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CHINA'S GREEN INDUSTRIAL POLICY AND DEVELOPMENT – TAKING ADVANCED ECONOMIES OVER?

ABSTRACT

This paper explores the factors behind the apparent superior performance of green industrial policy (GIP) in developmental states (exemplified by China), as compared with the inefficiencies of GIP in developed countries (exemplified by the USA). The specific context is the overwhelming export competitiveness of green energy industry (GEI) actors in developmental states. Two intuitive explanations are analysed critically: differences between the two country groups in (1) the objectives of GIP and the proxies that measure policy performance, and in (2) the alignment of institutions and policies with the requirements of the growth phase of the industry life cycle.

The article highlights that the institutional, operational, and governance-related differences between these two country groups are less clear-cut than what is suggested in the literature.

Turning to the prospects of GIP, the paper anticipates a turn of the tide in the ongoing global green race. It is argued that different phases in the industry life cycle are characterised by different drivers of growth. GEI actors in China displayed spectacular catching up and were forging ahead during the growth phase of the life cycle, when the development of green energy industries was driven by scale-up and progress along the learning curve. Since further development, in the current phase, is driven by complementarities and spillovers, 'game is not over in the ongoing global green race'.

KEYWORDS: green energy industries, green industrial policy, developmental states, industry life cycle, China
JEL Codes: Q42, Q48, Q55

INTRODUCTION

There are two usual ways how articles discussing environmental economics issues are introduced. The first kind of introduction discusses the formidable threat the disregarded *environmental limits to growth* represent for humanity. Ironically, the second usual manner of leading in studies on greening is to allude to the beneficial impact of environmental investments on *growth* and competitiveness.

The second kind of introduction became increasingly common when certain high-performing developmental states started to display phenomenal growth in installed renewable power generating capacity, and increased their export competitiveness in renewable energy technologies.

Indeed, the recognition that the promotion of green industries and technologies is an adequate instrument for fostering economic development, innovation, and upgrading has added impetus to a phenomenon coined by Fankhauser et al. (2013) as a 'green race'. It is acknowledged that green industrial policy (GIP) may engender indigenous innovation, generate new market opportunities, contribute to the creation of high-paying (green-collar) jobs, foster the development of new industries, and facilitate countries' shifting to a high-road growth trajectory (Mathews, 2017a; Mazzucato, 2015; Rodrik, 2014).

As recurrent trade disputes over renewable energy technologies demonstrate, certain developmental states[1] have managed to achieve good position in the global green race.[2] They have effectively built up domestic manufacturing capacity in the solar and wind energy industries (see Green and Stern (2017) and Mathews and Reinert (2014) for China; Manju and Sagar (2017) for India; and Hochstetler and Kostka (2015) for Brazil), and have also accumulated related technological and R&D capabilities (Gosens and Lu, 2013; Zhang and Gallagher, 2016). According to Huang et al. (2016), for example, China's solar industry has been able to bring leading manufacturers from industrialised nations to their knees – this happened for the first time in an emerging, high-tech sector. Indeed, the competitiveness of developmental states' greentech exports is increasingly perceived as a threat by developed economy actors (Knuth, 2018; Lewis, 2014; Wu and Salzman, 2013).

In contrast to the staggering results of developmental states' GIPs, studies on GIP in developed countries abound with observations of inferior-to-expectations environmental outcomes (Verzijlbergh et al., 2017), poor cost efficiency and questionable overall net welfare effects (Helm, 2014), costly frictions in the industry structure and in the energy system (Kungl, 2015; Lauber and Jacobsson, 2016), bankruptcies, and cases of outright policy failure (Gaddy et al., 2017; Knuth, 2018).[3]

This study explores what lies behind advanced economies' comparably greater difficulties in achieving satisfactory performance of their GIPs. Can the above-sketched phenomena be interpreted as suggesting that advanced economies are bound to relinquish their leadership position in GEIs to developmental states?

To set the context, we first provide a brief summary of the literature highlighting the main difficulties of GIPs in advanced economies. Thereafter, we advance and critically analyse two intuitive explanations that might lie behind the apparent superior performance of developmental states' GIPs: differences between the two country groups in (1) the objectives of GIP and the proxies that measure policy performance, and in (2) the alignment of institutions and policies with the requirements of the growth phase of the industry life cycle.

Next, we develop several new propositions that, together, help to predict whether the global green race is indeed, bound to culminate in developmental states' leadership in GEIs.

