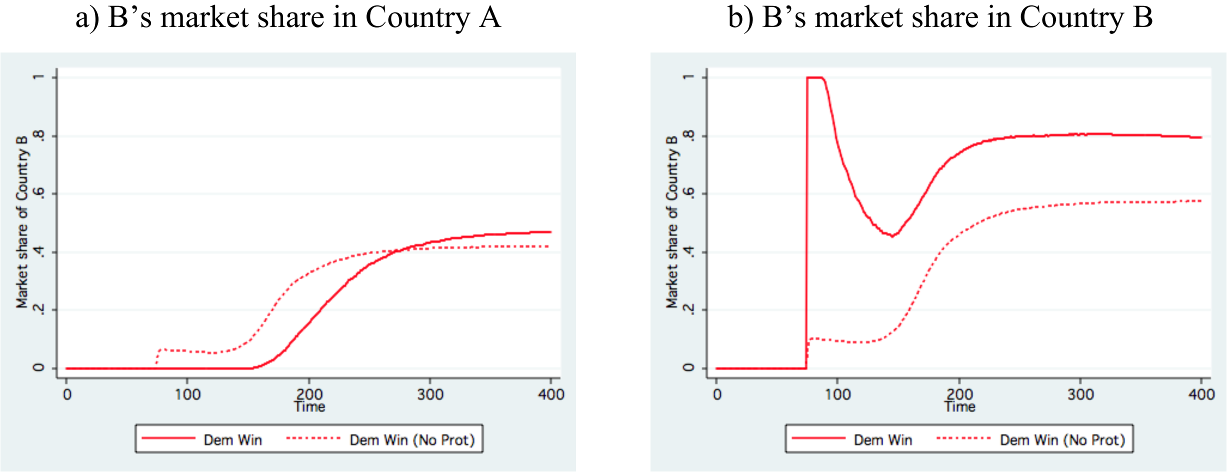


Figure 7: Demand window with low protectionism: Country A vs. Country B (market shares)


a) B’s market share in Country A

b) B’s market share in Country B

Overall, this evidence provides support for the well-known infant industry argument in support of catching up. In particular, the results of our simulations reveal that some degree of protectionism is indeed necessary for demand windows to effectively lead to a change of industrial leadership in favour of the latecomer (for similar evidence that relates protectionism with technological discontinuities, see Landini and Malerba, 2017).[2]

4.2.4 Experiment 4: Slow capability accumulation

The last experiment that we run focuses on the regime of capability accumulation. In particular, we investigate the extent to which a reduction (by half) of the speed of capability accumulation in both countries affects the competitive dynamics. This is the case, for instance, when the industry is radically new and, due to uncertainty and experimentation, the accumulation of capabilities proceeds somewhat slowly. This experiment is run both in the case in which only the demand window opens and in the case in which the demand window is followed by a technology window. The decrease in capability accumulation has two main effects: on the one hand, it creates an advantage for the incumbent country, as the latecomer takes more time to close the initial capability gap; on the other hand, it makes it more difficult for both countries to achieve the capability frontier, with the result that the competitive pressure among firms is reduced. The results of this experiment are reported in Figure 8. Panel a) shows the evolution of Country B's market share in the setting with the demand window alone, whereas panel b) reports the same statistics for the scenario with both demand-based and technology-based discontinuities. Interestingly, we notice that the regime of capability accumulation has a significant effect on the market dynamics. When there is only a demand window, the performance of Country B is much worse than in the history-friendly runs. Right after the window, the market share of B-firms remains steadily below 20 per cent, and by the end of the simulation, it reaches around 50 per cent.

The result is different, however, when a technology window opens sometime after the demand window. In the latter case, the relatively bad performance after the demand window becomes a strength as the new technology emerges. The slowness of capability accumulation coupled with the low market shares implies that B-firms are less likely to incur some form of technological lock-in. As a result, they adopt the new technology sooner than the competitors do, although at a relatively slow rate due to the low average capabilities. Still, the different rate of adoption in the two countries is sufficient to let B-firms acquire a significant portion

