International Journal of the Commons
Vol. 12, no 1 2018, pp. 301–331
Publisher: Uopen Journals
URL:http://www.thecommonsjournal.org
DOI: 10.18352/ijc.816

ISSN: 1875-0281

Decentralisation and drought adaptation: applying the subsidiarity principle in transboundary river basins

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Abstract: Determining how to adapt to freshwater scarcity and variability has become an important question for institutional analysis and development. This paper addresses the ***assignment challenge*** in drought adaptation, namely the challenge of assigning and coordinating governance responsibilities across nested levels of social organisation. The subsidiarity principle suggests that adaptation decisions and associated governance responsibilities should occur at the lowest level at which they can be performed competently. Droughts and related slow-onset 'shocks' throw into question which level is lowest, and how this varies with the duration, severity and extent of the event. This paper explores the potential for the subsidiarity principle to guide the assignment and assessment of governance responsibilities associated with drought adaptation. It reviews literature at the intersection of common pool resource studies and new institutional economics to elaborate four diagnostic questions: (1) what are the opportunities and limits of decentralised (independent) drought adaptation?; (2) how are social dilemmas and spillovers associated with drought adaptation managed?; (3) when do higher level institutions complement versus crowd out decentralised adaptation?; and (4) how does adaptation by individuals and groups affect adaptive efficiency? An illustrative comparison of drought adaptation in the US portions of the Colorado and Rio Grande Rivers of North America demonstrates: (i) the potential and limits of decentralised adaptation through urban water conservation and irrigation efficiency (ii) the importance of both formal and informal coordination institutions (e.g. river basin organisations) to address cross-border externalities, including conflicts and economies of scale, and (iii) the pivotal role of groundwater management for adaptive efficiency, requiring a balance between local, short-term dependence on groundwater for drought adaptation with transboundary, long-term outcomes caused by unsustainable extractions.

Keywords: Adaptation, Colorado River, decentralisation, diagnosis, drought, Rio Grande River, subsidiarity

Acknowledgements: Funding for this research was provided by the Social Sciences and Humanities Research Council of Canada, Grant 430-2014-00785 under the 'Transboundary Rivers and Adaptation to Climate Extremes (TRACE)' project. Feedback from Edella Schlager, John Fleck and three anonymous reviewers improved the manuscript. Responsibility for all errors and omissions lies with the author.

1. Introduction

Droughts cause disturbances to social, economic and ecological systems and the institutions governing them (Schoon and Cox 2012). Periodic deficits in precipitation, runoff or soil moisture lead to a 'temporary lack of water' in relation to long-term averages, but droughts are also socially constructed according to humanly defined thresholds and vulnerabilities (Kallis 2008). Droughts and other hazards disrupt 'day-to-day governance activities' (Melo Zurita et al. 2015), which tests institutional arrangements for allocating and managing scarce water resources. Confusion about roles and responsibilities creates conditions ripe for opportunistic behaviour by individuals, governments and civil society who attempt to shirk or seize responsibility (Garrick et al. 2016).

1.1. The 'assignment challenge'

This paper addresses the ***assignment challenge*** (Marshall 2005) in the context of drought adaptation, namely: how should adaptation efforts and associated governance responsibilities be assigned and coordinated across nested levels of social organisation? From a collective action perspective, the assignment challenge frames the opportunities and limits of independent and self-organised adaptation to droughts in large social-ecological systems like transboundary river basins. The assignment of governance responsibilities is a challenge of large-scale collective action involving centralised, decentralised or different types of polycentric governance systems. At one extreme, centralised approaches, such as national drought management systems, concentrate responsibilities in larger organisational units and must overcome barriers to collective action due to free riding and externalities across actors and sectors. At the other extreme, decentralised systems, such as voluntary water conservation and associated behavioural changes, imply the transfer (or retention of) political authority, administrative decision-making and fiscal resources to smaller organisational units (Treisman 2002).[1]

[1] In his oft-cited working paper on the topic, political scientist Daniel Treisman laments that scholarship on decentralisation (and centralisation) is 'littered with so many different usages…that it is often unclear just what they mean, if indeed they mean anything at all' (2). His response to this conceptual

In the context of common pool resources, decentralisation assigns 'all responsibility for making decisions related to smaller-scale common-pool resources' locally to the resource users (Ostrom 1999, 526).

Neither centralisation nor decentralisation have offered adequate guidance for assigning governance responsibilities for larger social-ecological systems due to the prevalence of polycentricity 'where citizens are able to organize not just one but multiple governing authorities at different scales' (Ostrom 1999, 528). Assignment of governance responsibilities therefore involves a challenge of facilitating self-organisation while ensuring coordination across scales to account for externalities, spillovers and economies of scale. Prior analyses suggest that larger common pool resource systems may benefit from the assignment of governance responsibilities according to the nesting principle (Cox et al. 2010), where nesting entails "progressively larger, more inclusive organisational units emerging from and then 'nesting' smaller and more exclusive ones" without compromising the autonomy of more exclusive groups (Marshall 2005, 47).

The assignment challenge is complicated by spatial and temporal variability, which may create uncertainty about the distribution and coordination of governance responsibilities during extreme events (Janssen et al. 2007). Droughts and other periodic disturbances create temporary circumstances when individuals, civil society and governments can shirk responsibilities or encroach on the responsibilities of others by citing 'extraordinary droughts' (Garrick et al. 2016).