Note that the empirical context used to illustrate our arguments is narrower than what the title of this article suggests. The case of China will illustrate the experiences of developmental states, with an obvious caveat that there are non-negligible differences across developmental states in terms of both the specifics of environmental governance and the problems GIPs need to address. As for advanced economies, the country cases that illustrate our arguments will be confined mainly to the USA and occasionally to Europe. Similar caveats

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[1] This article uses the concept of developmental state in accordance with Johnson's (1982) original conceptualisation. Accordingly, states systematically and selectively intervene in the economy by means of industrial policy, to achieve a high rate of economic growth and development, competitiveness, and catch-up with advanced economies. A developmental political elite is responsible for the design and a powerful, competent bureaucracy for the implementation of economic policy. Private and state-controlled firms characterised by institutionalised collaborative linkages and intensive exchange of information with the bureaucratic elite, constitute a key component of developmental states' 'governed market' models (Wade, 1990).

[2] Top solar technology exporters include several developmental states, e.g. China, Taiwan, Malaysia, Korea, Singapore, Philippines and Mexico. China, India, Vietnam, Singapore and Mexico are major wind technology exporters (Jha, 2017). Note that Brazil is an important player in wind technology manufacturing but except for wind turbine generators, Brazilian companies produce mainly for the domestic market.

[3] Gaddy et al. (2017) demonstrate that the cleantech boom in the USA, in the mid-2000s ended up in a bust by the end of the decade with venture capital investments yielding prohibitively low returns, coupled with expensive failure cases (Rodrik, 2014).

apply. Further, the term of GIP will also be used in a narrow sense, referring to industrial policy focusing on green (renewable) energy related issues. Over and above GEIs, green industries encompass, among others, energy efficiency-related industries, pollution control industries, energy storage industries. The focus of this study is, however, limited to GEIs, where differences between the two country groups in the performance of GIP are conspicuous.

To anticipate our arguments, we propose that over the past couple of years, the evolution of GEIs has progressed, leaving the growth stage of the industry life cycle, and reaching a phase referred to as 'transition to maturity'. We show that the features of this phase of the life cycle, and consequently, the determinants of the effectiveness of state intervention are different from those of the growth phase.

Contrary to the growth phase, when the development of GEIs was driven by scale-up and progress along the learning curve, in the transition-to-maturity phase further development is driven rather by complementarities and spillovers, that is, by the development of complementary technologies and by the integration of renewable energy into new sectors and applications. This will generate numerous scientific and technological problems, restructure the determinants of comparative advantage, and pose new challenges to be addressed by GIP.

Another outcome of the changing drivers of GEIs' growth is a growing interdependence between the two main objectives of GIP. While earlier in the growth phase, *developmental* objectives could be pursued independently from objectives envisaging green energy-driven transition to *sustainability*, the previously synergistic relation between the two objectives is now changing. For example, the further diffusion and development of green energy technologies (a developmental objective) becomes *contingent* upon progress in green energy-driven transition, that is, it requires not only developmental but also sustainability-oriented policy interventions.

GEI actors in developmental states, in particular, in China, displayed spectacular catching up and were forging ahead during the growth phase of the industry life cycle. Since the drivers of the industry's growth and the challenges to be addressed by industrial policy are changing in the transition-to-maturity phase, we conjecture that despite the enviable global market position of some developmental states, 'game is not over in the ongoing global green race'.

DIFFICULTIES IN THE PROCESS OF ADVANCED ECONOMIES' CLEAN ENERGY TRANSITION

Apart from common coordination challenges, such as coping with the resistance of existing regimes, governing amidst political struggles, reconciling contradictory interests, and aligning the efforts of isolated agents (Geels, 2014; Leipprand and Flachsland, 2018), the literature would point to three main types of difficulties to be overcome by the stakeholders of the green (energy) agenda in advanced economies.

The first and most conspicuous challenge is trade related. Green energy technology exporters from developmental states have effectively outcompeted advanced economy producers, who, in turn, struggle with overcapacity and financial losses. Consequently, neither public subsidies nor venture capital investments delivered on expectations (Gaddy et al., 2017; Lewis, 2014; Knuth, 2018). On top of that, part of the public subsidies fostering the deployment of renewable energy technologies in advanced economies has been captured by developmental state green technology exporters (Harrison et al., 2017; Karp and Stevenson, 2012). By contrast, advanced economy exporters face difficulties in penetrating the markets for renewable technology in developmental states because of protectionist local content regulations (Lewis, 2014; Mathews, 2017b).