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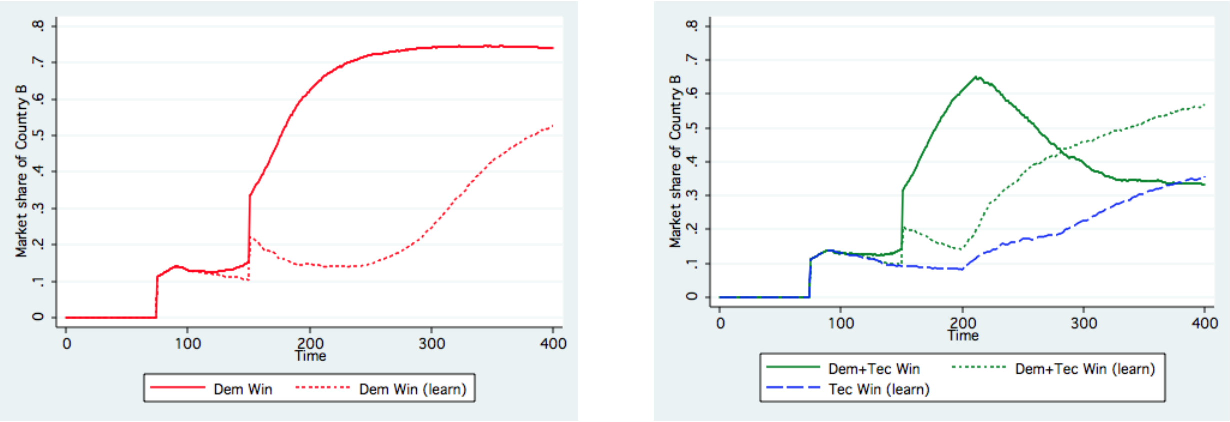
[2] It is important to stress that under the current World Trade Organization rules, protectionism is not always an option for latecomer countries. Still, it is interesting to analyse the role it could play in support of a catch-up strategy based on a local demand window.

of the market. Moreover, the larger size of the market allows B-firms to grow faster compared with the case in which the demand window does not open. By the end of the simulation, Country B becomes the new market leader, obtaining nearly 60 per cent of the market.

Figure 8: Demand window *in a regime of slow capability accumulation* in Country B (market shares)



a) Dem Win

b) Dem + Tec Wind

Once again, the results of the simulations point towards the existence of interesting and complex interplays between demand windows and other drivers of catching up. While in the presence of high learning opportunities the opening of a technology window after a demand window can have deleterious effects on the performance of the latecomer country (because of lock-in; see Experiment 1), in a regime of slow capability accumulation, the result is actually reversed. The slower pace of capability accumulation implies that the demand window alone is not enough to support a successful catch-up process. However, when a subsequent technology window opens, latecomer firms might benefit from the weaker lock-in effect and eventually take full advantage of the larger internal consumer base. It follows that in this setting, the opening of a technology window amplifies the initial weak effect of the demand window, leading to a shift of industrial leadership.

5 Discussion

5.1 How industry-specific are the results of the empirical and modelling analysis?

The results of the history-friendly model are generalizable to other industries that share some similarities with the sectors examined. In this respect, it is important to note that wind, biomass and hydro power are complex product systems industries (Davies and Brady, 2000). These industries are characterised by high service intensity, project-organised sales, professional users and investment-centred global value chains. Importantly, the demand windows in these green industries are typically characterised by major capital requirements, high levels of subsidies and a domestic supply chain, which has a propensity to serve the domestic market first.

In terms of technology type and characteristics of incumbent and latecomer firms, our key tenet is that these three green industries have some common features, which make local demand creation particularly relevant for catch-up, although the specific role of a domestic demand window in an industry is ultimately sector specific. We briefly elaborate on both the technology space (see Section 3.2) and the market space (see Section 3.3).

The *technology spaces* in these sectors are characterised by the following features (Dai et al., 2020; Hansen and Hansen, 2020; Zhou et al., 2019):

- A dominant design has emerged in 'core technology' in all three cases, with a three-bladed, vertical axis turbine in wind, a 'Francis turbine', as the main component in hydro[3] and standardised designs for the construction of high-pressure and high-temperature boiler plants in biomass. However, there are variations in deployment technology, such as in onshore or offshore wind power or the different design options available in hydro energy.
- Innovation is mainly incremental, centred on both the core technology sphere (e.g. turbines) and the deployment sphere (e.g. reservoir and dam construction). Improvements in technologies and capabilities means that capacity factors steadily increase in all three technologies.

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[3] The Francis turbine is today the most widely used hydro turbine. It was developed by James Francis in 1848, and although there have been competing designs, this inward-flow reaction turbine is now the global standard.

