Sustainability transitions and technological catch-up:

Guidance of search as a strategic mechanism for leapfrogging[1]

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Abstract

The challenge of preparing for more sustainable futures increasingly finds resonance outside OECD countries. One salient development is that manufacturing bases for clean-tech industries are shifting to emerging economies. So far, the question how latecomers may achieve leapfrogging in sustainable technologies has not yet been clearly spelled out in the two most important literature streams in the field: Transition studies are just about to address issues of globalization, whereas catch-up studies have given scarce attention to the specific challenges of clean-tech industries. This paper states that one of the major challenges is the elaboration of a more systemic understanding of how windows of opportunity for leapfrogging can be addressed. To achieve this, we draw on recent insights on industry emergence from transition studies. In particular, we argue that the concept of "Guidance of Search" provides a fruitful starting point for analysing how actors may influence the selection environment in an industry so as to support the emergence of a new dominant technology. The framework is illustrated with a case study on China urban water management. Over the past twenty years, a number of radical transformations in the sectoral selection environment led membrane bioreactor technology to become the dominant choice, a development unmatched in any other country in the world. Despite entering the industry as a latecomer, China caught up with multinational players in a tremendous speed. Drawing on 44 in-depth interviews with triangulation of secondary reports and data, this paper argues that this framework is able to account for explaining the observed shifts and ultimately enables the identification of a broader set of leapfrogging strategies compared to those proposed by the extant catch-up literature.

Keywords:

Sustainability transition; catch-up; leapfrogging, Technological Innovation System; urban water management

[1] This is a reduced version of the paper. The full version can be accessed upon requesting the authors.

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1. Introduction

The world is undergoing 'the Fifth Great Surge of Development' - an era driven by the information and communications technology (ICT) revolution and the gestation of an ever more globalised world (Perez, 2013). The Fifth Surge is itself at the critical 'Turning Point', of which an ICT-driven techno-economic paradigm (TEP) coupled with global sustainability transitions is supposed to lead to the full deployment of a next new golden age (Perez, 2013, 2016). It is however argued that unleashing this next global golden age requires the return of an active State to direct convergent and synergistic actions towards a transition where green innovations radically transform modern lifestyles. Economists have furthermore recently called for a rethinking of capitalism to deal with challenges of this era and argued that a revisit to policy-making is in need (Stern 2007; Jacobs and Mazzucato, 2016). With globalisation increasingly changing the spatial configuration of world economic activities, policy making and innovation research need to be ever more attentive to the progresses made in developing countries (Perez, 2013; 2016). A fundamental question therefore lies in whether developing countries are able to keep up with world-frontier transformative innovations that may ultimately lead to deep transitions (Schot and Kanger, 2016).

Making sustainability transitions is a huge challenge to developing countries, which are already struggling to catch up with the world in terms of economic and technological developments. Conventional catch-up studies have argued that path-following strategies as well as step-by-step moving up the global value chains (GVCs) would lead to economic development (Hobday, 1995; Kim, 1997; Pietrobelli and Rabellotti, 2011). However, these strategies are probably not sufficient to make technological leaps in a global transition period. Latecomer countries have to find radical approaches that are path creating or path breaking within a short time frame, as they are arriving rather late in certain industries (Mathews, 2002; 2006). Furthermore, ignoring sustainability transitions is not a wise option for fast-emerging economies, as they do often suffer prominently from increasing global change problems.

Challenging existing GVCs is difficult as they are mostly controlled by of global incumbents. Instead, latecomers have to create new GVCs. Catch-up studies have mainly argued that latecomer leapfrogging requires the presence of windows of opportunity (WO), which mostly arise due to external events (technological breakthrough, major shifts in market structures, financial crises or large shifts in politics). Catch-up studies have therefore treated WO as rather an exogenous event to which latecomers 'respond' and only very recently began to discuss about the possibility of WO being endogenous to firms (Lee and Malerba, 2017). In conventional catch-up studies, technological capabilities accumulated in specific latecomer countries determine the latecomers' ability to catch WO. Under the conditions of a TEP shift many WO are likely to occur. However, latecomers should consider more proactive options to influence and shape the emerging opportunities –strategies that go beyond the generation of firm-level internal capabilities. Instead they should identify options to proactively create and widen WO in order to position themselves as future global industry leaders. A revisit to latecomer strategies is therefore required for innovation studies to go beyond the conventional contentment of catch-up and to provide a broader understanding of leapfrogging opportunities.

While existing catch-up studies have not yet articulated a more endogenized view on how WO may be tapped, transition studies can potentially contribute to fill this gap because of their explicit attention on endogenous deep sectoral transformation processes. In particular, the literature on Technological Innovation Systems (TIS) has provided very elaborate accounts on how a broad set of actors is often necessary for developing the aligned social and technological learning processes that are required for a new dominant technology to emerge in a specific sector (Carlsson and Stankiewicz, 1991). More recent contribution to the TIS framework have focused on early phases of industry emergence in a number of clean-tech sectors (Markard et al. 2015; Markard et al. 2012). We maintain that this approach can complement current limitations of catch-up studies. The TIS approach specifies a set of six core processes (or functions) that interact in a balanced way in successful industry formation processes: knowledge production, guidance of search, legitimation, market formation, entrepreneurial experimentation and resource mobilisation (Bergek et al., 2008; Hekkert et al., 2007). These functions emerge through the interplay of strategies of different actors and by this create critical externalities, for a technology to mature and grow into a full sized industry. By this, the TIS framework also provides an elaborate framework for identifying interventions by government and firm actors to shape the course of technological trajectories. Functions thus enable an endogenized understanding of how actors may relate to emerging WOs and could therefore complement existing catch-up theories.

In order to bridge these two approaches, we propose to more specifically focus on how actors may influence the ‘selection environment’ of a sector to shape new dominant designs. Generally, established technologies can be viewed as being embedded in strongly institutionalized rules and norms which result in so-called “socio-technical regimes” (Fuenfschilling and Truffer, 2014; Geels, 2002). Turning a new technology into the dominant choice of a sector therefore requires work on different aspects of a predominant regime (Fuenfschilling and Truffer, 2016; Geels and Schot, 2007). The proponents of the emerging industry have to influence the existing norms and preferences, so that they better fit the characteristics of the new innovation. For the context of latecomers wanting to leapfrog, we articulate how latecomers can intervene and proactively shape the technological selection environments by strategically addressing one of the six TIS functions – Guidance of search (GS). GS is understood as accounting for the systemic-level influences on the orientation of search processes related to technologies, applications, markets, business models, etc. (Bergek et al., 2008). Existing transition studies have conceptualized GS as a process of exerting influences to the shape and pace of technological trajectories. This includes making selections by widening or narrowing the scope of technological variations, and deepening or truncating the depth of particular technological developments. Common examples of GS actions as pointed out by existing TIS studies are the formation of visions and expectations, standards, regulations and policies (Bergek et al., 2008). The contribution of this paper is therefore twofold: On one hand, we show how latecomers, by proactively influencing the selection environment, can endogenously create industrial leapfrogging opportunities in the current global transition process. On the other hand, we elaborate how the function of GS, often treated as a broad process in TIS studies, can potentially be operationalized. By highlighting GS, we do not want to belittle the importance of other functions in TIS development. Knowledge generation, legitimacy formation, resource mobilization, entrepreneurial experimentation and market formation have to develop in parallel with GS for a new industry to successfully emerge. The function of GS however enables us to scrutinize strategies to shape the selection environment in a given sector and by this provides inroads for actors to gain predominance over their competitors. It therefore provides a solid starting point in order to conceptualize an endogenized account for the shaping of WO.

