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Path Dependency in Technological Trajectories:

Switching in Energy and Implications for Evolutionary and Development theories

Nathalie Lazaric[1] and Smita Srinivas [2]

1) University of Nice Sophia-Antipolis, GREDEG (Research Group on Law, Economics and Management), 250 rue A. Einstein Sophia Antipolis, 06560 Valbonne, FRANCE; lazaric@gredeg.cnrs.fr

2) School of Economic Development, Indian Institute of Human Settlements (IIHS) 2nd main Road Sadashivanagar, Bengaluru, 560 080, INDIA; ssrinivas@iihs.ac.in. Senior Visiting Fellow, London School of Economics; Visiting Professor of Economics, IKD, Open University, UK.

Abstract:

Our paper aims to contribute to the analysis of path transitions or 'switching' behaviour between different technologies. We do this with select cross-national case-based analysis on energy investment choices. Drawing on both meso- and macro-level frameworks, the paper lays out preliminary institutional observations of transitions observed, and what this means for evolutionary and development theories. Based on conceptual perspectives shared with others, we focus on transition and 'lock-in' not as a moment in time but as an institutional process, with specific institutional configurations and actors.

We are interested in the energy sector because of its enormous potential for development as well as climate change response. For instance, the deployment of new energy services and technologies is introducing opportunities in the electricity value chain, improvements to the overall management of electrical systems, and potential gains for consumers. However, the energy sector's technological dynamics in developing countries remain contested. Such countries face substantial developmental tensions of unmet demand for energy, raising questions of how best for consumers, policy, or firms to choose between co-existing technologies. Yet the issues are not merely pricing choice alone, because the paths may represent differential learning opportunities with obstacles to transitioning between the paths. These considerations also shape the policy options for consumption and demand in other essential goods and services (e.g. health, water). In this direction, two country cases -France and India-are briefly discussed, deliberately drawn from across the "developed, developing" divide to further elaborate on the institutional context and implications for evolutionary perspectives and path-dependency in development theory and policy.

Introduction

Evolutionary theories weigh path dependency heavily in explanations for economic transformation, especially their technological trajectories. This paper aims to contribute to how we analyse switching behaviour between different technology and development paths by focusing on select cross-national data on energy investment choices. The relation between electricity utilities and households in France is, as in India, a social construct inherited from the past. Drawing on both meso- and macro-level frameworks, the paper lays out the institutional implications for if and how transitions occur and what this means for evolutionary and development theories.

In the energy sector, deployment of new services and technologies is introducing opportunities in the electricity value chain, improvements to the overall management of electrical systems, and potential gains for consumers and citizens. Moreover, climate negotiations have shown us that developing countries with industrial ambitions have different priorities and trade-offs. Energy studies can therefore benefit from technological innovation literature focused on developing countries, especially tensions of unmet demand, differential learning opportunities, and obstacles to transitioning between the paths (Arocena and Sutz 2000; Srinivas and Sutz 2008; Kaplinsky 2010; Chataway et al. 2014; Srinivas 2014). Furthermore, energy has always been perceived by households as an invisible commodity (Thaler and Sustein, 2009; Hargreaves et al., 2010; Maréchal 2010), and its invisibility has been accentuated by local and historical conditions, which has provided opportunities for introducing changes and testing new Business Models according to the institutional context and potential lock in inside current technological trajectories. Reducing the asymmetry between demand and supply is, among others, a critical component of this transformation for learning about demand-side determinants and for discovering future strategic investments in this and related fields (Manral 2010, 2011; Maréchal and Lazaric 2010; Pehrsson, 2011).

In this paper we argue that path dependency is not a state but a process that can change the present cumulative causality by opening windows of opportunities (Martin and Sunley, 2006). Indeed the energy field witnesses important possibilities to navigate among diverse spaces of innovation. It allows for rejuvenating old technologies and for providing new institutional bifurcations changing current and/or emergent technological trajectories.

In this context, two country cases -France and India-are briefly discussed, deliberately drawn from across the "developed, developing" divide to further elaborate on the institutional context and implications for evolutionary perspectives and path-dependency in development theory and policy. Our paper is organized as followed. Section one presents the theoretical foundations about path dependency theory and recent elements for developing countries (DCs) and Advanced Industrialised Economies (AICs) for navigating inside the space of innovation with new potential combinations. Section two develops some brief empirical observations on what can be learnt from France and India in the progress of their technological trajectories.

Section 1. Path dependency and beyond: breaking some current cumulative causality and providing new opportunities

One and or several paths for innovation and developing countries: historical constraints and 'windows of opportunities' for developing countries DC and AICs

Arthur (1988) and David (1985) carried out important empirical studies that have allowed for enriching our understanding of the selection process. Arthur and David's empirical and analytical efforts were to be decisive in illuminating which technologies get chosen and initiating reflection on the dynamics of the capitalist system. In effect, for these authors, as competition is highly unpredictable, it depends upon an accumulation of small social and institutional events that together have a decisive impact on the adoption process. The outcome of the competition is therefore far from being optimal. To put it differently, according to this hypothesis, a "technology is not chosen because it is efficient but becomes efficient because it has been chosen" (Rip and Kemp 1998, p. 353). For Arthur, behind this foreshortened selection, lie increasing returns of adoption (IRA), which can be summarised in five main mechanisms[1]. The consequences of these IRA permit us to observe potential inefficiency that will later create potential forms of irreversibility. To describe this process, David speaks of "path constraints", for a sum of "small events" can turn out to be decisive. Arthur and David's models therefore invite one to retrace the history of the technology during its adoptive phase in order to understand better the choices made by the public or private agents concerned.

This historical approach can turn out to be delicate, for it is difficult, in retrospect, to show that another technological path would have been conceivable. In this vein, some critics of Liebowitz and Margolis (1994) emphasized that the QWERTY keyboard was more a myth than a reality[2]. The example of adopting the dominant standard for the gauge of railroad tracks thus shows the significance of this dynamic on the basis of a collection of data exempt from all ambiguity (Puffert, 2002). At the beginning of the 19th century, the engineer George Stephenson, at the time of choosing the width of the railroad bed ties to send carbon to the ports, was led to take an important decision to standardise the local railroad lines. He chose this gauge by reference to the width of the railroad tracks in the region of Newcastle (his homeland). Following the example of this initial gauge, the first railroad lines were built in 1825. Thereafter, when the network was extended from Liverpool to Manchester, "Stephenson's" width was used and spread to neighbouring countries, in particular Holland. The adoption of this standard illustrates

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[1] Notably the following ones :(1) Learning through use. This process, described by Rosenberg (1982), relies upon the fact that the more technology is adopted, the more economic agents learn to know its characteristics and improve its performance. (2) Externalities of the network. This is the dynamic by grace of which the more technology develops, the more its user value rises (e.g., the typical case of the telephone or internet). Increasing the utility of the technology induces an increase in its variety and the quality of services offered. (3) Economies of scale. The more a given technology is spread, the lower the fixed costs in relation to the increase of the quantities produced. The price goes down, making the technology more attractive. (4) The growing harvest of information. At the time of adoption for any given technology, the aversion to risk concerning the innovation decreases and widens the community of reticent users. (5) Technical interrelations. This concept, very close to that of technological interdependence developed by Rosenberg (1982), highlights the fact that as a technology develops, its scientific and technical environment becomes structured, thereby offering components necessary to its production. The technology not chosen will hence become less efficient because it can lack the « inputs » necessary to its production. This is the classic case of the electric vehicle that was developed in the early twentieth century, but that was gradually dropped in favour of the internal combustion engine. In the 1980s, the electric motor could not take off because all research converged on other options, depriving the electric trajectory of research for the improvement of batteries. Technological interdependence therefore highlights how innovation embeds itself into a vaster whole, one that structures its advancement: a technical system or a system of innovation.