Another series of difficulties are cost related. Transition to clean energy imposes hardly affordable costs on energy users, particularly, if compared with the cost of competing cheap conventional or unconventional energy sources, such as shale gas (Helm, 2014; Verzijlbergh et al., 2017). According to Follett (2016), despite substantial fiscal support to renewable energy, which in turn exacerbated budget deficit, the average German (private) customer pays more than 3.5 times as much for a unit of electricity than its American counterpart. In order to preserve the competitiveness of its energy-intensive industries and prevent massive relocation, Germany and some other OECD economies[4] offered subsidies or other forms of state aid[5] to energy-intensive users, which represents a conspicuously uneven burden sharing system. Nevertheless, the detrimental impact on industrial competitiveness of a system, in which energy users finance the costs of transition, could not be avoided (Böhringer et al., 2017; Helms, 2014).

Ironically, the rapidly declining price of clean energy technologies (Wesoff and Lacey, 2017), that was achieved mainly because of developmental states' overwhelming price competitiveness, have also caused problems. Renewable energy technologies need further development, for instance, further improvement of the reliability and the conversion efficiency of photovoltaic (PV) modules. However, the rapidly falling price of imported solar modules and components prevented incumbent clean energy manufacturers in advanced economies from pursuing long-term investments in quality competition. Venture capital investment in cleantech start-ups has also become prohibitively risky, and fell sharply (by nearly 30 percent in the USA, between 2011 and 2016 – Saha and Muro, 2017).

The third kind of challenge concerns the additional prerequisites of clean energy transition. Over and above the triple requirement of developing, producing, and deploying clean energy technologies, a multiplicity of complementary innovations are indispensable to overcome technological and infrastructural constraints (Markard and Hoffmann, 2016). For example, breakthrough innovation in storage technology is regarded as a precondition of achieving transformative change in the energy system. Additional complementary innovations need to modernise grid technology, to enhance the flexibility of the grid. Since the grid system is designed for steady electricity flows, which is hardly compatible with volatile renewables providing fluctuating energy inputs, these complementary innovations are indispensable for integrating renewable energy.

This latter bundle of challenges is rooted in the systemic character of green energy-driven transition to sustainability. Consequently, scholars investigating the reasons of the slow progress of renewable energy-driven transition would point to lock-in (Seto et al., 2016) and system failure (Negro et al., 2012).

Although the latter two kinds of challenges apply not only to advanced economies, our review of the literature identified hardly any articles *discussing difficulties* with respect to developmental states' GIPs (notable exceptions are Cai and Aoyama, 2018; Hayashi et al., 2018; Manju and Sagar, 2017). The above-listed challenges are usually elaborated upon in studies discussing the reasons why transition to green energy is progressing slowly in advanced economies, and serve as explanatory factors of the inferior-to-expectations effectiveness of GIP in advanced economies.

In the following sections we advance and critically analyse two tentative explanations of the apparent superior performance of GIP in developmental states.

DIFFERENCES IN POLICY OBJECTIVES

[4] For instance, the USA, Denmark, and the UK (Böhringer et al., 2017).

[5] For instance, legal exemption from the requirement to buy renewable energy at an established, above-market price.

An intuitive explanation is that the objectives of GIP and thus, the proxies that measure policy performance are different in the two country groups.

Developmental states consider investments in green energy transition primarily as an opportunity of creating new growth engines, building new industries, gaining new (export) market opportunities, and accelerating technological learning (Kim and Thurbon, 2015; Mathews, 2014; Schmitz, 2017).[6] A telling quote by Schmitz (2017, pp. 521-522) illustrates the ranking of policy priorities.

> „…key actors behind climate-relevant policies are not primarily concerned with environmental or climate issues. Their prime concerns are securing energy for the country, fostering new green industries and making them competitive, creating jobs and incomes in these industries, or laying the foundation for increasing public revenue. Mitigating climate change is not irrelevant, but it tends to be a co-benefit rather than driver."

With some simplification, it might be argued that the first component of an industrial policy for GEIs, the promotion of industries that produce green energy technologies, is apparently more at the forefront in developmental states than the second component: incentive provision to traditional industries and sectors to invest in the improvement of their sustainability performance.[7] Zhang et al., (2013) used the twin constructs of 'green energy industrial policy' and 'green energy policy' to refer to this difference in policy objectives.

Although developmental motivations are also present in advanced economies' green growth strategies (Mazzucato, 2015; Tienhaara, 2014), studies discussing GIP in advanced economies would mainly consider *environmental* (planetary boundaries-related – Rockström et al., 2009) *and not economic* proxies to evaluate policy performance.

