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EXPERIENTIAL LOCK-IN: CHARACTERIZING AVOIDABLE MALADAPTION IN INFRASTRUCTURE SYSTEMS

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Introduction

Facing the combined challenges of environmental, social, and technological change long-lived Infrastructure Systems run the risk of getting locked into unsustainable, maladapted pathways. This is particularly challenging in the context of climate change, given projected climate impacts are characterised by high degrees of uncertainty (Hallegatte, 2009). "Lock-in" is a concept developed by economic historians to describe how economies get tied into using inefficient technologies, and it is linked to the concept of path dependence (Arthur, 1983; David, 1985), which refers to the fact that infrastructure systems follow specific trajectories that are difficult and costly to change. As shown in Arthur (1989), these trajectories depend on historical circumstances, timing and strategy as much as on optimality. In the 1990s, some investigations highlighted the need to approach the analysis of technological changes through co-evolutionary approaches which recognise that the technological systems influences and are influenced by the social, economic and cultural setting in which they develop (Rip and Kemp, 1998). Liebowitz & Margolis (1994) argued that the role of some elements of the system, such as network externalities remains contested. Of particular interest is the extent to which by favouring incumbent infrastructure systems limits the development capacity of socio-economic groups such as communities, industries or countries. While exploring the whole phase space of possible fundamental influences is impractical, the authors argue that it is still possible to avoid some lock-in by effectively utilising existing anticipatory capacity.

The paper elaborates on three ideas, firmly rooted in the scholarly literature and recent studies, which characterize one type of avoidable lock-in: (1) the observed dominance of experiential versus analytical anticipatory capacity of communities, industries and countries in the governance of socio-technical systems; (2) the existence of formal approaches to quantify the limits to adaptation in such

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systems and (3) limitations of the impact and capacity approach to adaptation. The elements of an avoidable lock-in are then summarized and illustrated by an example. Finally some conclusions are given on the implications of this type of avoidable lock-in and how it might increasingly affect policy decisions that have long-term implications, such as those related to long lasting infrastructure systems and spatial planning.

The role of experiential vs analytical capacity

People process uncertain information in two qualitatively different ways, namely through experiential and analytical processing (Marx et al., 2007). Experiential processing relates current situations to memories of one's own or others' experience. Analytic processing, by contrast, includes mechanisms that relate the current situation to processed ensembles of past relevant experience and thus can easily and naturally express statistical constructs such as probability and sample size.

In long-term planning, far too often the preferred future scenario is driven by experiential rather than analytical anticipatory capacity (Vervoort *et al.*, 2012; Adger *et al.*, 2013). Vervoort and co-authors (2012) highlighted that at the individual level, experiential anticipatory capacity, compared to analytical anticipatory capacity, is more emotionally engaging, difficult to forget and therefore plays a major role on the process of selecting participatory future scenarios. This is supported by psychological research (e.g. Tversky & Kahneman, 1973; Kahneman & Tversky, 1982; Johnson & Levin, 2009; Slovic, 2010) and by the observation that extreme events can have significant roles in both small regulatory changes and in large political upheavals (Adger *et al.*, 2013).

Limits to adaptation

Quantifying the benefit of adaptation in terms of risk reduction, Dow *et al.* (2013) defines a limit to adaptation as a point at which an agent can no longer protect valued objectives from intolerable risk through adaptive action. Breaching adaptation limits will thus result in escalating losses or require (or trigger) transformational change. This challenge is aggravated by three basic patterns of how socio-technical systems fail to adapt: (1) they tend to exhaust their adaptive capacity as challenges escalate and cascade; (2) they tend to work at cross-purposes with behaviour that is locally adaptive but globally maladaptive; and (3) they tend to get stuck in behaviour that was adaptive in the past but not in the present and future (Branlat & Woods, 2010).

Furthermore, as Dow and co-authors (2013) highlighted, the existence of adaptation limits has broad implications. If the capacity to adapt is unlimited, a key rationale for investing on mitigation (i.e. reducing emissions of greenhouse gases) is weakened and replaced by considerations of adaptation costs and benefits, and of equity concerns. However, research suggests that opportunities and resources to adapt may be finite for many social actors, whether these are individual households, businesses or governments (Moser & Ekstrom, 2010).