[2] Nonetheless, their empirical data confirm the facts more than they contradict them. According to Margolis (2005), the Dvorak keyboard seemed, from a technical point of view, to represent a slight advantage. Actually, it is more of a methodological criticism on the level of a counterfeit analysis than a true challenge of IRA because it is very hard, in hindsight, to show the technological superiority of an option, given that it was unable to develop in its own time. Many authors were thereafter led to manipulate the empirical facts more meticulously in order to arrive at more solid conclusions.

localised learning. Effectively, as a function of geographic space, it either does or does not behove networks to harmonise (on this subject, see the case of Spain, whose gauge remains different, and other countries like New Zealand). In addition to the flagrant importance of the notion of network externalities, these new data bring out the choice of technologies in a historical, social and institutional context that creates diverse processes of cumulative causality.

For these reasons, the concept of path dependency has been applied at in diverse fields, from technological fields and industries, to the macro-level of institutions (Vergne and Durand, 2010). In the broader path dependency literature, micro-level paths include persistent choices with regard to product-markets (Helfat and Raubitschek, 2000; Danneels, 2002), business models (Schreyogg et al., 2011), and innovation approaches (Thrane et al., 2010; Park, 2011). Macro-level studies of path dependency are also common in the fields of historical sociology and political science for observing the path-dependent character of institutions, including legal systems and other regulatory frameworks (Martin, 2010).

In this context, paths are depicting institutional patterns that have strong or some deterministic properties or are locked in for significant periods of times (Mahoney, 2000; Martin, 2010).

As mentioned in Witt (2003, p.15) “the evolutionary process cannot repeat itself identically even though as a consequence of its regularity, it may display some recurrent patterns”. Bearing this in mind, we follow Foster (1997, p. 433) and identify the lack of formal historical connection as a major drawback of many analyses. Indeed, even though these models incorporate a form of learning processes with increasing returns, they still fail to integrate the main features of an evolutionary-inspired approach of TC, namely systemic interdependencies, heterogeneity of agents and historical contingencies. For example, Koehler et al (2006, p. 24) clearly mention "David and Arthur theory", but historical contingencies are nonetheless ignored in the surveyed models. This is also the case of the heterogeneity of agents, but this is explicitly recognised as a weakness (Koehler et al., 2006, p. 49). Unsurprisingly, systemic interdependencies are not mentioned at all[3]. It is interesting to note that both systemic interdependencies and heterogeneity of agents are typical features of meso-level analyses - the “conceptual heart of evolutionary economics” (Dopfer et al. 2004, p. 269) but also the “missing link”.

For instance the existence of bifurcation points, when alternative future paths appear, which can be interpreted as opportunities for divergent progression (cf., e.g., Araujo and Harrison, 2002). This implies that new paths tend to originate from outside existing industries and that industry incumbents can be severely challenged when new technological options emerge (cf. Henderson and Clark, 1990; Christensen and Rosenbloom, 1995). However in a Schumpeterian world actors are also able to learn and to shift from existing paths in response to changing demands and opportunities (Araujo and Harrison, 2002).

In the words of Garud et al. (2010: 770), “[a]ctors mobilize the past not necessarily to repeat or avoid what happened, but, instead, to generate new options” (cf. also Hakansson and Waluszewski, 2002). This potential bifurcation has been well summarized by the notion of disjunctive progression inside a technological trajectory: «The conjunctive-disjunctive distinction adds another dimension to progression: the relationship between earlier and later events in a series. In conjunctive progression, events are intrinsically related to each other (Van den Daele, 1969) and derive from a joint, underlying process (Poole et al., 2000). In contrast,

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[3] The need to “understand better the underlying elements and issues in experience curves” (Koehler et al., 2006, p. 31) can be considered as a plea for some form of contextualisation but the systemic nature of it is still lacking.

disjunctive progression implies that events are unrelated or even separated from each other. Thus, the carryover from one step to the other is not due to any underlying process-at least not one that can be observed (cf. Van den Daele, 1969) » (Bergek and Onufrey 2013, 7). Thus bifurcation may be perceived as an opportunity for countries to escape from current path dependency and for developing countries as « windows of opportunities » for designing their own vision of innovation according to their own constraints (scarcity for instance), specific uses and their idiosyncratic approach of the local market. As notice by Shove (2004), the view that technologies are embedded in a strongly influential social context of institutions makes that consumption is shaped by (whilst also shaping) technological constraints.

Lock in and lock out: when prior experience starts to be detrimental to prior adopters in energy and sustainable technologies

More recently, this perspective was developed to explain the difficulties facing the adoption of « sustainable » technologies aimed at reducing the emission of CO_2. The findings were the following: there are technologies using low levels of existing energy and, which are, sometimes less expensive and more economical (for example long-life, low-consumption light bulbs), but that remain infrequently adopted. This paradox showing the inertia on the individual and institutional levels rests upon several factors (Unruh, 2000; Könnöla and Unruh, 2007). For Unruh (2000), much of the process of technological isolation can be explained by institutional dynamics: the technology is part of a self-generating system. To understand, the difficulty of adopting so-called “clean” technologies in the American automotive industry, several variables must be examined. At the beginning of the twentieth century, the internal combustion engine was not the favourite option and the American automotive industry was more widely given over to electric infrastructures supplying electric motors. Other options co-existed, notably the steam engine or the gas engine. The battle over standards was to be won by the internal combustion engine and it reduced the number of players in the automobile industry (a dozen in 1890 and only three in 1920: Ford, Chrysler and General Motors). Once the internal combustion engine had secured dominance, and that Fordism had been set up, the scientific and institutional environment became structured with the appearance in American universities of new disciplines making the state of the art progress, along with that of new professional associations and a group of institutions that reinforced the development of the automobile network, i.e., the oil companies.