The development of clean-tech industries has been a focal case for functional analyses. Many examples were from the energy sector such as the solar photovoltaic or wind industries. As these examples have already proceeded far into the industry maturation cycle, longer-term historical analyses would be needed to reconstruct successful shaping accounts. We therefore prefer to analyze an ongoing industry formation process, where the core processes can be more readily analyzed. The urban water management sector has only recently been identified as requiring high attention from transition scholars (Larsen et al., 2016; de Haan et al. 2015). More specifically, the proposed framework in this paper is applied to a case study of China urban water management (UWM) sector. Chinese catch-up policies targeted advanced waste water treatment as a focal area on its way to an innovation country by 2020. In particular, membrane bioreactor technology (MBR), which is the most advanced treatment technology has been identified as a strategic target by Chinese policy makers. Over the past few years, MBR technology turned into the dominant choice advocated by the government and many policy makers, replacing the conventional active-sludge (CAS) treatment approach. China entered the MBR industry as a latecomer only in the early 2000s. While the worldwide MBR market has steadily increased over the years, it experienced an exceptional growth in China. By 2016, Chinese firms have become the largest user and producer of MBR in the world. Concomitantly, Chinese MBR products are being exported across the world today, which has changed the global industrial landscape of the MBR industry.

The analysis draws on in-depth semi-structured interviews with 44 experts of Chinese UWM sector, with triangulation through content analysis of government and company reports, as well as secondary data sources. The remainder of this paper is structured as follows: section 2 reconstructs how existing catch-up and transition studies can be combined in order to provide a framework for endogenized leapfrogging dynamics. Section 3 introduced the historical background on recent development of the Chinese UWM sector and elaborates the major development phases of the MBR TIS. Section 4 elaborates the results of the empirical study on actor strategies influencing the selection environment of the sector. Particular emphasis will be put on the role of the leading company in the MBR field, Origin Water. In Section 5, we discuss how the lessons from this case contribute to an endogenized account of leapfrogging in the UWM sector. Section 6 concludes with implications to both catch-up and transition studies, particularly on the role of developing countries in this global transition process.

2. A systemic framework for analysing influences on the selection environment

A common challenge from which latecomer countries suffer is the inability to embark on rapid economic development despite years of investing in catching up with high-end industries with advanced countries. This has been coined as constituting a “middle-income trap” for many attempts to implement economic development (Cherif and Hasanov, 2015). While existing studies on catch-up have made significant contributions to how latecomer countries may compensate for weak starting conditions, like deficiencies in technological capabilities, finances, infrastructures and networks (Mathews and Cho, 2007; Rasiah, 2007), the issue of middle-income trap seems to have become ever more prevalent internationally. In this section, we want to critically take stock of extant theories on catch-up and identify how the portfolio of strategies for latecomer countries could be broadened in order to take advantage of and respond to challenges provided by the shift towards an ICT and sustainability based new TEP. We will first argue for a more endogenized understanding of the dynamics of selection environments, draw on recent teachings from the functional approach to Technological Innovation Systems in order to finally propose a framework for analysing how different actors can attempt to influence the selection environment and by this shape the technological trajectories that might become dominant in a specific sector.

2.1 The need for a broader perspective on catch-up dynamics

Catch-up studies have mainly argued that latecomer leapfrogging requires the presence of windows of opportunity (Perez and Soete, 1988). The existing literature mainly conceptualises WO as arising due to external forces (technological breakthrough, major shifts in market structures, financial crises or large shifts in politics) (Perez and Soete, 1988; Brown and Linden, 2009). Catch-up studies therefore treat the emergence of WO as rather an exogenous event to which latecomers merely respond. The kind of technological capabilities accumulated in latecomer companies or regions will then determine their ability to catch WO. But leapfrogging in a TEP shift requires more. In particular, we have to ask how latecomers might build up endogenous capacity to influence and engage in the changing techno-economic systems – a strategy that is beyond generation of internal capabilities. Merely focusing on 'responses' to WO through internal capabilities is therefore insufficient to explain industrial leaps in a changing TEP. To leapfrog and to create new GVCs, latecomers have to explore strategies beyond existing GVCs, i.e. to proactively create and widen WO to position themselves in future global industries. A revisit to latecomer strategies is therefore required for innovation studies to go beyond the conventional contentment of catch-up and to arrive at a more elaborate understanding of which global industrial leapfrogging opportunities can be endogenously created and appropriated.

These questions have originally been elaborated by Lee and Lim (2001) who proposed different leapfrogging trajectories, including path-skipping, path-creating or path-breaking. More recent research on catch-up cycle theory builds on this early work (Lee and Malerba, 2017). It provides a closer scrutiny on how WO emerge by identifying three factors that engender WO: changes in knowledge and technology, changes in demand, and changes in institutions and public policy. However, the emergence of WO still remains largely an exogenous event to which latecomers merely 'respond'. Technological capabilities built up in latecomers determine their ability to catch WO. Exceptional cases are when new technologies have developed along the direction of a firm's internal capability accumulation or when latecomers lobbied their institutional environment.

To endogenize WO, catch-up scholars have to change perspective towards the proactive interplay of strategies by different actors. This means that industrial firms are able to proactively engage in shaping the direction of public policies and finding strategies to influence the technological development of the MNCs. These are processes that deserve more explanations than simply treated as "lobbying" (Lee and Malerba, 2017). Some useful examples have been discussed in existing studies, e.g. how South Korean Samsung reaped first-mover advantages and how latecomers can leapfrog via path-creation or path-breaking strategies (Kim, 1997; Lee and Lim, 2001; Lee and Malerba 2017). Nevertheless, a systemic framework that explicitly outlines a broader set of actors and mechanisms as strategies to endogenize these leapfrogging processes is still missing.

2.2 Guidance of search and the endogenization of Windows of Opportunity

A salient systemic framework to analyse early phases of industry formation is the approach of TIS (Carlsson and Stankiewicz, 1991; Bergek et al. 2008; Hekkert et al. 2007). The six core TIS processes or functions (i.e. knowledge generation, guidance of search, legitimation, market formation, entrepreneurial experimentation and resource mobilisation) interact in a balanced way in successful industry formation processes (Bergek et al. 2008). Functions emerge through the interplay of strategies by different actors coordinated in different kinds of networks and embedded in various institutional arrangements. The success of an industry emergence is a result of the aggregate outcome of these different actions. We argue that this approach can significantly complement the limitations of extant catch-up studies. By focusing on the strategic interplay of actors at different structural levels, the framework does not pre-assign specific roles to different actors. Rather, it shows that each actor can play a proactive role in contributing to the aggregate outcome of the system at one point in time. Functions therefore can provide an endogenous perspective on how WO could be strategically addressed and influenced by actors in a technological field.