- They are project industries with large share of 'heavy-industry' activity dominated by EPC firms and their supply chains. They depend less on R&D for deployment because construction-related civil works activities account a large share, not least in hydropower (where it accounts for as much as 85 per cent of upfront investments, whereas powerhouse equipment or 'core technology', such as turbines, generators and transformers, only account for 15 per cent; IRENA, 2012).

The *market spaces* in these industries are different from market spaces in typical manufacturing or service industries:

- As outlined earlier, they have increasingly received extraordinary demand support as compared with conventional energy because of the energy-environmental benefits of zero direct carbon emissions and localised air pollution.
- Demand patterns are influenced by idiosyncratic industry characteristics in terms of public good nature, tendency towards natural monopoly and high state involvement in electricity provision worldwide. From the outset, this was even more pronounced in China than in other countries, as it developed alongside the economic reforms initiated by Deng Xiaoping. Energy infrastructure provision and distribution is still considered a core national strategic priority in China as well as in other countries. Hence, these sectors are not always fully exposed to market-based competition.
- The sectors are characterised by a segment of professional users, typically highly state-directed utilities and electricity distribution enterprises. Price, measured as the levelised cost of energy (LCOE), is a key parameter in terms of demand preferences. The other major user preference is for a steady (non-intermittent) and manageable supply of electricity from the power plant. This means the ability to adjust the volume of supply of electricity depending on end-user demand load at a given point in time.

These salient features are important because they shape industrial dynamics and the trajectory of the sector's development. They are a good reference point for discussing salient characteristics of some green industries that are also process intensive and characterised by incremental innovation and dominant designs. Other industries, such as concentrated solar power, share the process intensity but have faster technological change. Therefore, they differ mainly in this respect. Differences across green industries are also present in the market structure and competition, in particular with respect to the national and international dimension and tradability.

5.2 The role of local industry protection

In Section 4, it was suggested that to be effective, demand window creation needs to be combined with industrial policies for infant industry protection and localisation. The reason for this is that there is a risk that the economic benefits and learning potentials arising from demand creation might be captured by multinationals from incumbent countries, thus working in a way which is counterproductive to catch-up objectives.

The insights obtained through the simulation experiment are consistent with recent economic theorising around green industrial policy (Altenburg and Rodrik, 2017) and energy-related industrial policies in emerging economies, such as Argentina, Brazil, China, India, Malaysia and Turkey (Lewis, 2014). These countries have introduced measures which combine different types of subsidies with infant industry protection, import substitution and localisation policies. Hence, these policies have generated international political tensions and several requests for consultation in the World Trade Organization (WTO).

In the three baseline cases – biomass, wind and hydro energy – the very early stages of industry development were characterised by openness, inflows of external knowledge and the involvement of multinationals for technology transfer and expertise. However, except for very early stages, multinationals have never gained significant stakes in the local industry. Conventional market mechanisms with the use of competitive bidding open to multinationals have been largely bypassed.

For example, hydro energy is subject to natural protection, both because it is under the domain of public procurement and because there are few internationally traded elements of hydro plant construction, apart from powerhouse components. In wind multinationals were involved in the early stages but complained of unfair treatment in competitive bidding rounds for large-scale projects and in the policies for sourcing local project developers. Today, multinationals have very low market shares in the Chinese wind industry. To support catching up, the government successfully enforced local content requirements during the critical phase of firm- and system-level capability accumulation (Lema et al., 2016). In this case, several aspects of policy design and implementation rendered the policy effective, such as the temporal nature of local content requirements and the matching of these local content requirements to the capability levels in the supply chain (Dai et al., 2020).

However, the small but growing literature on green industrial policy in emerging economies suggests that while the use of protective measures is widespread, their effectiveness is varied. The local content measures in India’s National Solar Mission were rather effective in promoting domestic manufacturing, but because of disjunctions and insufficient investments in the sectoral innovation system, they were less effective in building the capabilities required for innovation ‘to sustain competitiveness and make India a solar leader’ (Johnson, 2016: 191). In South Africa’s Renewable Energy Independent Power Projects Procurement Program, the insights generated from other countries about the effectiveness of industry protection were not sufficiently incorporated into the programme (Leigland and Eberhard, 2018).