At the very heart of these firms, such as General Motors, specific competencies emerged and R & D was structured around the internal combustion engine. General Motors set up a work division around the new development of motors based on 22 existing sub-systems of the internal combustion engines, a factor that created a strong resistance to developing new motors (Unruh, 2000). Its dominant position in favour of the internal combustion engine and the division of labour which followed in its wake engendered strong inertia limiting any allocation of new resources towards new engines. The blockages are now on the technological level, now on the institutional level with the structuring of a system of innovation, now on the organisational level with the competency of firms capable of becoming veritably rigid (Leonard-Barton, 1992) and now on the individual level. The force of habit and the efficiency of certain daily gestures also create behavioural inertia, for individuals are rarely aware of their importance (Maréchal and Lazaric, 2010). Some forms of automatic reflexes occasionally make it difficult to abandon some practices executed without any process of deliberation (energy consumption habits, consumer habits, recycling, etc.). These forms of inertia require a true effort and investment to be thoroughly modified. Thus, at the root of this blockage, diverse causalities that cannot be resumed solely by the technological variable appear.

Path dependency is not restricted to technological trajectories, it encompasses also social and institutional dimensions. Indeed technological systems can be defined as "interrelated components connected in a network or infrastructure that includes physical, social and informational elements" Unruh (2000: 819). Adding the fact that technologies are also dependent upon and connected with the wider range of cultural, organisational and institutional aspects of their environment that enable them to work together, we end up with what Geels and Kemp (2007) call Socio-Technical Systems (STS)[4] or what Unruh (2000) calls Techno-Institutional Complexes (TIC). This intertwining of different elements that characterises a STS sheds light on the potential inertia of such systems. Indeed, once historical conditions have led to the emergence of a STS, their multiple components contribute to stabilise the system in a self-reinforcing manner. The nature and type of a STS is thus dependent upon the path followed[5] and is further perpetuated through the interactions of its multiple elements. Positive feedbacks (i.e. increasing returns to adoption) act as a sort of snowball which results in the locking-in of the incumbent STS following a path-dependent process.

In this context, it is clear that new and aggressive approaches may be required in order to combat climate change, and the practical approach would necessarily require the adoption of a range of new energy friendly technologies in several industries. Do the traditional approaches of path dependency assist us here, and how might we make sense of some of the empirical evidence available? In particular, the Paris climate change negotiations have demonstrated considerable split in how nation states perceive their energy-use intensity in terms of their developmental goals and projected processes. Their claim to exception or exemption for global greenhouse gas emission targets, rest on strong assumptions about the path of economic development and the role that energy technologies and industrial structure play.

As Martin (2009) and other economic geographers have well-recognised, there is a tension in the theoretical idea of "lock in" to the degree that it lends itself to an evolutionary analysis. The same is true of path dependency, because it clings in different respects to the idea of equilibria from which exogenous forces might nudge a shift in trajectory. On the one hand, the equilibrium idea militates against the notion of evolutionary change resting in dynamic, endogenous sources. Martin (2009, 3) for instance argues that : ", [….] the concept of 'lock-in' actually serves as a rather limited and restricted way of thinking about path-dependent economic evolution. The idea of 'lock-in' emphasizes continuity and stability rather than change." Both network externalities and increasing returns in the frameworks of path dependency and lock-in have important local characteristics (from labour market specialization, to local strategies of planners, and so forth).

On the other path dependency and lock in may describe change or not, but with too wide a brush to reveal the complex institutional shifts and cognitive factors associated with actors and strategy. In Martin and Sunley (2006) usefully analyse whether lock-in might not be a « state » but a « process». If it is seen not as a state but as a process, they may be more evolutionary

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[4] It should be noted that a "system" is a network of *elements* whereas a "regime" is a network of *peoples*. Socio-technical regimes serve to maintain and stabilise socio-technical systems (see Geels and Kemp, 2007).

[5] In line with the concept of "path-dependence" which refers to the fact that technological systems follow specific trajectories that it is difficult and costly to change (Arthur 1983; David, 1985). As shown in Arthur (1989), these trajectories depend on historical circumstances, timing and strategy as much as optimality (i.e. the main focus of mainstream economics). As defined in Puffert (2002), p 282, a path-dependent process is "one in which specific contingent events – and not just fundamental determinative factors like technology preferences, factor endowments and institutions – have a persistent effect on the subsequent course of allocation".

attributes that one can pull into the analysis of technical change as well as covertly move away from equilibrium characteristics that seem to cling to the original formulations and even subsequent clarifications of Paul David and Brian Arthur's works.

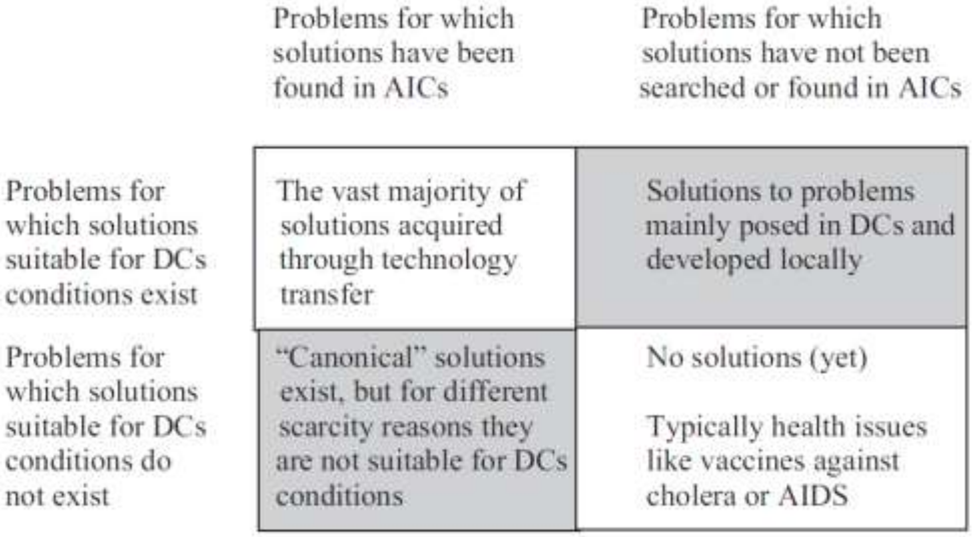
The nuances of development dilemmas in path choices

If indeed there is utility to viewing 'lock-in' as a process of institutional change, then more discussion is needed regarding the developmental dilemmas of multiple paths. The need to move away from equilibria and overtly toward an evolutionary schema is most visible in the case of industrialising contexts in developing countries, where multiple levels of sophistication in capabilities and availability of technologies may be present alongside. In this case, the traditional theoretical manoeuver to assume a state with some technology, then firms or agents facing a choice, then bifurcation(s) in pathways is analytically less useful because such states are the norm, not the exception. In other words, within developing countries, the very process of industrialisation has to do with the constant, perpetual, uncertain process of choice in a highly unclear regulatory environment in which "better" or "worse" choices are deeply contextual, not easily judged in terms of some manifest quality of the technology. (I.e. we could not ask about optimality because the selection environment and its reward systems for that particular choice are quite opaque). Note that this could be true even when a policy ostensibly rewards the investment in a particular technology, but the overall market and nonmarket environments surrounding the firm or agent are a mix of many levels of sophistication at once.