We identify GS as one of the functions being particularly important in a leapfrogging context. GS encompasses all activities that contribute to the selection and shaping of dominant technological trajectories (Hekkert et al., 2007; Bergek et al., 2008). While previous studies have very much linked GS to guidance in a technical sense, i.e. in terms of the choice of product design, by setting standards and regulations, Johnson (2001) suggested that GS should also be applied to processes attracting new actors to join a new technological field. Hence, GS can affect technical progress, as well as resource mobilization and market growth positively or negatively. Common examples of GS are the formation of visions and expectations, standards, regulations and policies (Bergek et al., 2008). Even though individual actors may aim at shaping some of the dimensions of GS, the overall outcome is typically an aggregate result the interplay among different actors. By this, GS also contributes to the shaping of shared expectations among TIS actors, which in turn facilitates coordination (Konrad et al., 2012). While we maintain that GS is an integral part of the interplay of functions leading to system maturation, we highlight GS as the one function that provides most leeway to influence and shape the direction of a specific technological trajectory and by this determines the relative position of a technology compared to its competitors in a given sector. In other words, we relate GS strongly to the ability of actors to influencing the 'selection environment' of an innovation process. Understanding how actors in a TIS proactively set influences on a technology selection environment will contribute to the understanding of how dominant technological trajectories emerge and form.

In latecomer contexts, GS therefore has particular strategic importance. Influencing the selection environment is crucial for channelling the flow of resources, may be decisive in path-creation for first-mover advantages and enable the targeted build-up of complementary structures and functions. Being able to influence the shape of future socio-technical trajectories may be a means for latecomers to ascertain stronger roles in future GVCs and by this reap a greater share of the added value in global industry sectors. Being able to influence the direction of technological development also decreases the risk of catching up on the "wrong tracks" in technological fields that will soon undergo fundamental reorientations. GS therefore can serve as a latecomer strategy to endogenously create or widen WO proactively.

2.3 A framework to analyse the endogenous dynamics of selection environments

In order to provide an endogenized perspective on how latecomers may interact with WO, we have to extend the established understanding of the GS function in the context of TIS development. GS relates to selections by widening or narrowing the scope of technological variations, and deepening or truncating the depth of particular technological developments. In other words, this paper emphasizes the role of GS as a process that differentiates dominant choices from what considered as alternatives. Discussing GS in the context of the TIS framework has the advantage to not lose sight of the multiple interdependencies that are related to the other functions and which actors have to accommodate for when aiming at the promotion of specific technological alternatives. The framework developed in the following elaborates how GS can be operationalized by specifying the sub-processes as endogenous strategies available to TIS actors which lead to changes in the selection environment and by this shapes new dominant trajectories in a specific sector.

GS becomes particularly important when it comes to latecomer leapfrogging. Leapfrogging requires strategic interventions at different structural levels to shape the development of the selection environment in order to be in line with the benefits of the latecomers. This perspective considers the proactive role of organizations in the latecomer countries, including government agencies, associations and firms. Profit-oriented actors may seek to influence GS in order to sustain market leadership or to increase market shares of a product, e.g. by adding new features to existing products or setting barriers to the growth of alternative products. They may also create and tap new market opportunities or stay technologically competitive by appropriating first-mover advantages. Furthermore, they may try to solve or mitigate technological bottlenecks and stay cost competitive by reducing manufacturing costs. Non-firm actors such as government entities, policy-makers, public research institutes, citizen movements, etc. typically seek for broader goals and objectives that generally concern social development issues as they set influences to innovations.

Essentially the different actors may be attributed to four generic levels (see figure 1): societal discourses, governmental strategies, industrial networks or at the level of their own organizations. Actors can influence the selection environment of a particular level by direct and indirect actions. Direct actions represent attempts to influence actors in their strategies and preferences. Indirect strategies address core dimensions of the selection environment (external conditions; visions and expectations; regulations and policies; standards; firm internal capabilities; see figure 1). Actors may act on these dimensions either individually of by forming alliance of power across different levels. The overall outcome of GS is an aggregate result of the individual and collective actions by different actors.

The different dimensions of the selection environment can be further specified as *regulations; standards; visions, beliefs and expectations; external forces; and capabilities.*

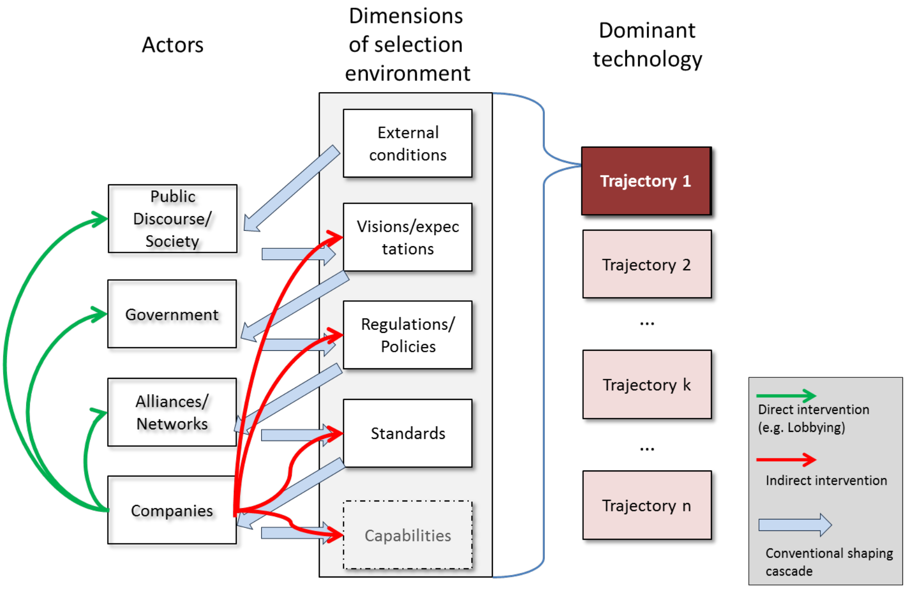

Figure 1: Endogenous mechanisms for influencing selection environments

GS is particularly important in catch up contexts where firms aim at influencing the development of dominant technological trajectories. We therefore argue that the sub-processes of GS are key for latecomer actors to proactively engage in the development of a technological field, while acknowledging that GS will ultimately emerge as an aggregate outcome of these various interventions. Furthermore, it is appropriate to emphasize that GS does not work in isolation. It interacts in manifold ways with other TIS functions such as resource mobilization, legitimacy creation, market formation, but also in a more indirect way with entrepreneurial experimentation and knowledge generation. For instance, GS will only be effective if preferential trajectories can be backed up by promising research results and if an increasing number of firms engage in the corresponding technological variants, if future promising markets can be sketched out, if they respond to major legitimacy concerns of major actors and by this lead to the mobilization of critical resources to support the preferred trajectory. A specific TIS variant will only be able to mature, if all the functions develop in a balanced way. GS is therefore a major input to TIS maturation, but it will ultimately also be the result of the actual development of the development of the innovation system as a whole.