5.3 Demand window, technological change and the speed of learning

Even if local industry protection measures are carefully designed and implemented, the successful exploitation of demand windows for catching up and the overall trajectory of industry evolution depends on a range of other factors. As the history-friendly model indicates, these include the characteristics and timing of the demand window and the relationship between this window and the characteristics of technological change in the industry. The simulation experiment (Experiment 1) suggests that demand window creation might not translate into realised catch-up opportunities if there are subsequent technological discontinuities (a technology window emerges). This is because incumbents with stronger capabilities might have better opportunities to stretch (deeper and broader) their existing capabilities to exploit the technological windows, whereas latecomers might experience aborted catch-up trajectories (Lee and Malerba, 2017).

In this respect, Dai et al.(2020). show that in wind the capabilities developed in the exploitation of the original demand window proved insufficient and were misdirected when meeting the new demand for offshore wind. A current question is whether the shift to offshore wind may constitute an insurmountable technological discontinuity in the long run. In other words, problems related to capability lock-in could occur if a significant technological discontinuity does not allow existing capabilities to be stretched to meet new requirements in the offshore wind regime.

On the contrary, sectors such as solar and biomass are relatively mature industries with few recent major technological disruptions. However, they face the possibility of major sectoral disruptions in the longer run caused by, respectively, unfolding shifts to new technologies for advanced biomass for power generation and for concentrated solar power (Gosens et al., 2020; Hansen and Hansen, 2020). Such shifts might render technological capabilities acquired in the existing demand window obsolete unless they are matched by a corresponding renewal of capabilities.

The previous section also suggests that low learning rates can have a detrimental effect on demand-led catch-up when latecomers take more time to close the gap in capabilities vis-à-vis incumbents. However, in a regime of slow capability accumulation, the advent of a technological discontinuity may mean that given a certain level of capabilities, latecomers have leapfrogging advantages (fewer sunk costs and fewer established routines) which can enable them to rapidly acquire the new technology and then gain market shares faster than incumbents. In general, learning rates are significantly influenced by the features of the domestic sectoral innovation systems and the national support from public authorities.

The interplay between capability accumulation and technological change is exemplified once again by the case of wind energy in China. While China has accumulated significant capabilities in the wind energy industry, spurred mainly by growth in domestic demand, this industry has witnessed a notable technological discontinuity at the global level with a significant shift from onshore to offshore deployment. As mentioned above, this shift has had consequences for the Chinese industry, because China had built and deepened capabilities relevant for the onshore growth trajectory dominant in the domestic market (Lema et al., 2016).

However, as emphasised by Dai et al., (2020), the direction of search is now moving into 'post-turbine technology' focusing on energy system integration and management. The industry is thus witnessing the unfolding of a second technological discontinuity which could provide a new window of opportunity. It remains to be seen how China will fare in the new context, because this new technology window is still in an era of ferment and it is not known how fast and effectively incumbent firms will react to this technology. Yet, with China's advances in IT knowledge base, hardware and software, it is likely that domestic firms may benefit from this window of opportunity and eventually take full advantage of the large internal consumer base which is investing heavily in IT-dependent 'smart grids'. In sum, further developments in the wind sector may depend on continued investment and on capability stretching with respect to the integration of advanced software solutions, storage and monitoring. Thus the shift to 'post turbine' systems technologies may allow the sector to escape the 'technological discontinuity trap' and eventually lead to China to a position of industrial leadership

6 Conclusion

This paper has shown how domestic demand can play a major role in the catching up of latecomer countries in green technologies and has taken the cases of three green sectors in China as examples. It has started with the analysis and discussion of the development of wind, biomass and hydropower; identified the factors leading to China's catch-up; and then used a history-friendly model to study the role of a demand window in the catching-up process. The paper also presented some simulation experiments regarding (a) how a technological discontinuity occurring after a demand window may reduce the effectiveness of the catch-up process; (b) how the specific timing of the demand window may significantly alter the dynamic patterns of catch-up; (c) how protectionism is a necessary condition for the demand window to have its effect; and (d) how a regime of slow capability accumulation could turn out to be beneficial in the case of a technological discontinuity.

More fundamentally, this paper stresses that the role of the domestic demand in fostering catch-up has to be seen in a dynamic, evolutionary way. Dynamics here has to be viewed in terms of the opening of a demand of large size that sets in motion learning and capability building in latecomer firms and triggers a process of catch-up by the latecomer country. However, the timing of a demand window might be too early or too late, thus affecting quite differently the evolution of the catching-up process. In sum, this paper places a major emphasis on the time dimension of catch-up, something that analysts and policymakers should carefully take into account and that Bell (2006) pointed out as a key understudied dimension.