Consider, for example the differences between the two country groups in their purview of renewable energy technology deployment. Advanced economy GIPs consider it as part of a broad process: the uptake of low carbon technologies across economy and society (Geels et al., 2017). Developmental states, instead, regard it mainly in terms of building an internationally competitive renewables sector (export volumes and international market shares are analysed), and in terms of capturing the domestic market by indigenous companies (Chen and Lees, 2016).[8]

Altogether, intuition suggests that the developmental targeting of green industries and the building up of domestic manufacturing capacity are easier than achieving good performance in the highly complex field of renewable energy-driven environmental sustainability. Differences in policy objectives account for the relative inefficiency of GIP in developed

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[6] Of course, other motivations are also at play, such as mitigating environmental deterioration, achieving energy security, and reducing dependency on fossil fuels (Mathews and Reinert, 2014). Moreover, developmental states have also been implementing more or less strict policies in the framework of their Nationally Determined Contributions to Paris Agreement targets (www.climateactiontracker.org).

[7] GIP also has a third component that is gradually gaining ground in advanced economies, and to some extent also in selected developmental states, that of "aligning the structure of a country's economy with the needs of sustainable development within established planetary boundaries" (Lütkehorst et al., 2014, p. 6). In this latter sense, GIP refers to policies aiming to phase out environmentally harmful technologies and discontinue traditional fossil-fuel-based activities.

[8] This is best illustrated by a quote from Knuth (2018, pp. 223-224): "With strong state supports, including in some cases state ownership, Chinese companies rapidly scaled up production of both wind turbines and solar PV modules […] achieved significant economies of scale, and several quickly became globally ranked solar and wind companies […] Chinese renewables manufacturers targeted both China's booming domestic market and international exports, and rewrote the rules of the global industry virtually overnight."

countries, which is particularly annoying in the light of the trade-disputes-prompting expansion of GEIs by selected developmental states.

While it is safe to argue for this proposition, it represents, at best, partial truth. The next section is concerned with another explanation of advanced economies' apparently greater difficulties in the field of GIP, compared, at least, to the success stories of developmental states.

DIFFERENCES IN INSTITUTIONAL AND POLICY ALIGNMENT

The point of departure of the other intuitive explanation is that the institutions and policies of advanced economies are less suitable to address the challenges of the growth phase of GEIs than those of developmental states. This proposition draws on the industry life cycle theory, more specifically on the established scholarship of coevolution of institutions, governance and technology (Nelson, 1994, 1995).

Advanced by Abernathy and Utterback (1978), and further developed by Klepper (1997), Nelson, (1994, 1995), Tushman and Anderson (1986), and others, the industry life cycle theory postulates that the evolution of industries exhibits regular patterns. Accordingly, four stages (emergence, growth, maturity, and decline) can be distinguished, and each is characterised by different patterns of growth (in firm numbers and industry output), competition, market structure, and innovation.

A particularly important assertion of the industry life cycle scholarship, analysed among others in Mowery and Nelson (1999), Nelson (1994, 1995), and Von Tunzelmann (2003), is that institutions, public programmes, and policies need to co-evolve with technologies and industries. As the patterns of growth, competition, and innovation differ in the individual stages of the life cycle, industrial policy needs to address different problems. Phase transitions require adjustments in institutions and in policy design to maintain policy effectiveness.

When GEIs graduated from the emergence to the growth phase in their development trajectories,[9] industrial policy also had to be accommodated to the changed context and to the associated new types of challenges.

Contrary to the emergence phase of GEIs, when industrial policy was concerned mainly with supporting R&D and new technology-oriented start-ups, the growth phase requires, among others, support to scale-up, that is, to companies' overcoming poor initial economies of scale and bringing technologies down the learning curve. Support to scale-up necessitates increased emphasis on demand-pull instruments – compared with the predominantly technology-push ones in the emergence phase – which requires related adjustments in fiscal and regulatory policies.

Additionally, since the diffusion of renewable energy technologies presupposes structural change, policy needs to combat lock-in, by addressing cultural, infrastructural, economic[10] and institutional barriers (Seto et al., 2016; Unruh, 2000). This involves extensive coordination problems. Moreover, the financing requirements of GIP in the growth phase are much higher than the expenses of funding and nurturing emerging industries.

[9] Although it is hardly possible to identify a clear end point of the emergence phase (see Bento and Wilson, 2016, for a set of relevant indicators that measure the duration of formative phases for energy technologies), there are numerous signs indicating that solar and wind energy technologies have been progressing already along the growth phase of their evolution trajectory. These include the rapid diffusion of these technologies and the ongoing extraordinary growth in the global market and in installed renewable power capacity (REN21, 2018).