Building up strategic resources in an emerging industry (or TIS) an drawing resources from a broader systemic context will allow latecomers to uncover possible leapfrogging trajectories that were not identified in studies using the conventional catch-up approach. In this regard, GS serves as an important alternative for latecomer leapfrogging by offering a broader portfolio of activities as strategic targets, which latecomers can act upon. New leapfrogging trajectories will potentially emerge as more actors act upon strategic targets in order to influence the selection environment at multiple levels. Through GS, latecomers are exposed to more optional strategies to endogenously shape the development of an emerging technology. The leapfrogging mechanisms that take place however go beyond the aspect of technology and involve a broader set of actors and sub-processes, which can be captured by the proposed framework.

We will in the following analyse the emergence of MBR as the dominant technology in the UWM sector in China focusing on processes of GS in shaping the selection environment of this sector. The analysis draws on a series of 44 semi-structured interviews with key informants of different stakeholder groups in China UWM sector, including academia who are also active policy experts; intermediaries (associations, alliances, consultancy firms, and design institutes); domestic technological companies; foreign technological companies; and key part suppliers. The annexed table lists the details of the interviewees and their assigned descriptor codes in this paper. All the interviews in this study were thoroughly transcribed and checked. The transcriptions were subsequently analyzed using the MaxQDA software, which is a reliable system for qualitative analysis. The findings were further triangulated through content analysis of government and company reports, as well as secondary data sources.

3. China waste water challenges and the emergence of the MBR TIS

The case of China UWM sector offers a promising ground to examine the issues discussed above. Not only is China greatly challenged by its water sustainability crisis, i.e. water shortage, water pollution and unsafe drinking water, the nation has undergone tremendous dynamics within this sector through its dire search for innovative solutions. Generally, public discourse is running high on how the nation is dealing with its water challenges. For instance, the public increasingly got dissatisfied with the huge investment spent on the South-to-North Water Diversion (SNWD) a major diversion plan of water from the Yangtze river in the South to the arid Northwest including Beijing. This project increasingly was perceived as ecologically unfriendly and impractical due to high end user costs. Among different segments of the national management of water, the growth of wastewater treatment systems has played a crucial role in mitigating problems of water shortage over the years. The government infused huge financial resources to build plants that treat household and industrial wastewater. At the same time, the Chinese government also connected this sector with the nation's economic and industrial catch-up policies.

In particular, there has been a major shift in the preferred technology implemented in wastewater treatment plants from old CAS designs to MBR among policy makers, water utilities, industrial technological companies, design institutes and researchers. However, the emergence of this preferred choice was not un-controversial among the general public and established sector experts. Major incumbents in the sector argued about the rather immature, risky and expensive nature of this new technology and conducted institutional work to maintain the established standards that were backed by Chinese government but also by large parts of the international professional community. Before that background it is all the more remarkable how over the course of a few years the dominant priorities in a sector could be turned around towards achieving world leadership in an otherwise rather conservative sector. In the following, we will reconstruct these developments by following the activities of one leading actor who activated a large number of GS processes to promote MBR technology in the UWM sector. The indigenous company Origin Water stands out as promoting the technology replacement process most forcefully. Within a short time-frame of catch-up, Origin Water has sufficiently built up its political and industrial networks, as well as its capabilities in MBR manufacturing, innovations and operations. MNCs operating in China have lost their competitiveness in the Chinese market over the years. Meanwhile, a few leading indigenous players have also demonstrated potentials to leapfrog the global incumbents in the future. By focusing on the leading company, we do not intend to promote a heroic account of an individual actor, who managed to reshape the selection environment at its own will. Rather Origin Water serves as a focusing device to highlight the different systemic interdependencies that had to be enacted in this process and what sort of strategies were necessary to shape the selection environment.

4. Endogenizing industrial dominant technology

4.1 Major shifts in the selection environment

The selection environment of China UWM has experienced structural transformation from the trial and embryonic stage (late 1990s to 2003) to the current stage of exponential growth (after 2011). Before the transformation, the dominant choice of China UWM was heavily gravitated towards the internationally established CAS systems, which we will call in the following the Selection Environment I. The dominating actor in the selection process was the government who delegated the task of assessing and selecting promising technologies to the state-owned design institutes. The selection process operated through a rather conventional top-down governance approach, with the government formulated environmental and industrial policies based on their discretions. There were eight leading design institutes inside China which played a crucial role in the selection processes, running feasibility tests for wastewater projects and advising the government or the end users (which mostly consist of municipal water utilities or industrial water users) about which technology to apply in wastewater treatment projects. They formulated the industrial standards which led conventional CAS treatment become the solution of choice. These design institutes were especially experienced in engineering design for the construction of treatment plants. Most actors in the earlier stage relied on these standards when planning for wastewater plants, which created huge inertia to switch to alternative technologies. Since design institutes were state-owned, they were also key to influence the formulation of policies on which technology to be widely applied, promoted or incentivized. Industrial firms did not have an important role in the selection process and they mainly interacted with the design institutes during the project tendering process. Overall, Selection Environment I was highly bureaucratic, mainly determined by the design institutes, Ministry of Housing and Urban-Rural Development, as well as, Ministry of Environmental Protection. Over the years however, design institutes experienced diminishing power in the selection process. This happened as a consequence of a general development in Chinese industrial policy that aimed at privileging market oriented approaches, following the economic reforms in 1978 (Ling and Naughton, 2016). However, it was not before the late 1990s that the design institutes began to be privatized.

At the end of this transformation, the structure of China UWM selection environment (i.e. Selection Environment II) became much more decentralized. MBR became the emerging dominant choice in UWM projects, especially in the wastewater segment. Although the official technology decisions remain in the hands of governments, customers or investors, the selection process very much takes place between leading industrial firms and the mediators (i.e. the newly privatized design institutes, engineering design companies, and technical consultants). In Selection Environment II design institutes had to compete with other profit-oriented engineering design companies in the market. As a result of these changes, industrial firms emerged to leverage more agency in the technology selection environment. They also played an increasing role in influencing several policy domains. Leading industrial firms can influence policy makers directly or indirectly through close coordination with the design institutes or through strategic networks in the industry.