The Intergovernmental Panel on Climate Change (IPCC) recognised this challenge in its Special Report on *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* in 2012 (Field et al. 2012). Embedded in the summary findings are strong claims about the allocation of roles and responsibilities, and their integration, in the management of climate extremes:

> *Community participation in planning, the determined use of local and community knowledge and capacities, and the decentralisation of decision-making, supported by and in synergy with national and international policies and actions, are critical for disaster risk reduction (**high confidence**).*

Blending decentralised decision-making with synergistic and supportive institutions creates the challenge of assigning and coordinating roles and responsibilities across levels of governance. This paper addresses this challenge and contributes to the literature on common pool resource governance by examining how governance responsibilities are assigned and coordinated during periods of drought. In this context, what are the opportunities for, and limits of, decentralised adapta-

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confusion is to identify six conceptions of decentralisation. The six conceptions are based on the number of tiers of governance in a compound political system (vertical decentralisation) and, then, how five other attributes are distributed across the tiers: decision-making authority, appointment authority, elections, fiscal resources and government personnel.

tion? How can coordination institutions be designed to complement rather than crowd out decentralised adaptation efforts by individuals and small groups?

1.2. Paper organisation

This review paper develops a new institutional economic perspective on drought adaptation in five additional sections. The next section summarises materials and methods. The third section reviews the academic literature at the intersection of three overlapping areas, often treated separately: drought adaptation, subsidiarity and new institutional economics. The fourth section elaborates a set of diagnostic questions about the assignment and coordination of governance responsibilities associated with drought adaptation. The questions diagnose, or characterise, how adaptation efforts and associated governance responsibilities are assigned and coordinated in the context of droughts, drawing on key concepts and evidence from new institutional economics. Specifically, it explores synergies and tensions between the ideas developed by Elinor Ostrom, Oliver Williamson and Douglass North related to the assignment challenge. The fifth section examines the interplay between decentralised adaptation decisions (by individuals and water user groups) and inter-governmental coordination in the *US portion* of the Colorado and Rio Grande River Basins in North America. A final section summarises insights and implications from the literature review, diagnostic questions and illustrative case studies before highlighting lessons and priorities for future research.

2. Materials and methods

This paper is patterned after Marshall (2008), which examined the nesting principle in common pool resource (CPR) governance. That paper included a review and analysis of the literature related to the nesting principle, coupled with an illustrative case study. The methodology here consists of three main components: a literature review, the development of diagnostic questions and an illustrative case study comparison based on the diagnostic questions.

The literature review is a thematic review, focused on establishing linkages among three well-established fields: drought adaptation, subsidiarity and new institutional economics. The boundaries of the review are therefore restricted to the intersection of new institutional economics with subsidiarity and drought adaptation. This requires excluding several important and relevant areas in light of a recent review of frameworks for examining social-natural systems, which identified 63 theories linking social and natural systems in 117 studies (Cox et al. 2016). Relevant literature in political science (federalism, multi-level governance) as well as a range of interdisciplinary approaches focussed on institutional fit and interplay are beyond the scope of this analysis, although many of these other theoretical perspectives share similar conceptual foundations and assumptions as those associated with new institutional economics (cf. Cox et al. 2016). As a consequence, the insights from new institutional economics may be trans-

lated or integrated into other fields to form hypotheses and propositions for future research.

Second, the paper elaborates a set of diagnostic questions for institutional analysis and development; Cox (2012, 7) defines diagnosis as 'a set of questions asked of a particular system', which involves selecting causally relevant concepts and variables from a wider range of potentially relevant options to understand patterns of interactions and outcomes, and the factors that drive them. Such questions provide the basis for diagnostic evidence that can support empirical measurement and assessment (Collier 2011, 824). The diagnostic questions in this paper characterise how governance responsibilities are assigned and coordinated during droughts in a transboundary context. These questions help to identify a set of propositions to guide the design and assessment of adaptation in multi-layered political systems.

Finally, an illustrative comparison of two case studies draws on previously published historical-institutional analysis of drought adaptation in two multi-jurisdictional river basins shared by the US and Mexico – the Rio Grande and Colorado – conducted by the author (Garrick 2015; Garrick et al. 2016). Process-tracing techniques are applied to assess the historical patterns and sequences of drought adaptation across levels of social organisation in the two basins, focussing primarily on two points at contrasting ends of the spectrum: decentralised adaptation (behavioural changes and actions by water users' groups) and inter-state coordination. Collier defines process tracing (2011, 823) as 'the systematic examination of diagnostic evidence selected and analysed in light of research questions and hypotheses posed by the investigator.' A detailed process-tracing is beyond the scope of this review article. However, description is seen as a key contribution in process-tracing, taking 'snapshots at a series of specific moments' (ibid, 823). An illustrative case study comparison explores the assignment of governance tasks and their evolution during a 15-year period of drought adaptation when both basins experienced severe water stress due to a combination of water supply deficits (drought) and increasing water use pressures (due to urbanisation and emerging environmental water needs). The brief comparison briefly addresses the diagnostic questions to identify propositions and implications for future research.

3. Drought adaptation and the subsidiarity principle: a literature review

The literature review proceeds in four short sub-sections applying new institutional economics (NIE) to frame: (i) assignment challenges in drought adaptation, (ii) the subsidiarity principle as a response to these challenges, (iii) opportunities and limits of decentralised drought adaptation and (iv) cross-scale interdependencies and social dilemmas associated with drought adaptation. This sequence of themes sets the basis for the diagnostic questions in the following section.

3.1. Drought adaptation

Adaptation is not a new term, although its application to *drought* has largely coincided with the growing attention to climate change adaptation.[2] In the 5th assessment report of the IPCC, released in 2014, 12 distinct terms related to adaptation are defined in the glossary, including 'adaptation options' which are categorised as structural, institutional or social (IPCC 2014). Adaptation in this context refers to a 'process of adjustment' to climate and its actual or expected effects, including the exploitation of opportunities and reduction of harm. Adaptation includes 'autonomous' and 'planned' measures, which are inter-related, as well as other relevant distinctions, such as incremental versus transformational adaptation.