[10] An important economic barrier stems from the fact that competing "dirty" technologies are usually more advanced than emerging green ones. Moreover, incumbent dirty technology providers further develop their technologies, which increases ambiguity concerning the alleged superior environmental performance of clean technologies.

Intuition suggests that the institutions and policies of developmental states are, in many respects, better fit to cope with these challenges than those of advanced economies.

Consider support to scale-up and market building. Achieving industrial leadership through the development of industrial capacity, technological catch-up, and foreign market penetration was a traditional policy-enabled development trajectory of industries in developmental states.[11] Accordingly, historical institutional contexts, firm strategies, and patterns of state–economy interactions have predestined Chinese GEI actors' effective scale-up and global expansion (Chen and Lees, 2016; Huang et al., 2016). By contrast, historical institutional contexts, firm strategies, and patterns of state–economy interactions are important explanatory factors of US firms' specialisation in clean energy technologies-related R&D and technology development (Knuth, 2018; Mazzucato, 2015; Nahm, 2017).

The implicit assumption behind the aforementioned arguments is that differences in countries' activity specialisation, in terms of their specialisation in R&D or in manufacturing, are shaped by their historically produced, path dependent institutional contexts and by the patterns of state–economy interactions. This implicit assumption was made explicit by Lachapelle et al. (2017), who argued that the current phase of the industry life cycle of GEIs is characterised by a 'green global division of labour'. Accordingly, countries specialise in and strategically promote *either* clean energy-related R&D, *or* manufacturing, *or* deployment.[12]

Consider also the intensification of coordination challenges in the growth phase. The mode of environmental governance in some developmental states, in China, in particular, is referred to as 'authoritarian environmentalism' (Beeson, 2010). Again, intuition suggests that in a top-down command and control mode of environmental governance, and with quasi powerless business groups and social actors, structural change-related coordination challenges can be more effectively handled than in participatory modes of governance prevailing in advanced economies (Dent, 2018). Developmental states are less subject to internal resistance by representatives of dirty incumbent industries (Dent, 2018; Gilley, 2012; Kim and Thurbon, 2015) and needn't face such a powerful internal opposition because of the distributional consequences of low-carbon energy transition (Lauber and Jacobsson, 2016). Hence, green industrial policy-makers in developmental states can more effectively steer the structural transformation related to the diffusion of renewable energy technologies.[13]

With regards to finance provision, again, developmental states are in a better position than advanced economies to fill the green investment gap and finance mission-oriented approaches, for example, through relying on state-owned development banks (Mazzucato and Penna, 2016; Mazzucato and Semieniuk, 2018).

Moreover, when it comes to mobilising resources for accelerating technology diffusion, developmental states, exercising executive power more autonomously than established advanced economies, face less internal resistance to employing vertical industrial policy instruments and resorting to direct subsidies – at least compared to the heated ideological debates on industrial and climate policy in selected advanced economies (MacNeil and Paterson, 2012). Vertical policy instruments are expected to have swifter impact, and are thus regarded more effective than horizontal, market-based instruments. Developmental states, for

[11] In China, for example, developmental interventions have consistently supported technology acquisition, local knowledge creation, and scale-up through export and integration in global value chains.

[12] „In most cases, the states that are doing better at deploying the technologies domestically are not necessarily playing a big role in inventing and patenting them or manufacturing, and vice versa – the ones inventing them may not be deploying them domestically so well." (Lachapelle et al., 2017, p. 320.).

[13] A detailed overview of incumbent regime actors mobilising power to resist climate change-related pressures and prevent fundamental system change is provided by Geels (2014) for the UK, and Kungl (2015) for Germany.

example, can directly promote strategic industries through establishing new state-owned enterprises, and providing direct guidance to existing ones (Dent, 2015).

Altogether, while the institutions and policies of advanced economies were well-aligned with the requirements of the emergence phase of GEIs, those of developmental states display a seemingly better fit with the requirements of the growth phase. As mentioned earlier, this intuitive explanation relies on the established scholarship of coevolution of institutions, governance and technology (Mowery and Nelson, 1999; Nelson, 1994, 1995; Von Tunzelmann, 2003).

Although these arguments seem easy to generate credence for, an unbiased evaluation of empirical evidence calls them partly into question. The first disputed component concerns the alleged differences between the two country groups in terms of activity specialisation. Advanced economies' comparative advantage in green technology development[14] notwithstanding, they are (for example, the USA, Germany, Denmark), at the same time, large *producers* and exporters of renewable energy technologies (Jha, 2017).[15] Conversely, OECD data on patents in environmental technologies indicate that China is rapidly catching up also in terms of R&D and innovations in green energy technologies (Huang et al., 2016; Mathews, 2017a).