As a consequence of the shifting roles of key actors in the selection environment, the assessment criteria of preferable UWM technologies also changed fundamentally. In the earlier stage, the criteria determining the dominant technology were its ability to treat the wastewater according to a specific (internationally rather low) discharge standard, which should lead to mitigating water pollution in China (see Table 1). At the end of the transformation, the selection criteria became much more diverse: Not only the technology selected had to be able to treat wastewater according to record high quality standards, the technology should also enable wastewater to serve water recycling and water reclamation purposes. Selection environment II is even gradually requiring standards of wastewater effluent that correspond to surface water. The discharge standard became one of the highest in the world. The criteria in the latter stage also began to rely more heavily on costs, including end user prices, operational and maintenance costs of the products, as well as, investment and sunk costs. Furthermore, the performance quality and efficiency of the products became a top priority in order for the technology to be profitable to different parties in the system. Furthermore, the selected technology has become more than just for social responsibility. The selected technology is expected to present futuristic optimism, such as adding market value to the land and bringing benefits to less developed regions. The selected technology was also expected to contribute to the innovation capabilities and industrial development of the country. As a result, factors that can improve product substitutability and increase industrial competition were also included as criteria.

4.2 Implementation of GS strategic target actions

In order to understand how the transformation from Selection Environment I to II took place, we have to analyze how different actors in China UWM have acted on different GS targets at multiple levels. We will in particular focus on the role of Origin Water – the indigenous MBR specialized company which stands out among other industrial players as a crucial GS actor. First, we will identify how Origin Water contributed to the emergence of widely accepted industry standards by acting on the internal development of the TIS, so to speak. In a second step influences on the broader context of the TIS will be elaborated (Bergek et al., 2015).

4.2.1 Origin Water business strategies and industrial leadership

Origin Water was established in 2001 when the founder returned to China from his engineering doctoral studies in Australia. Origin Water became a joint partner to Tsinghua University Membrane Technology R&D Centre at that time. While the wastewater industry held major doubts towards the feasibility of MBR, the founder of Origin Water had strong faith in the potential of MBR technology and focused on its R&D collaborations with the research team in Tsinghua University (AC/PE8). As the company grew, especially since completing the treatment plant for Beijing 2008 Olympic Games, its projects included large-scale centralized municipal wastewater plants. Instead of focusing on the concept of water 'treatment', the company subsequently advertised their concepts as dealing with water 'reclamation' and water 'recycling' (DTC14,15). Today the company is controlling 8% of the total daily municipal water discharge of the whole of China (170 million cubic meters) and about

90% of the MBR market. Overall this short recollection shows that Origin Water was contributing to all sorts of system functions of the emerging MBR TIS. In the following, however, we will focus on the strategic actions that were undertaken by this company and related actors in shaping the selection environment.

During the transformation period, Origin Water influenced the selection environment at the industrial level by initiating three key areas of technical standardizations for MBR technology: i) technical performance and design standards which ensure the quality and efficiency of MBR systems; ii) engineering design standards which lay out how MBR plants should be accommodated into the construction sites or into the existing old treatment plants; and iii) product standards which specify the required sizes, measurements or materials of particular MBR systems (DTC14,15). While the Chinese government was responsible to officially approve standards, Origin Water played a crucial role to initiate and influence the standardization outcome. Origin Water has implemented the GS actions through a number of formal and informal power alliances in its industrial networks.

The emergence of the first large-scale MBR project for Beijing Olympic game steered the government interest towards the MBR industry (IN/SC). To ensure *performance, quality and efficiency*, the state government of China issued the 'Catalogue of Environmental Protection Industry Equipment Encouraged by the State' in 2007, which defined the first national design criteria for MBR systems in China. It encompassed technical standards on influent water quality, operation flux, water-recycling rate, membrane and system operation lifetime, and Design Guidelines for wastewater reuse projects. In 2008, the Environmental Protection Ministry proposed the formulation of 'Aerobic Biological Wastewater Treatment Technology Standard - MBR Standard'.

Having experienced exponential growth and gaining substantial influence in the industry, Origin Water began to initiate the formulation of MBR *engineering design standards* for municipal wastewater plants since late 2014. In Selection Environment I, traditional design institutes were generally not familiar with accommodating MBR plants into the engineering construction designs (IN/DI1,2; DTC14,15). It was a major hindrance to all players in the industry to apply MBR technology in wastewater systems. Origin Water strategically "internalized" the role of design institutes by acquiring a few of them and formed strategic networks with large and influential ones since design institutes traditionally played a decisive role in technology selections.

In terms of *product standards*, Tianjin University pioneered the formulation of China national standards for membrane materials in 2006. These standards are applicable in a number of membrane-related technologies and marked the beginning of the nation's focus on indigenous capabilities in membrane materials. However, a decade since the first membrane material standards were formulated, these material-related standards are now deemed less demanding and rather common (AC/PE8, IN/SC). Origin Water went on to progressively push for the formulation of product standards for China MBR industry.

At a more general level, alliances had also been important in positioning MBR products relative to its main competitors. To establish the position of MBR products in a hostile environment predominated by pro-CAS actors, Origin Water sourced critical representatives in MBR value chain and created a *formal alliance*, including design institutes, engineering design companies, research universities, suppliers and buyers, as well as competitors in the flatsheet membrane TIS. The role of the MBR alliance is to convince the government their abilities to generate innovative activities across the value chain that solve technological bottlenecks such as high-energy consumption and high operation costs (DTC14,15).

4.2.2 Shaping of the supportive context

The selection environment does not stop short of the industry. Dominant technologies also have to respond to broader societal concerns and demonstrate that they are delivering services at optimal conditions of costs and performance. In other words, the new regime has to be in congruence with the dominant landscape forces in order to remain uncontested. As a consequence, the government and the industrial actors have to align their strategies in congruence with major public discourses. These public discourses may however also be impacted by specific strategies of actors by shaping new visions and expectations. More particularly, Origin Water strategically created opportunities for leveraging broader societal concerns and by this influence policies and regulations to their advantage.

The Chinese public is concerned with two main discourses, i.e. environmental sustainability and economic development issues. Specifically, the country's water crisis resonates with public concerns through impacts from water shortage, water pollution, and unsafe drinking water. To strategically deploy this public discourse, Origin Water presented a *vision* to the government of 'returning pure and natural water' since the early 2000s, which also coincides with the company's name (IN/DI2). It provided some positive visions to the policy makers as China was facing social pressure due to the heavy but impractical investments on SNWD project (IN/DI2). Origin Water promised that China water related problems could be solved through radical innovations in the UWM sector. In the latter stage of the transformation, the company also argued that water reclamation is a key solution to address the issues. To encourage Chinese economic development, the government has established dual-objective policies to encourage and support high-tech innovations simultaneously while seeking solutions for environmental issues. By pushing for high-tech solutions, the government aims to develop indigenous innovation firms in the water industries. This tendency provided benefits to MBR development as Origin Water positioned MBR as a highly innovative technology that constantly involves research and development (AC/PE8). In the latter stage, Origin Water also advertised the benefits of environmental protection projects contributing to economic development and positively impact its gross domestic product (GDP). It was expected that these projects could bring up to RMB 10 billion per year for China (DTC14,15).

At the *government level*, different policy realms contributed to the development of the MBR industry in China: environmental, economic policies and industrial policy. To change the selection environment, the leaders of Origin Water established high-level political networks and strategized corporate promises that appear to the government as favourable changes within the policy realms.