Thus, determining "the market" for a specific technology investment assumes perhaps too much power for the shaping of the environment by the regulator; at the same time, it presumes too much capability of decision-making and availability of technologies to the bulk of agents. In other words, issues of innovation, learning, and wider technological capabilities are at the core of the "development question", and cannot be seen in the narrow sense of strategy but should be seen in the broad sense of the institutional climate in which great industrial policy uncertainties persist (Lall 1982; 1984; Amsden 1989). At the very least, the deeply uncertain environment requires states to step in with not just government policies, but wide institutional restructuring in order to allow their domestic firms to compete. Technological learning in this sense is a deeply political process in the move toward seeing monopoly status and states "getting prices wrong" in order to achieve these ends (Amsden 1989). Indeed, choices between co-existing paths requires a conscious effort at assessing the policy architecture which best boosts technological capabilities alongside better accessibility/affordability options (see also Arocena and Sutz 2000; Kaplinsky 2010; Chataway et al. 2014).

The story of late industrial development when seen in these terms appears also to be an evolutionary but limited process, of lining up all technology ducks in a row. However, market failure approaches hide in fact what is a deeply evolutionary and institutional problem: of institutional variety (Srinivas 2012). The problem may not be market failure, but rather market variety: many markets, many non-market institutions, difficult to coordinate and regulate, and difficult to politically legitimize or select against (Ibid.). The states tasks are enormous and the agents' task challenging (especially for less capable firms). Multiple institutional sub-environments may exist alongside, several scarce and abundant environments may be persist in tandem (Srinivas and Sutz 2008). Indeed, the idea of a given 'innovation system' itself as a concept should be considered ex-post in most developing countries (Arocena and Sutz 2003).

While the problem of multiple institutional environments co-existing alongside in a developing country may seem like a variant of a multiple equilibrium process, the reality is more evolutionary and complex. As Srinivas and Sutz (2008) point out, there are at last four environments in which specific permutations of make-versus-buy pervade the technology choice space of developing countries, and only one of which refers to buying technologies created elsewhere but which must be adapted at home. In their framework (2008, 136), they differentiate between search and production efforts in developing countries (DCs) and Advanced Industrialised Economies (AICs) (or what could be termed "developed" countries). The schema underscores several explicitly evolutionary questions within and between the boxes. For example, one might ask how rain-water harvesting technology systems have developed in quite sophisticated and regulation dynamic ways in developing countries to suit their local contexts in developing countries even while many AICs have struggled to develop them. This would be a case of evolution "within" and learning "within" the upper right hand quadrant. (Problems for which solutions have not been searched or found in AICs but for which solutions suitable for DCs conditions exist). One might ask another evolutionary "within" question such as why the combustion engine which solved problems (transport of the time) within AICs, they were transferred quite so quickly to solutions for DCs (the upper left hand quadrant) and whether they could have been slowed since they have been so polluting. The scheme therefore shows how specific evolutionary paradigms can develop of multiple problem-framing and problem-solving worlds separated by geography (AICs and DCs). In this light, there are critical, urgent, development challenges for technology creation and adoption, such as the lower left hand quadrant or the lower right hand quadrant, or where solutions exist in DCs, but for important market or other reasons do not diffuse everywhere (the upper right hand quadrant).



	Problems for which solutions have been found in AICs	Problems for which solutions have not been searched or found in AICs
Problems for which solutions suitable for DCs conditions exist	The vast majority of solutions acquired through technology transfer	Solutions to problems mainly posed in DCs and developed locally
Problems for which solutions suitable for DCs conditions do not exist	"Canonical" solutions exist, but for different scarcity reasons they are not suitable for DCs conditions	No solutions (yet) Typically health issues like vaccines against cholera or AIDS

Fig. 1. A scarcity-induced innovation framework.

The scheme of four quadrants however could also be seen to ask a similar question to what has been posed by evolutionary geographers and economists of the path-dependency and lock-in question (Srinivas 2009; Arocena and Sutz 2012), which is how one treats worlds where all four (or more) permutations live alongside. How are choices then to be framed? If the scheme represents several types of regulatory and search and adoption worlds that co-exist, it appears that the upper left-hand quadrant represents the 'standard model' of most advanced technologies and systems emerging in the AICs and being adapted and modified for use in DCs.

However, DCs have all four quadrant worlds co-existing. In energy use for example, they have people using candles or kerosene lamps and cooking with wood fuel living entirely off the grid (energy-friendly, even if not health-friendly), alongside homes which are over-users of energy with the latest gadgets and high carbon footprint. These latter households consume from firms that supply in the Upper Left hand Quadrant but also several others from other quadrants that may well sell locally as well. The regulators task in a DC is thus not the same as in an AIC. The framing selection environment in evolutionary terms must simultaneously be doing the job of building technological capabilities while at the same time shepherding people into the most energy-friendly options available. This means having an overt set of priorities built into technology and industrial policy, but also simultaneously in a traded world, expanding the options for firms creating solutions in the off-diagonal grey areas of the 2X2 (see also discussion in Metcalfe and Ramlogan 2008, Srinivas 2009).

But evolution is not a passive selection [process (Martin 2010). Agents after all, have agency, and can make continent choices in the arena they face. As such, they may well adopt cognitive or institutional lenses in order to adapt (Srinivas and Sutz 2008, 132). “Doing things differently’’ in adaptation in DCs therefore means:

“1. Searching for different solutions to problems that have been already solved because existing solutions are inappropriate or unaffordable, including the necessity of adaptation stemming from specificities of natural endowments.
2. Developing innovative efforts to respond to prospective users who face scarcities of some type.
3. Fostering specific ‘‘scarcity-driven’’ heuristics to deal with well identified but not yet solved problems.” (Ibid., 132)

As such, the agents’ adaptation is an exercise of ingenuity and problem-framing not one defined by the outside. It is in terms of its policy environment and its infrastructure, as well as its socio-economic context, endogenous (Ibid).

Similarly, for DC firms which must compete as price-takers but some of which also intend to strategize toward a monopoly position, the literature is unequivocal about the multitude of strategies such firms use to adapt, imitate and innovate (e.g. Dutrenit 2004; Lee 1997).

However, the evolutionary question it can be recalled, is not simply a statement of evolution along a linear path (which would be a misnomer of evolution), but one of multiple paths and bifurcation in an unpredictable manner. These institutional bifurcations generate institutional complementarities as a combinatorics question (Amable 2000). As such the multi-quadrant question is a combinatoric and non-linear switching process. While national industrial policy may smooth over some unevenness and institutional scarcity, national policy alone will not define the problem and path. Indeed, Srinivas and Sutz (2008, 135) are focused in the evolutionary tradition of the agent’s innovation vector set of possibilities: “We argue that roughly speaking, people search for and design solutions within ‘‘technological universes’’. To innovate or to solve problems in a technological universe characterized by scarcity requires the development of a series of skills—learnt by doing, by searching, by interacting, by solving—that are idiosyncratic: we term them capacities to innovate in scarcity conditions.”