The need to bridge impact and capacity approaches

The need to integrate (analytic) impact approaches with (decision-maker oriented) capacity approaches are increasingly recognised (Vermeulen et al., 2013). Adaptation planning can incorporate scientific information both from projections of climatic impact assessments as well as stakeholder-based assessments of adaptive capacity. Impact approaches use statistical or mechanistic models to attach probabilities to possible outcomes under a range of scenarios; they arrive at adaptation options for agriculture and food security via analyses that start with climate forcing's and global circulation models, and from these project progressive impacts on local climates, crop physiology, crop yields, food prices, and, finally, outcomes for human welfare and nutrition. Capacity approaches start by assessing the existing capacities and vulnerabilities of socioeconomic groups such as communities, industries, or countries. From this base, they develop sets of "no regret" options that are considered politically and economically feasible over a range of possible climatic futures. Overall, capacity approaches to analysis and planning are more compatible with stakeholder-driven processes.

Key to our aim of characterizing avoidable lock-in is to understand how the different approaches to adaptation co-exist within the overall feedback structure of socio-technical systems. Figure 1 shows a conceptual model, of how socio-economic dynamism, economic benefits, socio-environmental welfare programs and risk are inter-related. In modern capitalist societies the prime source of insecurity is no longer nature but the economy itself. The economic system is no longer oriented towards stability and stagnancy but towards innovation and dynamism. It is characterized by "creative destruction" (Tom, 2003), in which new products and forms of distribution and organization displace older forms. In this fast developing economy, social inequality is on the rise and socio-environmental welfare programs have been developed to cope with growing inequality as well as effects induced by environmental (e.g. climate) change. Investments in social and environmental welfare programs reinforce returns by reducing the frequency of impacts but also balance the returns by increasing the assets at risk. To maintain or even build on past levels of economic dynamism (and associated returns) actors at all levels need to make optimal use of available long-term (analytic) anticipatory capacity to ensure a continuous transition between a limited set of adaptation options available at each point in time. How the socio-economic dynamism changes due to changes in risk levels will determine if a lock-in loop is active.

Example of avoidable lock-in: agriculture planning in Central America

An example of long-term agriculture planning in Central America is used to illustrate the concept of an avoidable lock-in. The example on agriculture planning in Coffee-Growing Regions of Central America (Vermeulen *et al.*, 2012) is chosen to show how robust decision can be made despite wide disagreement between model projections. In the mountainous regions of Latin America, Arabica coffee is a mainstay source of income for smallholders farmers, and a commodity that generate significant economic benefits for rural service providers and global supply chains. Coffee Arabica is grown in a very narrow climate niche, requiring mean temperatures of 19-22ºC with little inter-annual variation and ample rainfall. Furthermore, coffee is a perennial crop, planted either in exposed full-sun conditions or under shade, with significant upfront investments in a desired cropping cycle of 15 or more. Thus, the crop must be grown across specific altitudinal bands of suitable temperature, and changes in growing areas are multiyear investments. An evaluation of the impacts of climate change on suitability to grow coffee using general circulation model (GCM) scenarios for 2030 and 2050 in Nicaragua reported a very significant decrease in suitability of 80% of potential area by 2050, as the zone suitable for the crop move up the altitudinal gradient or coffee regions simply run out of mountain to climb.

The most important finding of this work is that despite differences among 19 GCM projections, they show absolute agreement with regards to shifts in crop suitability across the altitudinal gradient. Even when the significant uncertainty is fully quantified through impact analyses, there are robust no-regret actions for specific farming altitudes. The altitudinal bands correspond to progressive levels of incremental, systemic, and transformative adaptation as you move from the top to the lower altitudes.

Varangis (2003) has identified the need of investments in infrastructure regardless the strategy chosen -either improving competitiveness in coffee or diversifying out of coffee-. New transportation infrastructures are needed to access higher altitudes where coffee might still suitable or allow having sufficient land with which to diversify into alternative crops, improve access to markets and lower transaction costs and increase competitiveness. Some of the investment in transportation and communication infrastructure could be coordinated at the community level, along with investments in infrastructure for improved water and sanitation, and improved education and health as part of a comprehensive broad-based rural development strategy.

If the needed investments on infrastructure is not pursued the already limited incremental, systemic and transformational adaptation options will be even fewer.

The elements of an avoidable lock-in

Climate change will most likely not be experienced as a smooth change in mean conditions, but as series of what were once considered extreme events occurring more frequently (IPCC, 2013). The non-linear increase of indirect losses with respect to direct losses due to extreme events is likely to continue given current development trajectories (e.g. Hallegate, 2009; Hinkel et al., 2014). Together, these factors exacerbate a challenge for authorities in infrastructure development and spatial planning. Given that, investing in risk reduction of existing assets that we value today is demanded by society, how do agents (i.e. communities, industries and countries) allocate resources in the long term to facilitate the transformational change if the adaptation limit is reached?. By protecting existing assets without considering a broad range of future uncertainties we may be limiting the already finite set of adaptation pathways. There is the additional risk that as the number of extreme events and losses increases over time, actors may have to increase resources spent on protecting existing assets further delaying investment in emerging niches.