Different adaptation actions imply different approaches to assigning governance responsibilities. Drought adaptation describes a process of adjustment to the impacts of droughts on people, agriculture, economies and the environment. A recent paper in drought-prone Spain illustrated the types of adaptation options often considered in the context of water resource governance and transboundary rivers: the development of alternative water sources, inter-basin transfers of water, and sectoral demand management (i.e. water conservation) for urban households, agriculture and energy (Kumar et al. 2016). Adaptation to drought therefore encompasses a broad range of approaches, and different approaches involve different constellations of actors and responsibilities, ranging from new water supplies developed by either local or central governments to demand management depending on local governance and behavioural changes, as well as options such as inter-basin transfers that rely on a mixture of responsibilities assigned at different levels.

3.2. The subsidiarity principle as a response to assignment challenges

Subsidiarity offers a key organising principle for framing and responding to the assignment challenges associated with drought adaptation in transboundary governance systems. Subsidiarity is defined as the assignment of 'each [governance] task to the lowest level with the capacity to conduct it satisfactorily' (Marshall 2005, 97; 2009).[3] In later work, Marshall and Stafford-Smith (Marshall and Stafford Smith 2010, 271) note that the "principle prescribes that the various responsibilities … and corresponding rights, of environmental governance

[2] Drought adaptation is a subset of climate change adaptation; it has been well noted that many of the impacts of climate change will be felt through impacts on the water cycle (see Dettinger et al. 2015). However, drought adaptation is also required to address recurrent deficits in precipitation, runoff and soil moisture even in the absence of anthropogenic climate change.

[3] Note that subsidiarity is not synonymous with decentralisation. Deceentralising responsibilities to the lowest competent level presumes that the status quo or 'natural' assignment of responsibilities is to a central authority. In contrast, there are many situations where the status quo assignment of responsibilities is to a relatively local level, and where the subsidiarity principle might suggest that some of these responsibilities might be centralised to a higher level.

each be assigned to the lowest level of the system at which they can be exercised effectively."

The justification of subsidiarity is rooted in moral arguments (liberty and dignity) established by the Catholic Church and subsequently in its perceived political and economic advantages for enhancing representation and efficiency (Marshall 2008; Garrick et al. 2012; Stoa 2014). The principle has also been justified for the perceived practical value of taking complex decisions based on expertise on the ground (Marshall 2015). Subsidiarity is, however, distinct from decentralisation and local control through its explicit recognition that self-organised or centralised coordination institutions are needed due to externalities, economies of scale or inadequate capacity (Garrick et al. 2012). In the context of drought adaptation, the assignment of responsibilities according to the principle of subsidiarity may foster adaptive efficiency by enabling the advantages of decentralising some responsibilities (e.g. conservation) to be achieved at the same time as reaping the advantages of centralising other responsibilities (e.g. conflict resolution). It serves as an antidote to the panacea or one-size-fits-all mentality where policy makers look to assign all responsibilities to the same (either centralized or decentralised) level (Ostrom 1999, 2012).

3.3. Decentralised drought adaptation from a NIE perspective

A key premise of the subsidiarity principle is to vest decision-making as close to the citizen, and hence the individual, as possible. In this context, the assignment challenge involves determining the opportunities and limits for decentralisation: assigning adaptation decisions and governance responsibilities at the individual level or within small groups. A new institutional economic perspective on subsidiarity and drought adaptation therefore begins with a model of human decision-making and must account for bounded rationality and the evolution of norms. Herbert Simon identified learning mechanisms as part of satisficing by boundedly rational individuals (Simon 1979). Drought adaptation decisions are hard to differentiate from continuous information processing across a range of alternatives for adjusting to variable water supplies. Yet the slow onset of drought and its unpredictable recurrence makes explicit adaptation decisions by individuals and groups occasionally necessary, particularly when proactive preparation is insufficient to prevent or limit the impacts of sustained drought events.

Human capacity for behavioural change affords opportunities for decentralised drought adaptation. Voluntary water conservation by domestic water users, groundwater pumping by farmers and migration illustrate the potential drought adaptation choices facing individuals. These opportunities exist because boundedly rational individuals have developed heuristics and strategies for processing information related to drought risks, including adaptation strategies triggered by experience and local knowledge. However, cognitive constraints and behavioural 'failures' associated with prospect theory mean that individual adaptation is unlikely to be sufficient. For example, experimental data demonstrate that farm-

ers will choose to wait longer to irrigate than maximising agents (Van Duinen et al. 2016). This demonstrates the need to account for processes of human decision-making when considering the opportunities and limits for fully decentralised drought adaptations. This is particularly important early during droughts when behavioural changes are the primary form of adaptation and predate government action.

The linkages between individual and collective outcomes create limits to fully decentralised adaptation by individuals, particularly through the unintended consequences of uncoordinated drought adaptation efforts. Improved irrigation efficiency at the farm level is a prime example, illustrating how individual and collective outcomes may diverge. Irrigation efficiency improvements strive to increase the ratio of water consumed by the crop to the total amount supplied through irrigation; however, such improvements may reduce return flows and groundwater recharge needed for other users and ecosystems. It may also increase total water consumption by delivering water more precisely, which increases evapotranspiration and boosts yields (Ward and Pulido-Velazquez 2008). The benefits of irrigation efficiency as an adaptation to drought therefore depend on a coordinated approach, illustrating the cross-scale interdependencies of drought adaptation options. Groundwater storage and pumping are another prime example of an independent drought adaptation option that may afford substantial benefits for water supply reliability at the farm or rural household level, but which can contribute to maladaptation at the system level without adequate coordination institutions to limit overdraft, well-spacing and/or waterlogging issues (Shah 2010).