The move into international environments is consistent with late industrial political economy then, which emphasizes that firms from DCs although they act within their national policy environments, increasingly learn and ‘graduate’ into international environments. Occasionally, however, it is precisely the capacity to innovate under scarcity that makes the 'local innovator' a 'global innovator' and market leader. This moves the policy attention to new quadrants or policy attention moves a quadrant into dominant position (the off-diagonal elements become the diagonals in an iterative process, see Srinivas 2009).

Of course, if we take co-evolutionary processes seriously (e.g. see Dutrenit 2004; 2006), then we must see industrial policy for DCs especially in this light (e.g. Avnimelech and Teubal 2008). The iterative process of augmenting technological capabilities can be seen itself as a deliberative evolutionary policy choice (Lall and Teubal 1998). If markets are various and act at different scales simultaneously (Srinivas 2012), then goals of development policy could be stated at the minimum as if not outright targeting and blunt selection, to 'market stimulation' (Lall and Teubal 1998) in order to switch paths. The multiple quadrants can be framed by policy, and the switching can be forced by policy 'additively' or with quadrants effectively removed (e.g. if imports become prohibitive, the upper left hand quadrant disappears in principle, although old stock can be modified and adapted). But recognizing that the quadrants are co-evolving and co-exist, even if some garner much policy attention, means that some language for an evolutionary policy strategy must be attended to.

"The debate has tended to focus on the role of selectivity in government interventions - selectivity being defined as the targeting of particular activities ("picking winners", in crude terms) - as opposed to their functionality - functional interventions are intended to improve markets, in particular factor markets, without favoring particular activities.' This distinction, while useful for certain purposes, does not adequately cover the range of economic considerations involved: there is a need to consider a third category of interventions lying between "functional" and "selective". This category, termed "horizontal" [….], refers to policies that may go beyond functional policies in the sense of "improving" existing markets; they can try to promote selected activities across sectors. These activities provide specific economic benefits (for technology development), but are not selective in the industries or actors involved. Horizontal policies thus address activities for which markets are missing or particularly difficult to create in developing countries […]" (Lall and Teubal 1998, 1369, see also Teubal 1996, 1997).

Section 2. Escaping from historical constraints, exploration of new trajectories

(a) French evidence: a strong path dependency around the nuclear option.

In the French historical context the so called 'small' events reveal themselves to be significant political decisions notably those assumed in the decades following the end of World War II when several critical investments were undertaken and technological options exploited, including General de Gaulle's choice to invest in nuclear plants (Cowan 1990; Teravainen et al., 2011). As argued by Finon and Strapoli "the French nuclear system is a clear case of co-evolution of technologies and institutions….(….) Nuclear option justifies the slow and limited scope for liberalization, which the avoids the dilution of the national nuclear. It structures remains an exception regarding the electricity are (preservation of a quasi-monopoly with strong engineering activities) and the nuclear R&D. It thus helps to keep in France the same technological trajectory, which is oriented towards more complex large sized and capital intensive" (Finon and Straroploi, 2001: 1999). These decisions have also shaped the socio-material conditions and relations between utilities and households (Chick, 2002; Marty, 2007). After the Second World War II and during decades technological and political priorities were driven by a willingness to provide cheap and abundant electricity to French households. As a result, in France, the electricity utilities and the main provider, Electricité de France (EDF), have been delivering electricity at lower prices per Kwh compared to other European countries (Eurostat, 2013), resulting in the expectation of low prices and lack of awareness among consumers about their daily consumption (Keppler and Cometto, 2013; Lee and Cloaguen, 2015).

France remains a very specific (and rare) case where technological choices are combined negative learning by doing (Grübler, 2010). Indeed large scale projects are generating complex new energy supply technologies and important uncertainties generating additional costs over time in the scale up of large scale. Thus, paradoxically where increasing returns theories explains us a decrease of cost, we observe that costs increase with that accumulated experience because “the complexity of the technology inevitably increases leading to inherent cost escalation trends that limit or reverse “learning” (cost reduction) possibilities” (Grübler, 2010: 5286).

As Shove observed (2004): technologies are embedded in a strongly influential social context of institutions which shapes consumption while also being shaped by technological constraints. Given that a “structure is always both enabling and constraining” (Giddens, 1984, p. 169), choices in energy consumption are strongly influenced by the existing carbon-based STS through wider forces such as norms, media, technical designs, etc (Shove et al. 2008, Strengers 2009). To be functional, people’s habits have to be ”accordant” with prevailing sociotechnical forces which shape consumers’ choices towards more energy-consuming ways of life. For this reason, particular investments and types of public infrastructures may create a specific link to consumers that precludes potential technological and behavioural changes (see Maréchal and Lazaric, 2009). Ironically too, past technological choices about nuclear options are not put into question by the French society and benefit from a positive image among the young generation as it has been shown by a recent pilot study concerning student’s perception of nuclear energy (Lee and Gloaguen, 2015). This latter study confirms not only the role of the physical elements of the lock in but moreover the social elements where societal elements co- evolve with energy technologies and infrastructures to reinforce the institutional path-dependency.

(b) Indian paths in solar, wind, bio-mass: heterogeneity but limited policy clarity

Successive Indian national governments have wanted economic growth and industrial dynamism, but have not necessarily has the abilities or political strength to consider the detailed responses to climate change adaptation and mitigation requirements. Industrial development and energy availability/supply influence solar and wind energy sector pathways and these transitions are not shaped by climate change concerns alone (Chaudhury et al. 2014). Therefore, an evolutionary, and heterogeneity perspective, rather than muddying the waters, may well lead to a better and speedier climate-friendly transition.

For instance: “Our observations in this paper also do not point to any significant synergies emerging between climate considerations and development imperatives that would greatly accelerate the climate compatible transformation. What is clear is that development of policy capacity at multiple levels (central government, state government) to navigate the thicket of issues – the multiplicity of policy objectives, stakeholder perspectives and interests, the relevance of policy options for the local context – will be key to effective implementation of climate mitigation efforts. “(Ibid, 45.)

However, not all seats at the technology-choice table are invited or get policy attention (the point of the four quadrants in Srinivas and Sutz 2008). It has been long acknowledged that India's development concerns for energy-use exist on both the supply-side and demand. 43.5% of rural Indian households have no access to electricity, a staggering number (see Grover and Chandra, 2006; Srivastava and Rehman, 2006). Furthermore, some technology and industry options seem to offer important advantages for addressing these challenges, but have not scaled up (see Romijn et al.2010).