This problem can be theorised as an "experiential lock-in". In such situations, resource allocations are mostly informed by actors' experiential anticipatory capacity. Actions (i.e. small regulatory changes or large political upheavals) are triggered by events breaching the tolerable risk threshold. These actions translate into resource commitment towards certain infrastructures and spatial planning, which, over time, might induce non-bearable cost and the need to abandon the once valued assets. Even if non-bearable costs levels are not reached, the actors' limited resources are locked in previous commitments and investments in assets required for emerging niches are delayed. If a limit to adaptation is reached, a transformational change must follow. The portfolio of transformational pathways will vary with the level of previous attention to actors' analytical anticipatory capacity and actors' resource requirements at the time of the transformation. This logic is well aligned with lock-ins observed in other technological systems such as the energy system. For example Maréchal (2007) argued that due to the dynamism of socio-economic systems, and in particular the limitations imposed by lock-in points, any adaptation framework overly favouring the short-term is of limited use in the context of adaptation to climate change.

To synthesize and frame the dilemma explained above the authors favour the term experiential lock-in over other related but imperfect analogues. The term “experiential” is favoured over similar concepts such “affect heuristic” (Slovic et al., 2007) since affect is just one attribute of experiential processing (Marx et al. 2007). Recognizing the existence of experiential bias in decision making will eventually allow for the use of coherent narratives (McCloskey, 1990) when planning large infrastructure projects. Lock-in in here is not defined differently from the sunk cost effect: a greater tendency to continue an endeavour once an investment in money, effort, or time has been made (e.g. Arkes and Blumer, 1985). We prefer lock-in over sunk costs since sunk costs is a retrospective cost while anticipation based on our analytic processing capacity provides information of prospective costs, which are future costs that may be incurred or changed if an action is taken.

Conclusions and implications for infrastructure planning

Regardless of the evidence supporting limits to adaptation the contemporary planning paradigm remains linear and largely informed by experiential input. Basing contemporary adaptation strategies on such planning approaches downplays the path dependency of socio-technical development and is liable to creating lock-in points that limit future adaptation options and may push society into developmental dead-ends. Although available approaches to long-term analytical anticipatory capacity are limited at best and highly uncertain at worst, approaches such as adaptation pathways (Ranger et al., 2013, Haasnoot et al., 2013, Wise et al., 2014) should continue to be developed to facilitate a continuous transition between a limited numbers of adaptation options available at each point in time.

The identification and anticipation of lock-in points, which ensue from previous adaptation activities that directly or indirectly create conditions that limit the pool of current and future adaptation options, thus emerges as a topic of major concern. This is of particular importance for decisions that have very long-term implications, such as those related to long-lived infrastructure systems and spatial planning. Stating the weaknesses of such anticipation is not enough, but should spur investments into research and development to address these weaknesses and improve one of the more central capacities required to address the core challenges of humankind. Examples of future directions are (1) recognizing and overcoming the experiential bias that exists even in current analytical methods; (2) increasing the flexibility of analytical methods to represent structural and transformational change in socio-ecological systems; and (3) making analytical insights experientially relevant for decision-makers through improved communication to reduce the experiential bias.

The focus of this forum has been on the role of how anticipatory capacity of communities, industries and countries might contribute to build more resilient socio-economic systems. The author's would like to acknowledge that a better understanding of flexibility in system development is another ongoing worthy line of research towards more resilient socio-technical systems.