Severe, sustained drought events test the limits of decentralised decisions. Sustained droughts pose special challenges because it is rare to have planned proactively for the most extreme events (Wilhite et al. 2014). Social norms[4] may evolve to promote reciprocal cooperation and collective adaptation without requiring formal rule changes, such as risk sharing, particularly in small groups (Ostrom et al. 1999; Nyborg et al. 2016). In transboundary river basins, cultural diversity, large group sizes and complex linkages across water and climate systems pose formidable barriers to the emergence of such norms for large-scale collective action (Ostrom et al. 1999, 279), demonstrating the need to coordinate adaptation at higher levels of social organisation.

3.4. Cross-scale interdependencies and social dilemmas in drought adaptation

The interdependencies associated with drought adaptation in transboundary river basins can pose social dilemmas (Ostrom 2012; Cole 2015). Social dilemmas arise when there is an inconsistency between individuals' actual choices and their best

[4] Following Nyborg et al. (2016), a social norm refers to 'a predominant behavioural pattern within a group, supported by a shared understanding of acceptable actions and sustained through social interactions within that group.'

interest, namely 'at least one outcome yields higher returns for *all* participants, but it is not predicted that participants will achieve this outcome' (Poteete et al. 2010, 32; emphasis in the original). The structure of incentives affecting individuals when faced by drought impacts range from (a) situations in which adaptation requires a reduction in individual payoffs to improve collective outcomes to (b) situations in which everyone is better off through collective action (Bisaro and Hinkel 2016). In this context, the subsidiarity principle suggests that the assignment of governance responsibilities is impossible at the individual level, or at least cannot be limited to that level, and therefore also requires coordination at higher levels of social organisation.

As with independent adaptation efforts, collective adaptation decisions are often hard to differentiate from the broader and incremental adjustments to operational decision-making or periodic rule changes. Nevertheless, collective adaptation to drought can be understood by tracking the actions within multiple, linked action situations: the 'social space where participants with diverse preferences interact, exchange goods and services, solve problems, dominate one another, or fight' (Ostrom 2005, 14). The action situation is a helpful way to conceptualise collective adaptation efforts because it can be applied at different levels of social organisation and across different classes of actions. Table 1 provides examples of independent and collective adaptation options across different types of action situations (e.g. provision of public goods, appropriation of common pool resources) and levels of social organisation (e.g. from individuals to international).

The action situation highlights the interdependence of actors confronting drought, creating social dilemmas across multiple levels of social organisation and jurisdictions. Bisaro and Hinkel (2016) establish a typology of interdependencies associated with climate change adaptation, which applies to drought. First, there is an interdependence between providers and beneficiaries of 'collective adaptation goods', the term coined by the authors to describe 'non-excludable goods provided by a group of actors' to themselves or another group (355). Examples of this interdependence include the situations where irrigation districts fallow crops (providers) in exchange for payments by cities (beneficiaries), enhancing water supply reliability. Second, there is a relationship between supply-side (generation and maintenance of CPRs and public goods) versus demand-side (the consumption of CPRs) measures, as when regions bank (store) water to restore aquifer health and groundwater levels, creating buffers for dry periods and options for conjunctive management of groundwater and surface water during droughts (Blomquist et al. 2004). Finally, there is a relationship between additive (incremental) and joint (threshold) adaptations, the latter arising 'where there is a threshold in the number of actors that must contribute …for the collective adaptation good to be provided' (Bisaro and Hinkel 2016, 355). In the context of drought, the benefits of water storage can be additive or joint collective adaptation goods depending on the circumstances. In the Murray-Darling river basin of Australia, "carry over" rules allow individuals to store unused water in reservoirs for the following year, which confers incremental, or additive, collective benefits. Conversely, in the Colorado

Table 1: Selected action situations and examples of drought adaptation across levels of social organisation.

Level of social organisation	Action situations			
	Appropriation	Provision	Monitoring	Conflict resolution
Individuals	Efficiency measures groundwater pumping	On-farm or household infrastructure	Metering	Participation
Users association (single sector)	Adopt shortage sharing rules	Invest in groundwater storage facilities	Metering; coordinate monitoring and forecasting	Resolve allocation disputes at local tribunals
Regional (multiple sectors)	Negotiate shortage sharing between districts/sectors	Share storage	Enhance district and utility-level water accounting	Resolve allocation disputes at regional tribunals
Interstate	Adopt shortage triggers and shortage sharing rules	Share storage across state borders	Invest in monitoring networks	Resolve allocation disputes in court
International	Adopt shortage triggers and shortage sharing rules	Share storage across international borders	Monitor compliance with allocation rules	Resolve allocation disputes in international courts

River, individual conservation decisions will not deliver increased reliability for downstream users unless thresholds are reached to maintain or restore reservoir levels above prescribed shortage triggers; therefore, independent water conservation actions can require joint production, i.e. adoption at sufficient scale, depending on the rules and infrastructure in place.

The three types of interdependencies are also distinguished along at least two dimensions: levels of action (operational, collective choice and constitutional) and levels of social organisation (e.g. jurisdictional). Drought adaptation spans levels of action from operational (day-to-day practices) to collective choice (decision-making) and constitutional levels, involving increasing costs and time to change rules governing interactions at higher levels (Kiser and Ostrom 1982). For example, drought impacts have the potential to trigger operational rule changes to water deliveries, the formation decision-making venues, or, in extreme circumstances, constitutional level changes, as evidenced by the formation of a new federal authority to manage the Murray-Darling Basin during the Millennium Drought (1997–2009). Second, interdependencies span tiers of governance across geographic scales and political jurisdictions from more local to more regional (Gibson et al. 2000), requiring vertical coordination for joint provision of many collective adaptation goods required as drought impacts cascade from the local to 'system' level.