Within this dynamic, evolutionary perspective, the sequence and order of events in the catch-up process play a fundamental role (Malerba et al., 2016). For catch-up, in fact, it makes a major difference if the demand window follows a technology window (thus allowing the building up of learning and capabilities in a given technology), or if the demand window is followed by a technology window (which destroys much of the technology-specific learning and capability building that the demand window helped to create). This view of evolutionary dynamics as a sequence of events has to be carefully considered by policymakers when policies are launched, and the effects of policies have to be assessed. Furthermore, this paper shows that this sequence of events can be very well analysed for policy purposes with simulation models (Landini and Malerba, 2017).

Finally, for policymakers, this paper points to the need to consider complementarities among factors and to use systems of policies. Coherently with a sectoral system perspective, in fact, for catch-up often a single policy – such as one creating a demand window – is not enough. A wide range of other policies, which de facto have to consider the presence of feedbacks and complementarities among different parts of the sectoral system, need to be launched. For example, demand windows often need to be supplemented by protectionist measures and by policies that foster the adoption of new technologies, particularly when a technological window takes place near the demand window. Of course, this is a general point, and in this paper it has been proposed at the theoretical level. In practice, as far as protectionism is concerned, WTO rules might block the implementation of direct protectionist measures. However, different kinds of 'home biases' are increasingly embodied in the notion of 'new green deals'. In both emerging and advanced economies measures are increasingly introduced aimed at localising the economic benefits of sustainable green transitions to enhance the prospects of green growth at home.

Acknowledgments

We are grateful for constructive comments from Roberta Rabellotti, Xiaolan Fu, two anonymous reviewers and participants in the 'Green Windows Workshops' in Beijing and Copenhagen. The research was supported by AAU Grant 771107 and the Sino-Danish Centre for Education and Research (SDC).

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Appendix

In the following sections we present a formal description of the model.

A.1 Technology space

The technology space consists of an ordered vector of J (>0) techniques. The "merit" of a technique is captured by coefficient r_j ($\in$ [0,1]), with j ($\in$ [0, J]) being the technique's position within the landscape. Technical merit is distributed according to a beta cumulative distribution function, where parameters α and β define the shape of the technology landscape.

When the industry is born, the technology space is bounded by an initial frontier ζ_1 ($\in$ [0, J]). Firms can pick any technique j such that $r_j \leq r_{\zeta_1}$. Following a technological discontinuity, this frontier can shift. Firms that adopt the new technology can pick techniques such that $r_{\zeta_1} \leq r_j \leq r_{\zeta_2}$, where ζ_2 is the new frontier.

Firms have limited information on the shape and composition of the technology landscape. In particular, they don't know *ex-ante* the merit and position of potential techniques. Firms randomly search the technology space and if they find a technique with higher merit than the one they are currently adopting they switch to the new technique. Without loss of generality, we denote with $r_{f,t}$ the merit of the technique adopted by firm f at time t.

A.2 Market activities

Firms can sell their product in both the national and the foreign markets. To serve foreign markets firms face a sunk cost c_E (> 0), which is paid out of an "export account" (see below). The propensity for the product of firm f to be sold in the market depends on three components: technical merit ($r_{f,t}$), capabilities ($\theta_{f,t} \in$ [0,1]), and price ($p_{f,t}$ > 0), together with the size of public subsidies ($\sigma_k \in [0,1]$) and export tariffs ($v_l \in [0,1]$). Let consumers be uniformly distributed along the real unit segment. Demand is vertically fragmented and distinct market segments exist. In any of such segment, the propensity for the product of firm f coming from country k ($\in$ {A, B}) to be sold to a consumer i ($\in$ [0,1]) of country l ($\in$ {A, B}) is:

$$U(i)^{k,l}_{f,s,t} = \begin{cases} 0 & , if \quad q_{f,t} < Q_l(i) \\ \dfrac{q_{f,t}}{(1-\sigma_k)p_{f,t}} & , if \quad q_{f,t} \geq Q_l(i) \wedge k = l \\ \dfrac{q_{f,t}}{(1+\nu_l)p_{f,t}} & , if \quad q_{f,t} \geq Q_l(i) \wedge k \neq l \end{cases} \tag{1}$$

where *s* stands for the market segment (see below), $q_{f,t} = \theta_{f,t} \cdot r_{f,t}$ is the perceived quality of the product, and *Q*(.) is a beta cumulative distribution that assigns to each consumer *i* a minimum perceived quality requirement *Q*(*i*). The degree of vertical fragmentation is the same in all markets.