Moreover, wind and solar show us why a co-evolutionary approach and explicit attention to multiple paths is critical. Wind power seems to experience 'bottom-up' factors. While a wide range of firms, NGOs, brokers, and others are shaping this trajectory, a higher, long-term plan from national government that responds to both developmental and climate concerns is missing, and despite the fact that all actors apparently recognise its critical importance (see Chaudhary et al. 2014). This recognition is driving policy change and significant pressures for long-term policy stability and clarity. In sharp contrast, solar power has national governmental supports and 'top-down' plans, and clearer integration of multiple domestic actors and national and international instruments. The national plans also has room and process for state-level strategies. Yet, the sector itself is still early-stage in terms of firms and no evidence yet of a developmental or climate-friendly 'lock-in' (Ibid. see also Lema et al. 2015). Neither wind nor solar therefore show us a clear policy signal for which path is preferred, and therefore also, no clear response for how to attend to serious social inequities for households with little or no energy access. These households make do with sub-optimal choices of their own, negatively affecting them (usually with gendered health or education implications) and preventing them from participating in any scalable industrial transition (especially true of micro and small firms that need electricity).

…but windows of opportunities in France in the European context

Lock in, even deeply entrenched may be subjected to lock-out creating new paths. Some disjunctive process may be present for avoiding the solely repetition of the past. Renewable energies and climate change requiring significant institutional transformation may create opportunities for overcoming this current lock in. As noted some authors "regime resistance" and resilience inside traditional energy systems may negate the benefits for increasing renewable deployment and green innovation (Geels, 2014; Andrews- Speed, 2016). Indeed as emphasized Markard and Truffer (2006) " we may postulate that the widespread and coordinated resistance of established utility companies against radical innovation, which was characteristic under monopoly conditions, gives way to much more diversified responses "(ibid, 623).

In this direction, the European regulation concerning energy saving, notably Article 13 of the 2006 Energy Service Directive, provide some opportunities for changing the rules of the games for utilities by introducing notably a link between metering systems and energy management, and encouraging implementation of individual meters to show real consumption combined with accurate billing (Darby, 2010). In France the deployment of smart grids, and the requirement imposed by European legislation are raising questions about energy security and climate changes objectives (Clastres, 2011). The price of electricity per kWh is being debated, and opportunities for increasing tariffs to take account of the full cost of maintenance of nuclear plants are becoming serious issues for households in France (Finon and Glachant, 2008; Salies, 2010). In this context of institutional change, deployment of smart grids and renewable energies generate opportunities in the electricity value chain, improvements to the overall management of electrical systems, and potential gains for consumers. Reducing the asymmetry between demand and supply is a critical component of this transformation for learning about demand-side determinants and for discovering future strategic investments in this field (Kendel and Lazaric 2015; Pehrsson , 2011).

Additionally market liberalization at the European level change the handling of innovation by introducing a general broadening of innovation with potential disjunction in the system or at least more variety (Markard and Truffer, 2006). Whereas France is moving very slowly in the adoption of renewable energy and in the change to existing systems, wind energy industries create new technological paths in Europe. Windows of opportunities are diverging according to initial sociological conditions. For instance as noted by Simmie et al., (2014) the success of development to this renewable industry and the capacity of inventors to convert their idea in innovation and successful trajectory was largely due to the “anti-nuclear culture” present that supported inventors in the creation of small niche, whereas “such development in Britain have lagged well behind those in Germany” (ibid, 898-899). In a context of globalisation, wind power industry becomes a critical issue for DC. Indeed the force of installed bases has leveraged significant economies of scale and opportunities between AIC (Germany and Denmark) notably and DC such as China and India for creating a globalized process of innovation with diverse strategies for developing national and international capabilities (Lema et al., 2015).

Policy opportunities in India but planning confusion about transition

India’s immense SmartCities initiative covers financing and policy visibility for urban initiatives, several with practical energy-related facets from smart metering of electricity, to physical infrastructure investments from water usage to mobility enhancements[6]. The Smart cities covering 100 Indian cities is therefore one of the largest potential policy-inducements for switching paths at the urban scale. Nevertheless, the Smart Cities initiative depends, like all other policy changes, on the ability of local governments to plan, and numerous stakeholders including firms, to carry out these ‘smart’ investments and ensure that citizen services are improved.

The illustrative list the government emphasizes shows that energy management (not technologies) is one of several “smart” options.

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[6] « city improvement (retrofitting), city renewal (redevelopment) and city extension (greenfield development) plus a Pan-city initiative in which Smart Solutions are applied covering larger parts of the city”. http://smartcities.gov.in/writereaddata/Strategy.pdf, last accessed 10 Oct 2016.The features are indirect and in principle, technically diverse, focused more on urban plan improvements and health and environmental livability than technology-prescriptions, *per se* http://smartcities.gov.in/writereaddata/Smart%20City%20Features.pdf, last accessed October 10 Oct 2016.

ILLUSTRATIVE LIST

Smart Solutions

E-Governance and Citizen Services
① Public Information, Grievance Redressal
② Electronic Service Delivery
③ Citizen Engagement
④ Citizens - City's Eyes and Ears
⑤ Video Crime Monitoring

Waste Management
⑥ Waste to Energy & fuel
⑦ Waste to Compost
⑧ Waste Water to be Treated
⑨ Recycling and Reduction of C&D Waste

Water Management
⑩ Smart Meters & Management
⑪ Leakage Identification, Preventive Maint.
⑫ Water Quality Monitoring

Energy Management
⑬ Smart Meters & Management
⑭ Renewable Sources of Energy
⑮ Energy Efficient & Green Buildings

Urban Mobility
⑯ Smart Parking
⑰ Intelligent Traffic Management
⑱ Integrated Multi-Modal Transport

Others
⑲ Tele-Medicine & Tele Education
⑳ Incubation/Trade Facilitation Centers
㉑ Skill Development Centers

Source: Government of India http://smartcities.gov.in/writereaddata/What%20is%20Smart%20City.pdf, last accessed 10 Oct 2016.

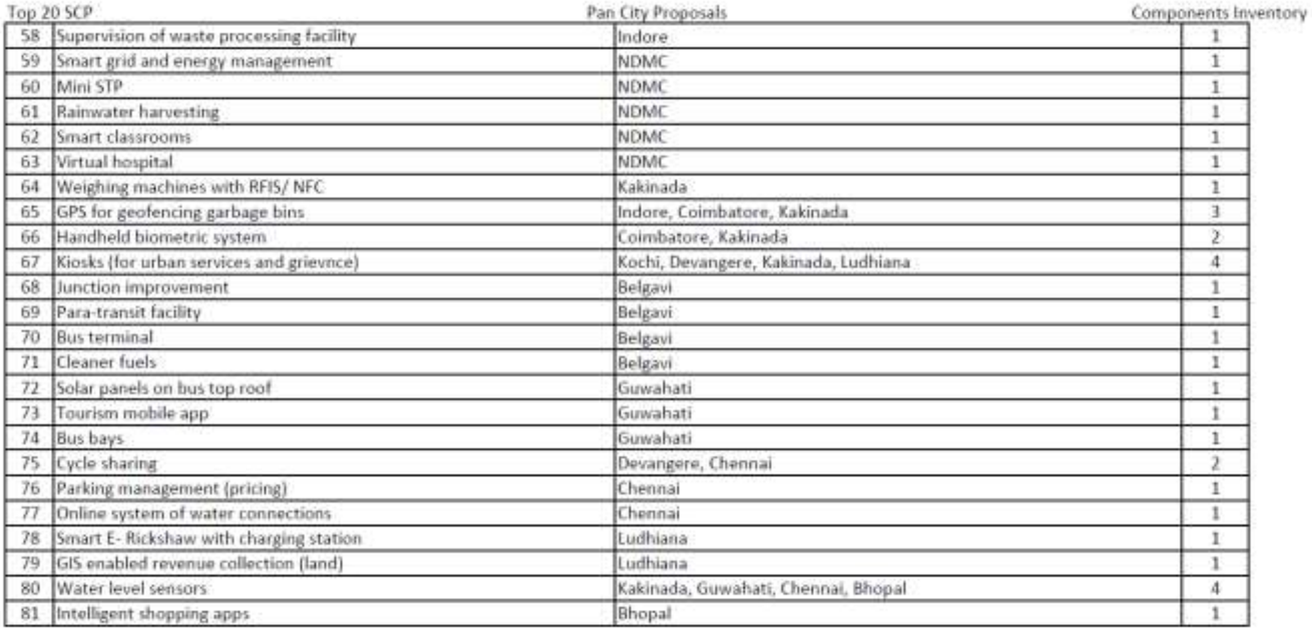
Similarly Round 1 winning cities and their focus components are listed below. Only some are explictly energy-friendly devices.