In the process of formulating *environmental regulations and policies*, the government mainly involved environmental companies with large operation scales such as Origin Water for formulating water discharge standards. Companies with high technological capabilities but less project scales have not been invited (FTC6). Since the construction of China's first large-scale MBR plant in 2006, Origin Water began advising the government to revise the national water discharge standards.

According to the 12th FYP, wastewater plants that were implementing Class 2 discharge standard had to meet Class 1 B discharge standard by the end of the 12th FYP, whereas certain selected areas had to meet Class 1 A discharge standard or higher (DTC14,15). Besides that, regions that face water shortage, were forced to achieve at least 10% of reclamation rate from wastewater treatment in 2015.

Since the release of the State Council's new requirement for water discharge standards in 2013, Origin Water argued that MBR technology was the only option able to meet the surface water level IV standard. The requirement of this quality posed detrimental threats to CAS as it is not able to deliver on these criteria. In its 2014 countermeasure report to the government, the company contrasted the effluent quality of MBR and CAS. It was justified in the report that conventional water treatment options are only able to reach Class 1A discharge standard whereas the MBR treatment can meet the surface water IV standard (DTC14,15). The water quality argument was also used to strengthen its argument against another competitor, the SNWD project. Origin Water emphasized in its advisory reports that not only the project destructs the environment, it is also unsustainable due to increasing costs. For instance, the company specifically mentioned that the cost of the water from the project reached RMB 18 per tonne compared to the cost of the running water in the city, which is RMB 4 per tonne (DTC14,15). This strategy propelled the government to channel more resources and investments into MBR in new wastewater projects.

Within the realm of *economic development policy*, Origin Water also formed new visions for the government by encouraging goals that set Beijing as the first example that turns wastewater into resources using the company's combined innovations of MBR and Duraflow membrane treatment. The company advised that, after Beijing achieves this goal, the same concept should be applied across different parts of the country. In September 2014, the first "new water resource centre" was built in Beijing at ChuiHu (rebuilt from existing conventional plant) as a demonstration project, with a treatment capacity of 20,000 cubic meters/day using the new membrane innovations of Origin Water (i.e. MBR + DF) (DTC14,15).

Finally, in the realm of innovation and industry policy, the Chinese government specified the "Technical Policy on Municipal Water Reclamation 2006" which showcased the government's interest in the R&D, marketing and promotion of membrane related technologies in the wastewater industry. In 2010, the government issued the "Policy for Nurturing New and Strategic Industries", which included high-tech membrane materials as one of the strategic new industries for the country. In 2011, the "Science and Technological Development Plan" under the National 12th Five Year Plan (FYP) clearly corroborated support for the membrane material industry by the government. By increasing more than 30% of the use of indigenously produced membranes in the local market, the government stated that they aimed to build a group of local actors with high membrane R&D capabilities and to industrialize these capabilities. Origin Water and its allied partners were successful in convincing the government that MBR is a highly innovative technology and deserves high investments from the government to incentivize R&D of MBR and to build MBR plants for wastewater (AC/PE8; DTC14,15).

We can therefore conclude that Origin Water had been extremely successful in shaping the selection environment of the UWM sector in a way that made MBR technology becoming the favourable technology. Table 1 summarizes the results of this section and identifies the major parties that were responsible for shaping the selection environment.

	Phase I		Phase II	
Targets of GS intervention	**Element of the selection environment**	**Key actors influencing the element**	**Element of the selection environment**	**Key actors influencing the element**
External conditions			Save on scarce material resources (concrete, steel)	*OW*, government*
			Market value of land	*OW, government*
			Lower end user price	*OW, society*
			Lower investment or sunk costs	*OW, government*
Visions and expectations	General social welfare (i.e. access to clean water)	*Government*	Social responsibility to mitigate crisis	*Society, government, OW*
			Future vision of clean environment/pure water	*Society, OW*
			China becoming an industrial world leader	*Society, government, OW*
			Increasing economic activities	*Society, government, OW*
			Futuristic image: Water reclamation and recycling	*Society, government, OW*
Policies and regulations	Environmental protection (mitigating water pollution and crisis)	*Government*	Water recycling, water reclamation as score goals	*Government, OW*
	Wastewater treatment for reuse purposes (weak)	*Government*	Turn wastewater into resources by complying to surface water standard	*OW, government*
	Low discharge standards (compared to international average)	*Government*	Very High discharge standards (compared internationally)	*OW, government*
			Economic development: GDP, less developed regions	*Government, OW*
			Innovation and industrialization policy	*Government, OW*
Industry standards	Technical standards focusing on CAS as dominant technology	*Design institutes (delegated by government)*	Technical standards for performance, quality, efficiency, maintenance	*OW, design institutes (privatized), industry alliances, government*
	Engineering design standards (only applicable to CAS systems)	*Design institutes (delegated by government)*	Engineering design standards (new standards to accommodate MBR system)	*OW, design institutes (privatized)*
			Product standards for quality, not limiting innovations but increasing competition	*OW, design institutes (privatized), industry alliances, competitors*

Table 1: Shifts in structure and content of the UWM selection environment

Note OW – Origin Water*

5. Discussion

5.1 Leapfrogging by endogenizing the shaping of selection environments

The emergence of MBR as the dominant choice in China UWM was a result of aggregated GS actions between the government and the industrial players such as firms and mediators (i.e. design institutes, engineering design companies, associations and alliances). The Chinese government formulated the country's environmental, industrial and development policies through a top-down centralized mode according to their visions and expectations for the respective realms. However, visions and expectations of the government will not be realized without positive reinforcement from the industrial actors. The development process of MBR in China however is also crucially attributed to numerous examples of how industrial players, especially Origin Water, deployed GS strategies to influence bottom-up the decisions of the government in regulations and policy realms, emphasizing on how MBR can help tackle public discourses. In China UWM case, the government has played an active role in 'listening' and providing feedback to the industry, and especially to the leading company. Therefore, actions at both government- and industrial level have to take place simultaneously to result in a converging development trajectory. At the same time, as the leading indigenous MBR company in China, Origin Water constantly set influences at the industrial level by initiating product and process standardizations for MBR.

The Chinese UWM case demonstrates how TIS actors deployed GS strategies to endogenously shape the development trajectory of the MBR industry. The empirical results showed how these actors drew resources from a systemic context. This offers a broader portfolio of strategies available to engender leapfrogging opportunities. Targets such as visions and expectations at multiple levels, regulations and policies, industrial standards and organizational technology management strategies were used strategically by key actors seeking to leapfrog. Successful GS, however, relies on the strategic interplay by different actors and on whether the implementation of GS actions (in concert with the other TIS functions) develop in complementary directions and ultimately converge towards the desired aggregate outcome. We may therefore formulate a general hypothesis about the effectiveness of GS oriented strategies: the more congruent the target actions across the multiple levels, the more likely GS will be successful.