For any degree of vertical fragmentation, market shares are computed as follows. Consider the market of country *l* and denote as F^l the set of firms that in any period sell in that country a product with strictly positive perceived quality. Assuming quality is observable, we can arrange firms in a non-descending order by quality, in such a way that $q_{1,t} \leq q_{f,t} \leq q_{F^l,t}$ for all $f \in F^l$. Let $Q^{-1}(q_{f,t})$ be the fraction of consumers whose quality threshold is no higher than $q_{f,t}$. On this basis, we can define $S^l = |F^l|$ market segments such that $S^l_1 = Q^{-1}(q_{1,t})$ and $S^l_s = Q^{-1}(q_{f=s,t}) - Q^{-1}(q_{f=s-1,t})$. Then, the market share of firm *f* coming from country *k* in segment *s* is:

$$m^l_{f,s,t} = \frac{U^{k,l}_{f,s,t}}{\sum_{f=s}^{S^l} U^{k,l}_{f,s,t}} \tag{2}$$

On this basis, the market share of firm *f* in the whole country *l* is simply the sum of its shares in the segments weighted by the segment's relative size, that is:

$$m^l_{f,t} = \sum_{s=1}^{S^l} m^l_{f,s,t} \cdot \frac{S^l_s}{Q^{-1}(q_{F^l,t})} \tag{3}$$

Firm *f*'s market share in the whole industry can be thus written as:

$$m_{f,t} = \frac{m_{f,t}^{A}\chi_t^{A} + m_{f,t}^{B}\chi_t^{B}}{\chi_t^{A} + \chi_t^{B}} \tag{4}$$

where $\chi_t^l (> 0)$ is the number of consumers in country *l*. It follows that the total portion of the market covered by the firms of country *k* at time *t* is simply the sum of all the shares of the firms that belong to that country, that is:

$$m_t^k = \sum_{f \in F_{k,t}} m_{f,t} \tag{5}$$

where $F_{k,t}$ is the set of firms that belong to country *k* and are alive at time *t*.

A.3 Price, profit and industry dynamics

When serving the market in country *l* firms of country *k* set price according to:

$$p_{f,t}^{k,l} = c_k(1 + w_{f,t}^l) \tag{6}$$

where c_k is the marginal cost of production that we assume to be lower for country *B* than for country *A* and constant over time. At time *t* firms choose the mark-up $w_{f,t}^l$ in order to maximize profit, given the elasticity of demand η (>1) and the local competitive pressure at $t-1$ as expressed by market share:

$$w_{f,t}^l = \frac{m_{f,t-1}^l}{\eta - m_{f,t-1}^l} \tag{7}$$

The profit of firm *f* at time *t* is thus the sum of the profits obtained in the two countries:

$$\pi_{f,t} = \left(p_{f,t}^{A} - c\right) \cdot \chi_{f,t}^{A} + \left(p_{f,t}^{B} - c\right) \cdot \chi_{f,t}^{B} \tag{8}$$

where $\chi^l_{f,t} = m^l_{f,t} \cdot \chi^l_t$, is f's number of consumers in country l.

Every period there is a probability ω ($\in[0,1]$) that a new firm is selected for entry. A new entrant starts by searching for a new available technique (i.e., a technique that is not yet patented, see below). Firms that do not find any available technique or that at the end of the period have a total market share lower than exit threshold m^e ($\in[0,1]$) exit the industry. This exit threshold is the same in all countries. It follows that while the probability ω does not depend on the structure of the industry, the actual rate of entry does: the higher the degree of industry concentration and the lower the number of available techniques, the smaller the chances that a selected new firm can effectively enter the industry.