Top 20 SCP Pan City Proposals Components Inventory

S.no	Component	Cities	Count
1	Centralised command and control centre	Bhubaneshwar, Surat, Kochi, Ahmedabad, Jabalpur, Visakhapatnam, Davanagere, Indore, Coimbatore, Belagavi,Udaipur, Ludhiana, Bhopal	13
2	Transit operations system (maintenance and tracking)	Bhubaneshwar, Pune, Jaipur, Ahmedabad, Indore, Solapur, Davanagere, Indore, Kakinada, Udaipur, Guwahati	10
3	Smart parking system	Bhubaneshwar, Pune, Jaipur, Davanagere, Indore, Coimbatore, Kakinada, Udaipur, Guwahati, Chennai, Bhopal	11
4	Common card (payment and operations)	Bhubaneshwar, Jaipur, Surat, Ahmedabad, Indore, Udaipur, Guwahati	7
5	Area based traffic control	Bhubaneshwar, Pune, Ahmedabad, Davanagere, Indore, Coimbatore,	7
6	leak identification system (SCADA/ and AMR)	Pune, Ahmedabad, Solapur, NDMC, Kakinada, Udaipur	6
7	Platform for citizen engagement and all citizen services; city dash board	Kochi, Visakhapatnam, Solapur, Davanagere, Indore, Bhopal	6
8	Traffic mobile app	Pune, Jaipur, Ahmedabad, Indore, Guwahati	5
9	Smart metering (water)	Pune, Kochi, Vizag, Solapur, NDMC, Coimbatore, Belagavi, Udaipur	8
10	CCTV surveillance	Pune, Ahmedabad, Devangere, Indore, Coimbatore, Guwahati, Bhopal	7
11	Emergency response	Bhubaneshwar,Surat, Ahmedabad, Visakhapatnam, Coimbatore, Udaipur	6
12	Public information system	Pune, Ahmedabad, Davanagere, Indore,	4
13	Public transit and traffic operations and mangement centre	Jaipur, Surat, Ahmedabad,Devangere, Vizag, Indore, Belagavi, Udaipur	8
14	GPS tracking and optimisation of routes of garbage trucks	Jaipur, Jabalpur, Indore, Kakinada	4
15	Wifi- IT connectivity	Pune, Surat, Kochi, Coimbatore, Belagavi, Guwahati	6
16	NMT infrastructure	Devanagere, Belagavi, Udaipur, Guwahati, Chennai, Bhopal	6
17	LED street lighting	Coimbatore, Guwahati, Chennai, Bhopal	4
18	Traffic analysis or roads and video survielance inside bus using CCTV surviellance	Pune, Indore, Kakinada	3
19	Mobile app based SWM and cleaniliness monitoring	Jaipur, Jabalpur, Indore	3
20	Fleet management system	Jaipur, Ahmedabad, Indore,	3
21	Automatic fare collection system (transport)	Bhubaneshwar, Jaipur, Surat, Ahmedabad, Indore,	5
22	Variable message sign boards	Ahmedabad, Indore, Bhopal	3
23	Optical fibre enabled communication	Ahmedabad, Indore, Bhopal	3
24	Pedestrian infra	Belgavi, Udaipur, Guwahati	3

Top 20 SCP Pan City Proposals Components Inventor

25	Smart bulk metering at WTPs	Pune, Surat, Kochi	3
26	24x 7 water supply	Pune,NDMC, Belagavi	3
27	Grievance redressal through web, app and phone	Pune, Vizag, Kakinada, Chennai, Bhopal	5
28	SWM operations and management centre/ system	Jaipur, Jabalpur, Indore, Belagavi	4
29	Smart card for all service payments	Surat, Ahmedabad, Kochi, Indore,	4
30	Smart Bus stops	Pune,Jaipur, Devanagere, Belagavi	4
31	Smart meters for electricity	NDMC, Udaipur	2
32	Solar power capacity implementation	NDMC, Belagavi, Guwahati	3
33	e-healthcare	Vizag, NDMC, Coimbatore, Kakinada	4
34	Air quality monitoring sensors	NDMC , Coimbatore, Bhopal	3
35	City buses	Bhubneshwar, Pune, Devangere, Udaipur, Guwahati	5
36	Hydraullic information system/ flood monitoring	Guwahati, Chennai	2
37	In-bus information system and wifi	Pune	1
38	Private bus aggregator	Pune	1
39	Intelligent road asset management	Pune	1
40	Give up water subsidy"campaign	Pune	1
41	ICT enabled billing and recovery department	Pune, Surat	2
42	e-challans for traffic violations	Bhubneshwar, Pune	2
43	ICT and social media based 2 way communication with citizens	Jaipur	1
44	ERP with GIS platform for corporation	Surat	1
45	Ticket vending machines and value machines	Ahmedabad	1
46	Water accounting at community level	Ahmedabad	1
47	RFID tags for SWM	Jabalpur, Coimbatore, Bhopal	3
48	Street sweeping and dustinf machines	Jabalpur	1
49	Capacity bulding of staff	Jabalpur, Ludhiana	2
50	Institutionalising SLB	Solapur	1
51	Mapping of utilities	Solapur	1
52	Data analytics centre	Solapur, Coimbatore, Bhopal	3
53	Intelligent solar powered lights	Devanagere, Belgavi	2
54	Bicycle pods with PIS	Devanagere	1
55	Smart paving (capture energy from movement)	Devanagere	1
56	One website, app and call centre	Devanagere	1
57	Pedestrian and bicycle activated signals	Indore	1