Glicksman (2010) considers the vertical interplay of local, state and federal climate change adaptation in the context of US federalism. He draws on collective action theory to explore the need for, and limits of, federal roles in climate adaptation, including: the potential need to address negative externalities at the transboundary scale, to pool and distribute resources, to avoid the race to the bottom, establish uniform – or at least compatible – standards, address the NIMBY syndrome[5] and, finally, to manage the threat of under or over-regulation. It should be noted, however, that the existence of transboundary externalities does not automatically require centralisation, which can produce catastrophic failures (Dietz et al. 2003), as well as less dramatic perverse effects, including crowding out and loss of downward accountability. This illustrates the fundamental tensions in assigning and coordinating adaptation responsibilities:

> *"Collective action analysis can help avoid or resolve such conflicts by assigning the authority to control the development of climate change adaptation policy to the level of government best situated to address a problem without exacerbating the adverse consequences of climate change for others. The conflicts are likely to arise both when states and localities fail to do enough to anticipate and react to climate change and when they do 'too much'" (Giicksman 28).*

4. Assigning governance responsibilities according to the subsidiarity principle: diagnostic questions

Based on the preceding literature review, four questions[6] can be used to assess the assignment of governance responsibilities associated with drought adaptation:

(1) What are the opportunities and limits of decentralised drought adaptation?;
(2) How are the social dilemmas and spillovers associated with drought adaptation managed?
(3) When do higher level institutions complement versus crowd out decentralised adaptation?;
(4) How does adaptation by individuals and groups affect adaptive efficiency?

Each of the diagnostic questions is presented below, followed by insights from new institutional economics based on the work of Coase, Ostrom, North and Williamson. Despite lingering tensions and contradictions across the different bodies of thought in new institutional economics, there are several overlaps and

[5] NIMBY refers to 'not in my backyard' and characterises resistance to activities that generate collective benefits (e.g. energy security) but impose concentrated costs (e.g. nuclear plant or waste storage).
[6] Melo Zuria and colleagues (2015) also elaborate four questions to apply subsidiarity to disaster risk governance; however, the questions here are only very loosely related to their considerations. Instead, the questions have been designed to ground subsidiarity in the new institutional economic traditions and pave the way for future empirical analysis, following Marshall (2005, 2008, 2013, 2015).

complementarities, which can inform the development of propositions about drought adaptation in transboundary river basins.[7]

4.1. What are the scope for and the limits of decentralised drought adaptation?

The scope and limits of fully decentralised drought adaptation are shaped by bounded rationality, as elaborated above, as well as capital endowments (human, technical, financial, social). Clear roles and responsibilities create the enabling conditions for independent drought adaptation. When rights and responsibilities for individuals and self-organisation are clearly defined and recognised, there are stronger incentives for behavioural changes (e.g. switching crops, household water conservation, and technological adoption) or efforts by self-organised user groups to undertake the necessary adjustments.

Allen and Lueck (1998) extend Coase's theory of the firm by examining the 'nature of the farm.' They explicitly consider 'seasonality' and uncertainty in farming decisions (379), noting that 'only when farmers can control the effects of nature by mitigating the effects of seasonality and random shocks to output does farm organisation gravitate toward [the kinds of industrial] factory processes, developing in the large-scale corporate forms found elsewhere in the economy.' Drought adaptation is a seen as a decentralised process of farm-level decisions to adjust to variability, drawing on markets and technology. Farms remained relatively small and predominantly family-owned until doubling in size over the past 25 years in the US context as technologies and organisational arrangements evolved to mitigate and manage effects of seasonality (MacDonald et al. 2013). New irrigation technologies and precision agriculture boosted productivity and provided tools for mitigating risks tied to seasonality and, by extension, drought. The expanding size and specialisation of the farm occurred within a relatively stable context of economic governance structures and formal and informal institutions. Sustained droughts since 2000 across the Southwest and Western US have exposed the limits of independent adaptation, and placed new pressure for collective adaptations at multiple scales (Fleck 2016). As impacts and interdependencies increase with the severity and duration of drought, roles and responsibilities may overlap or become blurred, requiring greater coordination.

4.2. How are the social dilemmas and spillovers associated with drought adaptation managed?

What happens when individual or local adaptation is not enough, or produces spillovers? The principle of subsidiarity implies that the vesting of property

[7] Propositions in this context refer to empirically derived theoretical claims regarding the relationship between institutional design and performance outcomes (e.g. the need for clear rights and responsibilities for decentralised adaptation, or the congruence principle for matching governance responsibilities to local conditions).

rights and decision-making authority in individuals and small-scale user groups is appropriate when there is sufficient capacity for self-governance at these levels by irrigation districts, water users' associations and related bodies. These capacities include human, financial and social capacities to internalise any spillovers from decisions at these levels, minimise cross-border externality problems, and resolve residual conflicts.

Cross-scale interdependencies and associated social dilemmas require the development of coordination institutions, or collective choice arrangements in the terminology used for Ostrom's (1990) design principles, to address spillovers and cross-border externalities. In the context of drought adaptation, coordination institutions define rules for sharing water during droughts within and between user groups, sub-national jurisdictions and national borders (Garrick et al. 2013). Regional authorities, such as catchment authorities or basin organisations, are one prominent example of a collective choice arrangement to address cross-border externalities and economies of scale. Such bodies have developed at multiple levels and facilitate horizontal and vertical coordination based on the spillovers involved: (i) water sharing arrangements between multiple water districts in the Taos Acequias of the Southwest US enable horizontal coordination (Cox and Ross 2011), (ii) a national drought management system in Spain guides drought declarations that trigger different sharing arrangements within and across district boundaries at lower levels, facilitating vertical coordination (González Tánago et al. 2016) and, finally, (iii) river basin authorities develop and implement water apportionment rules and reservoir operation criteria for sharing water across state jurisdictions during droughts, involving both vertical and horizontal coordination (Garrick et al. 2013). In many instances, multiple coordination institutions exist, as in the Murray-Darling Basin of Southeast Australia where a suite of formal and informal mechanisms have developed to address droughts and water sharing (Turral et al. 2009; Marshall et al. 2013; Garrick 2015). The proliferation of decision-making units is a hallmark of polycentric governing arrangements, which affords many theoretical advantages but also risks of institutional fragmentation and opportunistic behaviour.