The empirical case also clearly shows how China MBR actors, although they entered the industry as latecomers, strategically created and widened the emerging WO for themselves. The state government envisioned that China can simultaneously achieve industrial leapfrogging while seeking solutions to their water crisis. With emerging clean-tech solutions at the global arena, the Chinese government perceived this as a WO and imposed their dual-policy approach. However, the government actions alone would barely have been effective. Key actors in the industry, like the case of Origin Water showed, realized that the water crisis in China would enable them to influence the selection environment suiting their interests. Origin Water should however not been seen as an isolated superpower that manipulated the government and other industry partners at will. Rather it implemented a broadly based strategy, encompassing direct actions but more importantly the construction of alliances, the framing of public discourses, contributions via policy documents and the deconstruction of assessment frameworks. Only through this interconnected set of activities may we understand how the selection environment could change in such a fundamental way over a relatively short time frame. Compared to conventional catch-up approach, which treats the roles of government and companies as being rather separate, our GS focused approach enables the identification of more encompassing yet fine-grained roles and strategies of actors.

5.2 China leapfrogging potentials in global MBR

We may conclude that Origin Water had been extremely successful in influencing the selection environment. But did this also create a solid basis for leapfrogging? Through its actions, Origin Water grew exponentially in tandem with the development of the MBR industry and finally dominated the domestic MBR industry. By strategically implementing GS, Origin Water provided numerous opportunities for itself to catch up and leapfrog. Besides assimilating technologies from MNCs in the early stage, Origin Water used strategic networks (political and industrial) to justify the selection of MBR in the wastewater segment and to formulate engineering design, process and product standards that are in line with its internal capabilities and strategies. High number of large-scale projects led to deep financial resources and accumulative experience in operating MBR plant, which provided the company with sufficient opportunities and platforms to revise its MBR systems and to feed back to its R&D. As a consequence, competitors in the field became technology followers, filling up the portion of the market that was not prioritized by Origin Water, such as small-scale decentralized plants, wastewater systems in far remote areas and industrial MBR projects that involve customized treatment capacity. Within China's domestic market, Origin Water has outperformed advanced MNCs like Mitsubishi, General Electrics (GE) and Siemens. The monopolistic dominance of Origin Water in the MBR industry had propelled these MNCs to withdraw from the intense competition in the industry. Without having a 'say' in the development trajectory of the industry, GE and Siemens had aborted this business segment although they began their MBR line in China with the objective to tap the growing UWM market. Without strategically implementing GS, these MNCs lacked the network strings to develop standards that are in favour of their own strategies and capabilities and lacked the necessary 'test bed' experience to improve their systems.

Although the current focus of Origin Water is China's domestic market, the company has started exporting its MBR products to a number of countries, including Austria, Russia and the Philippines. Whether or not Origin Water can eventually leapfrog incumbents in the global industrial arena, the company has put itself in a very strong position that provides manifold leapfrogging opportunities. Supplying and operating MBR systems that fulfil one of the highest discharge standards in the world provides the company with a hard-to-copy reputation in the global arena. Furthermore, being able to solve complex water related issues in China positions Origin Water as having high capabilities. The company moreover owns a large number of testbeds by operating a tremendous number of wastewater plants. In addition, Origin Water constructed an institutional context that is supportive to the further development of the MBR industry. This includes incentives from the government in R&D and innovative activities related to MBR, which provides additional resources including knowledge, finance and networks. The company is highly ambitious and determined to be a leading global player in the future. Since Origin Water stands for a successful strategy to upgrade a country's dominant choice for wastewater systems, it may lead the way for other developing countries that are challenged by water related issues. This indicates that the approaches and standards of Origin Water might be adopted by policy makers in other places and the company has opportunities to replicate its strategies.

The case of China MBR industry is unique as it has experienced higher growth compared to any other country in the world. Whether China experience will be followed by other countries is beyond the predictability of the present paper. However, me may add some moderating claims about the longer term prospects of this seeming success story that were raised in controversies within China along the course of the reshaping of the selection environment. We abstained from presenting how the discourse developed over the different development stages so far in the paper, because this would have led to an overly lengthy elaboration. But it is appropriate at this point to state by which arguments the developments were contested over time. Some actors in the industry have raised the issue that the direction of this development is rather irrational and will bear negative impacts in the future. Transforming the selection environment of China UWM sector has resulted in a number of controversies among the professionals in government, the UWM industry, research and academia. Actors with a vested interest in CAS technologies have repeatedly protested about the increasing preferences given to MBR. They argued that MBR technology is technically impractical, given that it consumes higher levels of energy and is inefficient due to membrane fouling, while CAS is able to achieve the same level of discharge standards as MBR (AC/PE7; IN/AS). Furthermore, it is also controversial that MBR related product standards are emerging in China. Some parties think that having standardized MBR modules (with specific sizes and measurements) will limit the innovative capacity of industry players, which is critical to the future practicability of MBR (AC/PE8; IN/DI2). It is also perceived that current MBR product standards work in favour of large companies like Origin Water (IN/DI2; DTC12; DTC17). Smaller companies have difficulties in matching these standards. Therefore, product standards will lead to a further monopolization of the MBR industry (IN/DI2). Actors agreeing with the standardization process however emphasize that product standards will ensure high quality of products in the market, as technical standards serve as reference points to increase product substitutability and induce competition that eventually eliminate monopolistic markets (IN/DI1; DTC14,15).

There is also dissatisfaction from the professional society as China environmental policies include elements that indirectly promote the use of high-end technologies in conserving the environment (AC/PE7; IN/DI2). It is not clear whether the government's agenda actually lies in environmental protection or growing high-tech industries. Many professionals also think that the discharge standards have increased to an inappropriate level (IN/AS; AC/PE4; AC/PE7; PE3; IN/DI1). Some professional parties think that solving environmental issues via industrialization strategies is not feasible in the long term (IN/AS). Furthermore, the decreasing role of design institutes throughout the transformation has stirred controversies and discontent (IN/DI2). Since market competition emerged in the engineering design market in China and MBR became the dominant technology, some parties think that design institutes have lost much of their neutral standing in selecting the best technologies for the UWM sector (IN/AS; IN/DI2).

Overall, we could show with our analysis how the selection environment got fundamentally reshaped in a rather conservative infrastructure-heavy sector like UWM. Key actors mobilized a broad portfolio of direct and indirect strategies to shape the different dimensions of the selection environment as hypothesized in figure 1. Specific actors like Origin Water had been very instrumental in promoting these developments. But at the same time they were not able to control all the relevant aspects. The outcome has to be understood by the systemic interplay between the different actors in the different domains. It also became clear that the rationales to promote the specific trajectory of MBR was not only narrowly defined through industry internal visions and standards, but it had to draw on major societal discourses and positioned the new technology as the preferred option against its major alternatives (like CAS or the SNWD project). Finally, we may claim that GS did not get enacted as an isolated strategic domain but that it was tightly connected with and supported by developments in the other system functions like market formation, legitimacy formation, resource mobilization and entrepreneurial experimentation. Therefore, successful GS may only be understood if it is put into the context of broader system development and broader societal discourses (see also Bergek et al. 2015)

6. Conclusion

Latecomer leapfrogging has long been a central focus of catch-up studies. The emerging TEP opens up the realm of new clean-tech sectors that offer latecomers new industrial WO. Nevertheless, latecomers should seek strategic leeway to endogenously widen the WO. The strategies involved however go beyond the accumulation of technological capabilities in latecomer firms, but relies strongly on however latecomers are able to influence how the next-generation of industrial dominant technology will look like. As far as capability accumulation remains a crucial factor, the process of leapfrogging demands latecomers (be it individual industrial actors, networks or policy makers) to be simultaneously proactive in aligning a broad variety of elements relating visions and expectations, regulations and policies as well as multiple industry standards. In other words, endogenizing the understanding of reaping WOs depends on the ability a broad variety of actors to leverage guidance of search processes in a reflexive way.