Moreover, there are non-negligible differences across advanced economies in the relative importance of demand-pull instruments within the policy mix, as compared with the technology-push ones (R&D promotion). While the U.S. GIP is considered as the primary example of focusing mainly on R&D, and neglecting the promotion of deployment (Knuth, 2018), fiscal incentives promoting deployment prevail in a large number of advanced, developmental and developing countries alike (REN21, 2018).

The literature on GIP is far from straightforward with respect to advanced economies' alleged refraining from vertical targeting and employing dominantly market-based, horizontal instruments. Consider the studies on the direct, entrepreneurial role of states in developed countries, in the field of green (energy) technologies (Mazzucato, 2015; Meckling, 2018). The data published in REN21 (2018, p. 64) demonstrate that most high-income, advanced economies resort to direct fiscal incentives, such as investment subsidies, rebates or green energy production payments. Another well-known feature of GIP in advanced economies, questioning black-and-white differentiation, is that these countries also resort to state-owned development banks or to mission-oriented developmental institutions for funding green initiatives (Mazzucato and Penna, 2016). Conversely, the fact that China is gradually employing also market-based instruments such as carbon taxes and tradeable permits (REN21, 2018; Wang and Chen, 2015) also calls for adopting a nuanced approach when considering the differences between advanced economies and developmental states in the instruments of GIP.

The argument that the top-down command and control mode of environmental governance in authoritarian developmental states grant them exceptional advantage over advanced economies in implementing transformational GIP also falls short of empirical evidence. For example, evidence is accumulating that the effectiveness of China's authoritarian environmentalism is undermined by energy-intensive firms' weak compliance and by the failure of the central government to control local governments (Cai and Aoyama, 2018; Gilley,

[14] According to OECD data on patents in environmental-related technologies, the number of patent applications in climate change mitigation technologies related to energy generation, transmission or distribution was 1,810 in China between 2010 and 2014. The respective data for the USA and Germany were 7,277 and 3,727 (Source: author's calculation from OECD data).

[15] It should be noted that there are important differences also across individual advanced economies with respect to their technological specialisation. German actors, for example, focus on research and development of production equipment for the solar industry as well as on component development in both industries (Nahm, 2017).

2012; Lo, 2015). Moreover, Shen (2017) pointed out that influential corporations in the renewable energy industry and state-owned electricity utility companies have played active role in the design of China's renewable energy policy priorities. They have been able to constrain central and local governments' autonomy in policy design and occasionally, execution.

On the other hand, there are abundant examples of advanced economies' effectively implementing structural reforms, irrespective of some programmes being heavily contested by various interest groups. Removal of subsidies supporting fossil fuel, and phase-out programmes in the field of nuclear energy, coal, petrol and diesel cars, and incandescent light bulbs, implemented or decided in a variety of advanced economies, are salient examples (Rogge and Johnstone, 2017).

Altogether, empirical evidence indicates that the institutional and operational differences between developmental states and advanced economies in the design and implementation of GIP are less clear-cut than what is suggested by the better-institutional-and-policy-alignment proposition. Neither advanced economies, nor developmental states can be unambiguously classified by the degree, methods, and direction of state intervention in green industries.

Additionally, a common pitfall of extrapolations drawing on static comparisons of the effectiveness of GIP in the two country groups, and predicting China's leadership in GEIs is that they fail to take changes in the drivers of GEIs' growth into account. The next section takes up this issue. We propose that over time, GEIs have further progressed along the industry life cycle. In the current phase of their development, new factors have come to drive further growth and determine the effectiveness of state interventions.

NEW LIFE CYCLE STAGE – NEW FACTORS INFLUENCING THE OUTCOME OF THE GLOBAL GREEN RACE

Despite an ongoing strong growth in installed renewable power capacity (REN21, 2018), there are several signs portending a shift in the life cycle of GEIs from growth to maturity. Competition among firms pursuing different technology alternatives seems to have been resolved, and dominant design emerged, at least in the solar (Furr and Kapoor, 2018) and in the onshore wind technologies (Islam et al., 2013). Although R&D spending keeps increasing in GEIs, venture capital investment has been declining for several years, and R&D outlays are concentrated in large global companies (REN21, 2018, p. 145). These latter have been increasing their market shares for several consecutive years, which indicates an ongoing concentration of the market.[16] Competition has long become cost-based, as reflected by the falling price of solar and wind power, and by the slim margins of GEI actors (REN21, 2018, pp. 96, 114). Despite an overall improvement in top industry actors' cost-competitiveness, mergers and acquisition activity is intensive and the consolidation of GEIs continued (REN21, 2018, pp. 96,115).