The total number of consumers in the three countries changes over time according to:

$$\chi^l_t = \frac{\Phi \chi^l_0 e^{gt}}{\Phi + \chi^l_0 (e^{gt} - 1)} \tag{9}$$

where Φ (>0) is the carrying capacity, χ^l_0 is the initial number of consumers in country l and g is the growth rate. To economize on parameters (and without loss of generality) we assume that the initial number of consumers in the latecomer country is smaller than the initial number of consumers in the incumbent and the relative size is fixed (in particular we assume $\chi^A_0 = \chi_0$ and $\chi^B_0 = \chi_0 / 2$). We checked that the results are robust to changes in the relative size.

A.4 Innovation activities

Firms invest the profit earned in the previous period in two distinct accounts: an R&D account, $R_{f,t}$, which is used to finance innovation activities; and an export account, $E_{f,t}$, which is used to finance export, *i.e.*, to cover the sunk cost c_E. We assume that initially all firms invest a fixed fraction τ ($\in[0,1]$) of their profit in $R_{f,t}$, while the remaining part $(1 - \tau)$ is accumulated in $E_{f,t}$. This fraction is the same across all firms and does not vary over time. Once $E_{f,t}$ is sufficiently large to cover c_E, firms gain access to one of the foreign markets.

Innovation activities are modelled as follows. Every period, firms have the chance to extract a number of new techniques. The number of tries available to firm f is *floor*($R_{f,t} / c_R$), where c_R (>0) is the unit cost of search. Once a new technique is found it is allocated a patent and no other firm can use it. If more than one new technique is found in the same period, firms adopt the one with the highest merit.

The outcome of the searching procedure depends also on a country-specific “information effect”. Firms that innovate within paradigm h (i.e. using the h-th generation technology) do not know their actual position in the technology space and randomly search over the support $[\zeta_{h-1}, \zeta_h]$, where ζ_{h-1} and ζ_h are the technological frontiers of the previous and present paradigm respectively. If no firm in the country has picked any of the techniques included between ζ_{h-1} and ζ_h (i.e. the searching firm is a pioneer) the search is driven by a uniform distribution. Once a new technique is found, however, all firms of that country start searching using a Beta cumulative such that the larger the country’s average merit, the higher the probability that good techniques (i.e. techniques that are close to frontier ζ_h) are drawn.

A.5 Discontinuities

At certain periods a new technology emerges (discontinuity), which shifts the technological frontier rightwards. The parameter ψ_t ($\psi_t \in [0,1]$) measures the percentage shift in the technological frontier that occurs at period t and it is thus a proxy of the size of the discontinuity. In particular, after the discontinuity, the position of the new technological frontier is defined as $\zeta_{new} = \zeta_{old} + \psi_t \cdot J$, where ζ_{old} and ζ_{new} are the old and new technological frontier, respectively.

The probability that firm f of country k perceives the new technology is:

$$a^k_{f,t} = \theta_{f,t}\left(1 - \lambda m^k_{old,t}\right) \tag{10}$$

where $m^k_{old,t}$ is the country’s market share using the old technology and λ ($\in[0,1]$) is a parameter reflecting the strength of path dependency. If a new entrant enters the industry once the new technology has already been adopted by at least one firm in the country of origin, the new entrant perceives the existence of the new technology with probability one.

If at time t the perception of the new technology is successful, firm f will choose to adopt whenever the following inequality satisfies:

$$q_{f,t} < (1-\phi)\theta_{f,t} \cdot \bar{r} \tag{11}$$

where ϕ ($\in[0,1]$) captures the strength of the competence-destroying effect (the greater ϕ, the greater the "capability loss" if adopting) and $\bar{r}$ is the expected technical merit over the support [ζ_{old}, ζ_{new}], with ζ_{old} and ζ_{new} being the old and new technological frontier, respectively. In particular, we set $\bar{r} = r_{(\zeta_{old}+\zeta_{new})/2}$.

A.6 Learning

The capabilities of a generic firm *f* coming from country *k* evolve following the logistic process:

$$\theta_{f,t} = \frac{\theta_{f,0} e^{\gamma \bar{\theta}_t^k t}}{1+\theta_{f,0}(e^{\gamma \bar{\theta}_t^k t} - 1)} \tag{12}$$

where $\theta_{f,0}$, *i.e.*, the firm's initial capabilities, is a random draw from a uniform distribution over the support [0, $\theta_{\max}^k$] with $\theta_{\max}^k$ being the maximum level of initial capabilities in country *k*, $\bar{\theta}_t^k$ is the average level of capabilities in country *k* at time *t*, and γ is a parameter that captures the strength of country-level effect on learning.