4.3. When do higher-level institutions complement versus crowd out decentralised adaptation?

Clear boundaries and property rights define roles and responsibilities during normal conditions. Droughts may throw the assignment of responsibilities into question, posing risks that central government decisions will crowd out the capacities of smaller-scale organisational units. In this context, new institutional economics has contributed insights about the assignment of adaptation decisions across nested levels of social organisation to foster complementarity and minimise the risk of crowding out. Two concepts offer guidance: the notion of the 'discriminating alignment' developed by Oliver Williamson (1998) and the 'congruence principle' identified by Ostrom (1990).

Williamson describes the discriminating alignment as the alignment between governance structures and transactions based on the characteristics of the transaction, namely: asset specificity, frequency and uncertainty (Williamson 1985, 1998; Coggan et al. 2013). Frequency and uncertainty shape the governance structures for drought adaptation decisions, for example, by creating a system of stable rules and expectations for more frequent, moderate intensity droughts (assistance packages, water sharing rules etc.).

Asset specificity refers to "specialised investment that cannot be redeployed to alternative uses or by alternative users without a loss in productive value" (Williamson 1996, 377). Coggan et al. (2013) define eight types of asset specificity, which capture the influence of location, time, human capacity, physical assets and procedures. The concept of asset specificity can be useful in thinking about subsidiarity and complementarity in the drought adaptation. The concept suggests assignment of drought adaptation responsibilities based on the match between governance structures and attributes of the transactions, including local geographic and social conditions. For example, site-specific characteristics may require decentralised drought adaptation by farmers or local districts based on their local knowledge, capacities and access to technologies. On the other hand, monitoring and forecasting systems are less site-specific, implying that monitoring and forecasting networks may exhibit economies of scale often leading to proposals for national, continental and international monitoring networks (Pozzi et al. 2013). The notion of the discriminating alignment, which takes asset specificity into account, results in responsibilities being assigned according to fit, or congruence, between governance structures and local conditions.

Important parallels can be drawn between the concept of the discriminating alignment and congruence principle identified by Ostrom (1990). Ostrom (2010, 422) defined the congruence principle along two dimensions: (i) 'appropriation and provision rules are congruent with local social and environmental conditions' and (ii) 'appropriation rules are congruent with provision rules; the distribution of costs is proportional to the distribution of benefits.' Despite substantial differences in the intellectual traditions and theoretical foundations underpinning the work of Williamson and Ostrom, the discriminating alignment and congruence principle can be viewed as compatible and complementary insights for assigning governance responsibilities to match local conditions. The congruence principle provides a basis for applying the subsidiarity principle based on the match between drought adaptation and local social and environmental conditions, such physical (water storage, variability) and social (human capacity, group size and heterogeneity, learning) characteristics. Ostrom's congruence design principle brings with it the corollaries requiring the 'minimal recognition of rights to organise' and the need for nested enterprises, that is, the organization of governance activities in 'multiple nested layers.' Without a minimal recognition of rights to organise for water users, decentralised adaptation efforts, such as voluntary water conservation or market-based water reallocation, may be crowded out by centralised efforts, such as mandatory water restrictions.

4.4. How does adaptation by individuals and groups affect adaptive efficiency?

Adaptation decisions include trade-offs across scales, with the potential to improve outcomes at a given place or time at the expense of maladaptation in another place or in the future (Hill and Engle 2013). In this dynamic context, Douglass North's (1990) criterion of adaptive efficiency is a potentially powerful way to assess the cumulative and long-term effects of independent and collective adaptation decisions on institutional performance, particularly the trade-offs between the local and system levels and between short-term and long-term outcomes.

Adaptive efficiency is a performance criterion used to understand the relationship between institutions and economic performance over the long term (North 1990). Achieving adaptive efficiency is expected to 'allow societies to maximize efforts required to explore alternative ways of solving problems' by providing 'incentives to encourage the development of decentralised decision-making processes' (North 1990, 81; Marshall 2005, 2015). Decentralisation does not always enhance adaptive efficiency, however. For instance, Challen (2000) highlighted how decentralisation of property rights can strengthen vested interests, thus reducing institutional flexibility (and, implicitly, adaptive efficiency). As a guide to how rights and responsibilities should be assigned according to the subsidiarity principle, the metric of adaptive efficiency therefore needs to account for trade-offs between the benefits and costs of assigning rights and responsibilities to lower levels.

An operational, and hence measureable, definition of adaptive efficiency remained elusive (North 1990, 1994, 2006) until recently (Marshall 2005, 2008, 2013, 2015; Garrick and Aylward 2012). Marshall (2015) sees adaptive efficiency as accounting for the benefits and costs of institutional options for adapting to surprises, in addition to the standard kinds of benefits and costs accounted for by conventional economic (allocative) efficiency. In contrast with allocative efficiency which presumes a static or fixed set of institutions, adaptive efficiency fosters a 'flexible institutional matrix that will adjust in the context of evolving technological and demographic changes as well as shocks to the system' (North 1995, 26). Marshall has done the most to take this concept forward in the context of adaptive environmental governance, distilling key aspects of adaptive efficiency to apply to subsidiarity. His work demonstrates the importance of accounting for deferred costs of decisions associated with institutional lock-in (described as 'institutional lock-in costs'), and, more broadly, of assessing the cost effectiveness of alternative institutional choices in terms of the full range of costs and benefits involved (Marshall 2013, 2015).