This paper made an important contribution to existing catch-up studies by spelling out the above mechanisms while incorporating key concepts from transition studies in a latecomer context. The framework proposed in this paper details how actors in a latecomer context can strategically target different actions in order to influence the selection environment at multiple levels. The sub-processes of GS, i.e. influencing visions and expectations, regulations and policies, industrial technical standards, serve as strategic targets that latecomers can act upon and endogenize. In a systemic context, these actions can be clearly targeted by latecomers, which can lead to other possible trajectories that were not identified by conventional catch-up theories. For instance, our study highlights the crucial role of latecomer industrial actors in aligning the directions of societal discourse, regulations and policies, as well as industrial development trajectory to endogenously shape MBR as the industrial dominant choice in China UWM sector. It details how industrial firms systemically influence the visions and expectations of the government in formulating regulations and policies, compared to conventional studies that rather dismiss this process as mere lobbying. Furthermore, our approach also details how key industrial actors proactively initiated standardization and technology assessment to position MBR as the dominant choice in the UWM sector.

Although this paper is not able to predict the future success of China's MBR industry at the global arena, it has however unravelled the promising potentials GS can offer to a latecomer leapfrogging context. Furthermore, while GS serves as a crucial key to guide the course of technological development, it is also important to remind that a TIS emerges through interactions between different core functions. It would therefore be worthwhile to further scrutinize the interactions between GS and other functions, such as resource mobilization, market formation and technology legitimation, which are complementary processes in shaping industrial dominant choices.

The case of China as presented in this paper provides learning opportunities to other latecomer countries. The Selection Environment I of China UWM was no doubt a result of a government structure where central government played a strong role in shaping technological development. The empirical evidence in this paper however showcased the active participations of non-government actors such as companies and industrial networks in later times, which resulted in the new Selection Environment II. Therefore, Selection Environment II was only indirectly and not solely determined by governments. This has significant impact to developing countries seeking to achieve rapid catch-up in industries. The paper shows that the prerequisites of shaping a new selection environment depend heavily on an interrelated set of factors (i.e. multi-level visions and expectations, standards, regulations and policies), which in turn serve as targets to be interfered by government and non-government actors. The resonance and congruence of these factors across multiple levels of the system led to successful formation of a new dominant technology. Latecomer catch-up strategies should therefore focus on aligning these fundamental factors that shape the selection environment, instead of limiting themselves by assuming the traditional roles of government and non-government actors. The experience of China UWM hence provides significant insights on how these roles could in fact be strategically balanced or optimized in a process that seeks industrial leapfrogging. This will in particular be significant to middle-income trapped countries that are severely impacted by their institutional inertia and desperately seeking path-breaking ways to instigate fundamental changes.

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Annex

Table 1. List of interviewees, 2016.

Stakeholder Group	Interviewees	Code	Expertise (New of conventional technology)	Sum
Academia (AC)/ Policy Experts (PE)	Chinese Academy of Sciences	AC/PE1	New	9
	Chinese Academy of Sciences	AC/PE2	New	
	Tongji University	AC/PE3	New	
	University of Science and Technology Beijing (School of Civil and Environmental Engineering)	AC/PE4	Conventional	
	Renmin University	AC/PE6	New	
	Beijing University of Civil Engineering and Architecture	AC/PE7	Conventional	
	Tsinghua University (School of Environment and State Key Joint Laboratory of Environmental Simulation and Pollution Control)	AC/PE8	New	
	Jiangsu Provincial Academy of Environmental Science	AC/PE9	Neutral	
	Chinese Academy of Sciences	AC/PE10	Neutral	
Intermediaries (IN)	International Water Association (AS)	IN/AS	Conventional	5
	Beijing General Municipal Engineering Design & Research Institute (DI x 2 interviews)	IN/DI1, IN/DI2	New	
	Tsing Hua University* as Specialist Committee (SC)	IN/SC	New	
	Origin Water* as MBR Alliance (AL)	IN/AL1	New	
	Tongji University* as MBR Alliance (AL)	IN/AL2	New	
	Beijing CS Guoyi Environment Protection Engineering as Engineering Design Companies (EDC x 2 interviews)	IN/EDC1, IN/EDC2	New	
Domestic Technological Companies (DTC)	EnviroSystems Engineering & Technology	DTC1	Conventional	20
	Beijing Ecojoy Water Technology	DTC2	New	
	Rui Jie Te Technology	DTC3	New	
	HuaDe Creation	DTC4	Neutral	
	GoHigher Environment	DTC5	New	
	Forenv Environmental Technologies	DTC6	New	
	Beijing Enterprises Water	DTC7	New	

	Poten Environment Group	DTC8	New	
	BMEI (2 interviews)	DTC9, DTC10	New	
	Shanghai SINAP Membrane Technology	DTC11	New	
	Shanghai Zizheng Environmental Technology	DTC12	New	
	Beijing Drainage Construction	DTC13	New	
	Beijing Origin Water Technology (2 interviews)	DTC14, DTC 15	New	
	Jiangxi JDL Environmental Protection	DTC16	New	
	Tianjin Motimo	DTC17	New	
	Beijing Bluesky Advanced Technologies	DTC18	Neutral	
	Beijing Mohua Technology	DTC19	New	
	SENUO Filtration Technology (Tianjin)	DTC20	New	
Foreign Technological Companies (FTC)	Veolia (China) Environment Services	FTC1	Conventional	6
	Beijing Tri-High Membrane Technology	FTC2	New	
	Pentair Water Purification Systems (Shanghai)	FTC3	New	
	Huber Environmental Technology	FTC4	New and Conventional	
	Sino French Water	FTC5	Conventional	
	Veolia Water Solutions & Technologies (Beijing)	FTC6	Conventional	
Key Part Suppliers, Domestic/ Foreign (KPSD/ KPSF)	Shangdong Huadong Blower	KPSD	N/A	4
	Rehau Polymers (Suzhou) Shanghai Branch	KPSF1	New	
	Shanghai Alfa Flow Control	KPSF2	N/A	
	Tacwell Engineering	KPSF3	N/A	
Sum				44

Note* These entries relate to interviewees who acted in a double role as academia/ policy experts or companies but also representing important specialist committee or alliances in the industry. The interviewees were explicitly addressed in these different roles. However, the corresponding interviews were only counted as one.