Top 20 SCP		Pan City Proposals	Components Inventory
58	Supervision of waste processing facility	Indore	1
59	Smart grid and energy management	NDMC	1
60	Mini STP	NDMC	1
61	Rainwater harvesting	NDMC	1
62	Smart classrooms	NDMC	1
63	Virtual hospital	NDMC	1
64	Weighing machines with RFIS/ NFC	Kakinada	1
65	GPS for geofencing garbage bins	Indore, Coimbatore, Kakinada	3
66	Handheld biometric system	Coimbatore, Kakinada	2
67	Kiosks (for urban services and grievnce)	Kochi, Devangere, Kakinada, Ludhiana	4
68	Junction improvement	Belgavi	1
69	Para-transit facility	Belgavi	1
70	Bus terminal	Belgavi	1
71	Cleaner fuels	Belgavi	1
72	Solar panels on bus top roof	Guwahati	1
73	Tourism mobile app	Guwahati	1
74	Bus bays	Guwahati	1
75	Cycle sharing	Devangere, Chennai	2
76	Parking management (pricing)	Chennai	1
77	Online system of water connections	Chennai	1
78	Smart E- Rickshaw with charging station	Ludhiana	1
79	GIS enabled revenue collection (land)	Ludhiana	1
80	Water level sensors	Kakinada, Guwahati, Chennai, Bhopal	4
81	Intelligent shopping apps	Bhopal	1

Source: Government of India, Smart Solutions Components http://smartcities.gov.in/writereaddata/Smart_Solutions_Components.pdf, last accessed 10 Oct 2016.

As one can see from the table of the focus areas of the winning cities in Round 1 of the Smart Cities Competition, energy options come bundled not merely as:

A. Devices and instruments (e.g. solar panels (72), cleaner fuels (71), but also as
B. Technology systems and planning processes such as smart grid energy management (59), and furthermore also as
C. Resource-utilisation efficiencies. These last include ways to make public spaces better used (74, 69, 76), physical infrastructure better priced (78, 79) or other natural resources such as water more efficiently consumed (80).

While the Smart Cities might have been an opportunity for clarifying the preferred national pathway or innovation choices in solar, wind, or biomass, the reality is much more mixed and opaque. While the openness of the choices might appear attractive in policy design to signal wide choices, even a program at the scale of the Smart Cities policy initiative may not clarify or align the development and climate concerns. Rather, the multiple conflicts continue to exist in innovation and industrial policies. For instance, if one of the goals were to strengthen biomass policies and biomass-generated electricity, then it would follow that the government would privilege such firms and investments in biomass innovations, and the Smart Cities program could have signalled 'higher points' for alignment and targeting in the competition evaluations.

In principle, the greater the heterogeneity of paths and learning open in terms of policy and incentives, it might be argued that municipal governments may be least able to select amongst them. Lock-in through national policy choices and third-part monitoring for example, might narrow the choices available and the customisation by city or technology, but might simultaneously serve to signal stability, long-term commitments, or financing clarity. As cities must contend with enormous challenges of greenfield, brownfield, and off-the-grid private and public investments, the equivalent choices are enormous and uncertain (see Srinivas and Sutz 2008 for innovation typologies, Hurliman et al. 2012, on dynamic spatial planning for climate politics; Metcalfe and Ramlogan 2008 on policy implications of path-dependency). The policy nuances must lie in showing how to move between quadrants or preferential rewards for certain types of low-carbon investments in *each* quadrant, or only some of them.

This of course complicates the discourse of countries in a climate change treaty because it asserts that the process and outcomes of an uncertain, stochastic, innovation-adoption process are endogenously framed, and not equated easily with other countries. It cannot serve the question to be framed entirely within the frame of the upper left hand quadrant when we cannot exactly anticipate the different co-evolutionary interactions between all 4 (or others). Regulation then is not a simple coordination process, but harks more to implicit targeting as a selection choice.

While the cognitive and structural dimensions frame the problem set as it were, the trajectories of individual firms in a global marketplace (depending on the technology) may dominate, rather than 'national' trajectories (Srinivas and Sutz 2008; Lema et al. 2015) Yet, if national priorities are 'non-canonical', then unconventional policy strategies have to be tried to prevent one quadrant from dominating the policy attention to the exclusion of others (Srinivas and Sutz 2008). E.g in energy, some social priorities may not be adequately signalled in policy and planning process on the ground: "One would have expected the development of strong trajectories in China and India for developing small-scale and off-grid technologies, yet such trajectories were not identified. Given the relevance of such technologies for China and India and the potential for export to other countries, this is surprising." (Lema et al. 2015, 12). These conscious strategies may have to occur simultaneously at multiple scales (Martin and Sunley 2006) but also through multiple market varieties which the state may be unable to create, legitimize or regulate (Srinivas 2012). This means that the process of "switching" isn't a single moment but a process, but a set of politically mediated choices between multiple co-evolving options, only some of which are politically agile or legitimate (Arocena and Sutz 2012; Srinivas 2009, 2012; Dutrenit 2009, Metcalfe and Ramlogan 2008).

Conclusion

The motivation of this paper was to make some preliminary observations in the energy sector of the paths of development and the co-existence of technologies. We used the approach that a France-India contrast might present characteristics to probe the traditional 'developing' 'developed' country divide. We did so to see whether it is necessarily easier for developing countries to have more choices, and whether developed economies are more 'locked-in'. We need more research to answer this question, but we have been able to see some common conflicts at the policy levels on which paths to wholeheartedly support. In France, these trade-offs are seen as between energy security (especially not losing existing options) and climate adaptation, while in India, the trade-off is often posed as one 'developmental' between energy access (for those who have had little or none), 'developmental' for supply needs for industry, and climate adaptation. This makes the study of institutional bundles, in both country cases, especially in the larger context of India, we also see substantial path variance at sub-national levels, making more evident the need for 'lock-in' and switching analysis with different research design.

Learning how to bifurcate and to introduce disjunctive progression and new technological trajectories seem far from an easy task for France especially in the direction of renewable energy given the weight current nuclear lock embedded in social and physical technologies. In India the bifurcation may be present but there are too many policy ambiguities about market design and incentives for both renewables and fossil fuels (although the new post-Paris targets top towards renewables) but also amongst renewable sources-wind and solar. While these refer to the source fuel, the service delivery technology options and their business models are also ambiguous (e.g. metering, panel installation, storage, and 'last-mile' pipes, bulbs, or devices). In developing country contexts especially which are industrializing and therefore which have more make vs. buy permutations possible, there tend to be more, not less options, making the study of switching even more necessary. It is incorrect to pre-suppose that in these contexts, energy technologies are for the poor alone or inexpensive. Furthermore, bio-mass technologies as home-grown solutions, can be substantially technology-intensive depending on context of installation and scale of outputs.

In France European liberalization and globalization of energy markets are changing the rules of the game by introducing real opportunities for new players. During the same period the implementation of Smart Cities and renewable energies initiatives in both France and India create experimentations at the regional level in diverse fields. Whereas France is emblematic of strong path dependency, the next decade should be observed very carefully for seeing if the broadening forces present may create new technological avenues and if policy makers may enable conditions for overcoming current inertia and for opening the door to new players inside this current system.

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