In this transition-to-maturity stage of the industry life cycle, marked by the looming saturation of advanced economy markets for green energy technologies, the importance of green energy *consumption* increases rapidly among factors driving the further growth of GEIs. The further diffusion of green energy technologies will be propelled mainly by new end-use markets for renewable electricity, such as transportation, energy-intensive manufacturing industries, the building sector, and agriculture. These sectors can become new end-use markets if the problems related to the integration of renewable power are solved.

[16] The global market share of the world's top ten solar module suppliers accounted for 60%, while that of the top ten wind turbine manufacturers was 80% in 2017 (REN21, 2018, pp. 97, 115).

The integration of renewables into new sectors and applications requires large-scale fundamental and applied research, and technology development, targeting not only green energy technologies themselves but also and more importantly, related and complementary technologies. For example, efforts need to be devoted to modernising and digitalising the grid, solving vehicle–grid integration problems, and developing energy storage and charging technologies (Colak et al., 2016). The multiplicity and diversity of technology innovations that are indispensable for sustaining the momentum of growth in renewable energy industries purports that the share of pure scientific and technological problems will increase again among the challenges that GIPs need to cope with – just like in the emergence phase of the industry life cycle. This will restructure the determinants of comparative advantage in these industries, increasing the importance of innovation and commercialisation capacity.

A related consequence of the new life cycle stage of GEIs is a growing interdependence between the sustainability-oriented and the competitiveness-oriented objectives of GIP.

Previously, in the growth phase of GEIs' life cycle, that is, over the decade marked by the rapid rise of Chinese renewable energy industries, the effectiveness of interventions promoting the competitiveness of domestic GEIs was not dependent on the performance of sustainability-oriented policy interventions. That time, the developmental and the sustainability-oriented objectives of GIP were synergistic but independent. For example, the promotion of GEIs contributed to lowering the price of green technologies, and thus, had a beneficial impact also on sustainability-oriented transformative change in the energy sector. Similarly, sustainability-oriented policies providing financial support to the development and deployment of renewable energy technologies have also furthered developmental objectives. They enabled cost reduction and scale-up, fostering thus the competitiveness of actors in GEIs.

Accordingly, developmental states could adopt a one-sided 'green energy industrial policy', designed to maximise the developmental implications of 'climate-relevant' policy interventions, without addressing purely environmental objectives.

However, above a threshold level in the development of GEIs, in the transition-to-maturity phase of the industry life cycle, developmental objectives, for example, the further diffusion of green energy technologies can be achieved if and only if industrial policy effectively addresses also the issues related to green energy-driven sustainability. GIPs can no more be limited to strengthening the competitiveness of domestic GEIs: they will need to focus also, and increasingly, on clean energy transition to be able to sustain the momentum of growth in GEIs. Priorities need to be reshaped and more resources deployed to address system failures (such as technological issues related to the integration of renewables, infrastructural issues, institutional barriers) hampering the further development and diffusion of green energy technologies.

Altogether, policy mixes need to be more diversified than they were in the emergence phase of GEIs, when a pure technological approach, combined with the protection of new industries seemed sufficient. Even in the beginning of the growth phase, interventions supporting the development and deployment of green energy technologies were deemed sufficient. By contrast, GIP is now expected to steer energy transition, orchestrate institutional and regulatory changes, coordinate structural change, promote investment in energy technology innovation, and support technology diffusion focusing in particular on technological and infrastructural complementarities (Markard and Hoffmann, 2016) that are all indispensable for boosting clean energy consumption.

These arguments make it highly uncertain to predict who will 'lead the dance' in the transition-to-maturity phase of the life cycle of GEIs.

There are signs supporting the proposition that advanced economies, in particular the USA, whose industrial policy promotes specialisation in non-contestable, innovative activities (Leamer, 2007), can maintain leadership – not in terms of manufacturing and exporting green energy technologies but rather in terms of green energy technologies related value capture. Consider the effectiveness of the US innovation system in fostering the generation of scientific and technological solutions for the integration of renewable energy in adjacent industries (Knuth, 2018; Meckling and Nahm, 2018). Consider also the flexibility of the system, illustrated among others by the recent restructuring of the cleantech portfolios of US venture capital firms towards smart grid technologies, solar and wind forecasting technologies, electric vehicle and storage technologies, energy management platforms, energy analytics solutions and the like (Day, 2015).