Droughts are expected to require a blend of independent and collective adaptation efforts. An institutional evaluation of drought adaptation in terms of adaptive efficiency suggests: (i) a systematic and comprehensive assessment of the full range of costs and benefits of independent and collective adaptation, (ii) an examination of the distribution of the costs and benefits across levels of social organisation, highlighting whether costs are congruent, or proportional, with the benefits of adaptation (affecting legitimacy and trust) and (iii) explicit attention

to the distribution of costs and benefits over time, highlighting the inter-temporal trade-offs of adaptation decisions now and the consequences for the future.

5. Adapting to drought in transboundary river basins of the Western US: The Colorado versus the Rio Grande experiences

Severe, sustained drought and drying in the US portions of the Colorado and the Rio Grande river basins since 2000 presents a prime testing ground for exploring the assignment of governance responsibilities associated with drought adaptation. The US and Mexico share three rivers: the Colorado, Rio Grande and the Tijuana. The Colorado and Rio Grande are also shared by multiple states within each country and by sovereign Indigenous Nations, creating a complex 'institutional matrix' that has evolved over the past 200 years.[8] All three rivers are governed by the same the international treaty – the 1944 Treaty governing *Utilization of Water of the Colorado and Tijuana Rivers and of the Rio Grande from Fort Quitman, Texas to the Gulf of Mexico*. The treaty refers to 'extraordinary drought' conditions as the basis for reduced deliveries, but does not define the operational criteria that would trigger those provisions (Carter et al. 2015). These international agreements work in conjunction with other water laws and agreements at nested levels, including interstate compacts among the US states sharing the Colorado (1922 Colorado River Compact) and the Rio Grande (1938 Rio Grande Compact), state-level water codes, and users' associations (e.g. irrigation districts, water utilities). A map of the Rio Grande/Bravo river basin is used to illustrate the interstate and international transboundary characteristics of the river basin, see Figure 1.

A full assessment of the key questions noted above is beyond the scope of this paper. Instead, a brief comparative analysis will generate descriptive inferences through process tracing, as noted above (Collier 2011). The geographic focus will include the transboundary portion of each river basin within the US – the interstate Colorado (shared by seven US states) and Rio Grande (shared by three US States). Further, it will focus on adaptation at two discrete points along the spectrum of social organisation: behavioural change and interstate coordination.

After a short overview of drought impacts, the case studies will review decentralised (behavioural and local) adaptation decisions, the evolution of coordination institutions governing interactions between the US states sharing the basin, and the linkages between decentralised and coordinated adaptation decisions. The illustrative cases will apply the diagnostic questions above, while concentrating principally on (i) the opportunities and limits of decentralised adaptation and (ii) situations when higher-level institutions complement versus crowd out decentralised adaptation.

This illustrative comparison is drawn from institutional analysis of water allocation reforms in the US portions of the Rio Grande (Garrick et al. 2016) and Colorado River (Garrick 2015) since 2000. Drawing on these texts, as well

[8] The oldest water rights in the San Luis Valley of the Rio Grande date from 1852.

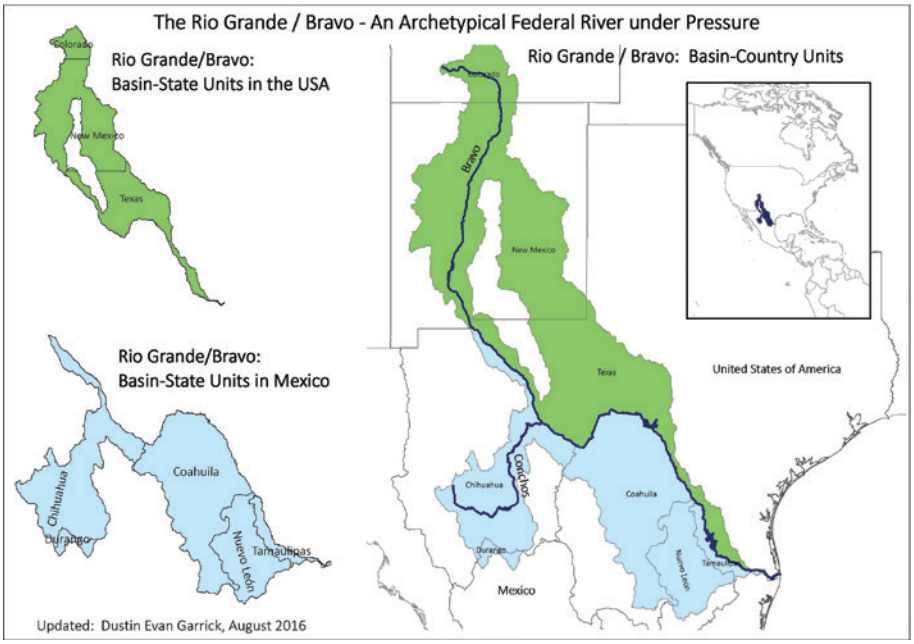

Figure 1: The Rio Grande/Bravo river. An interstate and international transboundary river basin.

as selected media reports describing major events and trends over the past two decades, the case studies illustrate the contrasting trajectories of two rivers confronting similar challenges with different 'institutional matrices' for balancing decentralised adaptation efforts with coordination institutions to build capacity, resolve conflicts and foster cooperation in drought adaptation.