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Figure 1
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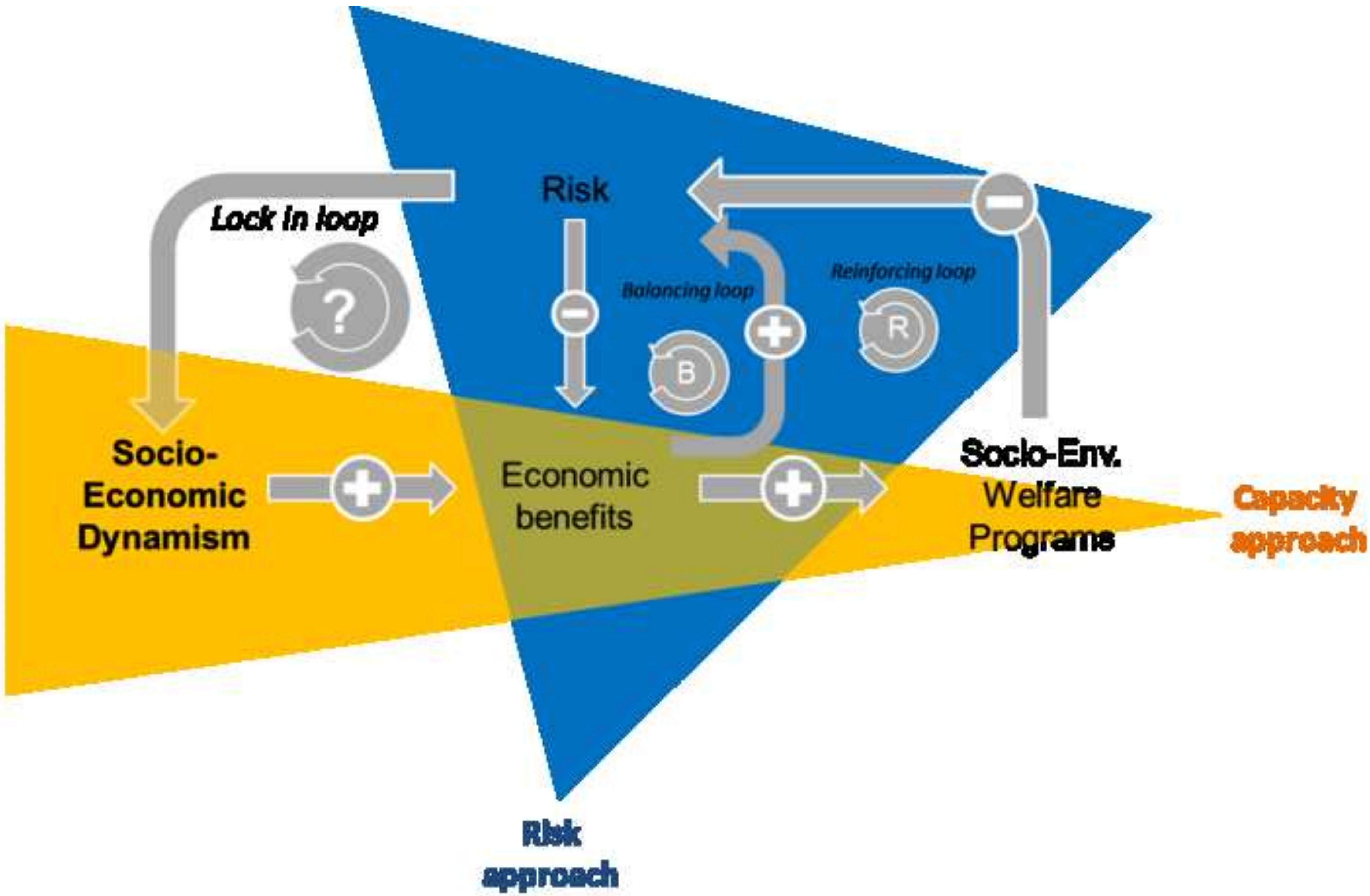

Figure 1.- Conceptual diagram showing how lock in loop falls outside the scope of risk (blue) and capacity (orange) approaches.

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The author's appreciates editor apologies and the constructive comments received from the two anonymous reviewers. In the following we briefly describe how the Editor and reviewer's comment has been addressed on the reviewed manuscript.

To the Editor:

Within the example section, the previously implicit connection between the agriculture example and infrastructure investment has been made explicit by adding the text below on line 114 and adding a new reference accordingly (Varangis, P. N. (2003). Dealing with the coffee crisis in Central America: Impacts and strategies (Vol. 2993). World Bank Publications.).

"Varangis (2003) has identified the need of investments in infrastructure regardless the strategy chosen -either improving competitiveness in coffee or diversifying out of coffee-. New transportation infrastructures are needed to access higher altitudes where coffee might still suitable or allow having sufficient land with which to diversify into alternative crops, improve access to markets and lower transaction costs and increase competitiveness. Some of the investment in transportation and communication infrastructure could be coordinated at the community level, along with investments in infrastructure for improved water and sanitation, and improved education and health as part of a comprehensive broad-based rural development strategy."

The caption for Figure 1 has been shortened

The initials J.A. has been added to the Moser, S.C and Ekstrom reference

References has been tidied up following the link provided by the editor.

Reviewer 1:

The connection between the agriculture example and infrastructure has been made more explicit and a new reference added (Varangis, 2003)

"Study case" has been replaced by "example" on lines 28, 93 to acknowledge reviewer suggestion

Reviewer 2:

"Recent" has been replaced by "In the 1990s" on line 14 and the citation re-edited to avoid characterizing Liebowitz and Margolis (1994) as recent work.

The connection between the example and agriculture has been made more explicit.