By contrast, China needs to cope with still substantial 'teething problems', stemming from the compressed development (Whittaker et al., 2010) of its GEIs, for example, grid connection problems and a high (albeit gradually declining) rate of curtailment (REN21, 2018).

Alternatively, consider China's efforts to develop its energy storage industry, in response to the recognition of the paramount importance of energy storage for the integration and consumption of renewable energy resources (Yu et al., 2017). Previously, over the past couples of decades, China demonstrated remarkable capabilities to bring about spectacular achievements in various industries and technologies – whatever its industrial policy decided to focus on. It has been particularly adept at leveraging its integration into global value chains to achieve technological learning. Currently, China is devoting immense efforts to build indigenous technological and R&D capabilities, also in greentech industries (Gosens and Lu, 2013; Huang et al., 2016). It is rightly depicted as a rapid innovation follower in the solar industry (Zhang and Gallagher, 2016) albeit somewhat more of a laggard with respect to wind technology innovation (Lam, et al., 2017). Altogether, although China still has a long way to go along the energy storage innovation cycle, these capabilities suggest that it may catch-up with currently more advanced competitors also in energy storage. At a later point along the cycle, it may even acquire industrial leadership in energy storage.

Nevertheless, there is more to addressing the systemic problems of green energy-driven transition to sustainability than gaining control of the market in specific industries, however high-tech they are. In contrast to solving particular *unitary* problems or accomplishing discrete policy objectives, such as achieving technological breakthroughs and industrial leadership in energy storage industry, promoting and orchestrating green energy transition requires the ability to resolve multi-dimensional and interconnected (trade-off laden) problems (Negro et al., 2012; Rittel and Webber, 1973).

Consequently, the further development and diffusion of green energy technologies and thus, GEIs-driven competitiveness will mainly be influenced by countries' ability to promote and effectively orchestrate the renewables-driven transformation of related technologies and industries.

As the aforementioned difficulties of advanced economies' GIPs demonstrate, advanced economies are not necessarily better at resolving these systemic problems. However, public policies in advanced economies have longer been exposed to addressing systemic problems, for example grand societal challenges, than those in developmental states, and have accumulated more experience in adaptive governance, policy learning, collaboration, and institutional adjustment (Nelson, 1974). Moreover, the institutional set-up, the policy-making mechanisms, and the governance modes of advanced economies grant them better adaptation capability than what is the case in China, irrespective of the long-term development planning, resource mobilisation and effective plan implementation capabilities of the latter.

CONCLUDING REMARKS

This study contributes to the discussion on GIPs in three ways. Arguing for a nuanced evaluation of the differences between developmental states (exemplified by China) and advanced economies (exemplified by the USA), the article highlights that the institutional, operational, and governance-related differences between these two country groups are less clear-cut than what is suggested in the literature.

Second, it draws attention to the evolutionary dynamics of the relation between climate-relevant green energy policy and green energy industrial policy. It shows that above a threshold level in the development of GEIs, the further diffusion of green energy technologies is contingent upon progress in low-carbon energy-driven transition, that is, upon the performance of climate-relevant, complex policy programmes. Contrary to the growth phase, when the development of GEIs was driven by scale-up and progress along the learning curve, in the transition-to-maturity phase, further development in and diffusion of renewable energy technologies is driven by *complementarities* and *spillovers*, that is, by the development of related technologies and by the integration of renewable energy resources into new sectors and applications.

Third, our study suggests that although there were notable differences between the two country groups in terms of the principal objectives of GIP, the above-outlined evolution of the relation between green energy policy and green energy industrial policy will start to revoke the resulting differences in the policy mixes, and will thus make the performance of GIPs easier to compare.

These results generate important implications for developmental states in general, and for China, in particular. An obvious implication is the imperative of reorganising industrial policy for GEIs, and placing higher priority on related and complementary technologies, and on the integration of renewables into new sectors and applications. Technology breakthroughs enabling the integration of renewables, combined with an effective management of complementarities could create new end-use markets for renewable electricity. This could open up new synergies, necessary for the further growth and development of renewable energy industries.

Regarding the policy implications for advanced economies in general, and the USA, in particular, our results indicate that there is more to industrial leadership than achieving and maintaining a large global market share in specific technologies. Instead of targeting supply side indicators by means of trade policy instruments, that is, by protecting / supporting production capacities and jobs in GEIs, leadership can be sustained rather by promoting novel means of value generation and capture.

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