5.1. Decadal droughts, basin-wide impacts

In the period since 2000, the Colorado and the Rio Grande have experienced severe, sustained droughts. In the Colorado River, between 2000 and 2014, annual flows averaged 19% below the 1906–1999 average (Udall and Overpeck 2017). The Upper Rio Grande – the portion of the river falling in Colorado and New Mexico upstream of the Elephant Butte Reservoir – has experienced similar conditions. At the basin level, reservoir supplies in Lake Mead (the Colorado's largest reservoir) have dipped to historic lows due to a combination of drought impacts and over-allocation, approaching the first trigger for lower basin shortages at the 1075 ft elevation (Figure 2); overall storage in the Colorado River System is at approximately 55% as of late September 2017.

In the Upper Rio Grande, one of the primary reservoirs, Elephant Butte of southern New Mexico, has remained below 25% almost without interruption

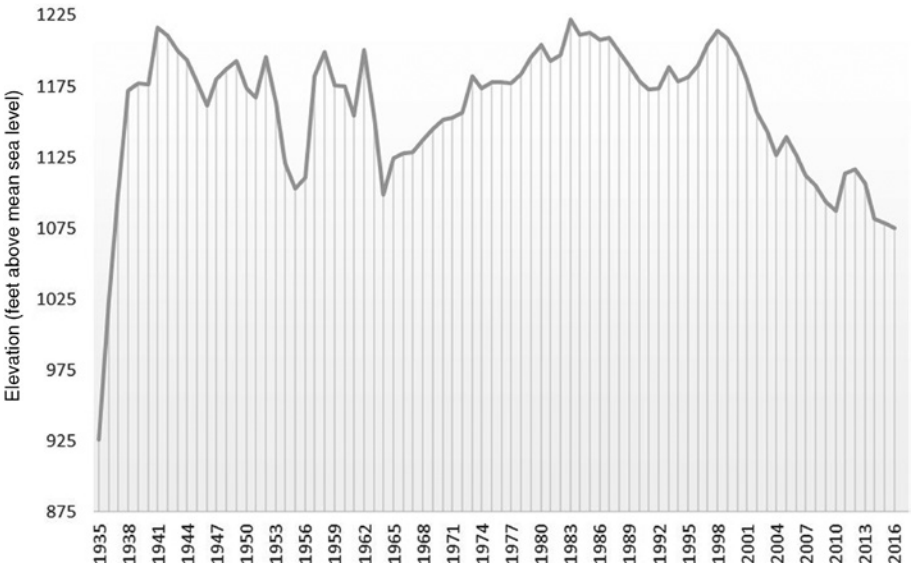

Figure 2: Reservoir levels in August of each year in Lake Mead, Colorado River. Data Source: US Bureau of Reclamation, http://www.usbr.gov/lc/riverops.html.

since 2002 (see Figure 3). Because storage capacity is a key buffer for drought in its early stages, the decline reservoir storage in both river basins since 2000 has prompted adaptation at multiple levels.

5.2. The trajectory of adaptation and assignment

The impacts of the drought have manifested in many ways and at multiple scales, felt primarily, and initially, in agriculture and rural towns, followed by cities. Cities have developed water sharing agreements to lease or purchase water from agriculture. The persistence of droughts has contributed to inter-state conflicts and negotiations. The past two decades have witnessed adaptation at five, nested levels of social organization: users (e.g. farms and households), users' associations, states, interstate, and international. This analysis contrasts decentralised adaptation with inter-state coordination to illustrate the interplay between independent and collective adaptation.

5.3. What are the opportunities and the limits of decentralised drought adaptation decisions?

Following the review and analysis above, the first step is to delineate the scope for and limits of independent drought adaptation decisions by farmers and domestic water users (particularly in urban centres).

Figure 3: Storage levels (acre feet) in August of each year in Elephant Butte Reservoir, New Mexico (Rio Grande).

5.3.1. Adaptation decisions in irrigation, and their limits

Behavioural change, occurring within households, farm enterprises and firms, has been marked by a steady, incremental process of voluntary conservation in both basins spurred by changing rules, norms and incentives. This trajectory of adaptation is captured by the adage 'when water gets short, farmers get very clever' coined in the Rio Grande (Wines 2015). The average application rate of water to land area in irrigated agriculture has reduced from four feet of water per acre in 1960 to just over two feet per acre in the 2010 census; although this reduction is attributable to both changes in crop choice and in shifting irrigation technologies and practices, the largest declines occurred in the two decades coinciding with the long-term droughts (1950s and 2000s) (Donnelly and Cooley 2015). This trend applies broadly in both the Colorado and Rio Grande Basins.

Adaptations at the farm level include changes in crop-types and irrigation efficiency. It is important to note that the reduction in application rates and, sometimes, total water use has often coincided with stable or increasing net and gross revenues. In the Colorado River, for example, farmers in Yuma County in the agriculturally productive lower valley have reduced their water use by one-third against a 1970s baseline. Through farm-level decisions to specialise, increase farm size, and to change crops and irrigation technologies (as anticipated by Allen and Lueck 1998), Yuma County has seen its inflation adjusted agricultural sales

increase from US$900 million per year in the 1970s to $1.2 billion per year since 2010, despite the reduction in overall water use (Fleck 2016). Similar stories, albeit less dramatic and systematic, have occurred in the Rio Grande with, for example, the conversion from alfalfa to pecan orchards. However, a major difference should be noted: in the Rio Grande, groundwater pumping has emerged as a key adaptation strategy for farmers, contributing to conflicts between irrigation districts, between districts and cities, and between states and neighbouring countries (Wheat 2015). The limits of independent drought adaptation are also clear; the dependence on groundwater as a drought buffer has proven controversial due to the risks of unsustainable groundwater pumping without regulations by users, states or regional entities (Ward et al. 2006).

5.3.2. Adaptation decisions in cities, and their limits

Urban water conservation has been striking in both basins. A systematic review by Cohen et al. (2011) noted a substantial reduction of per capita water use from 1990 to 2008 in 27 cities drawing water from the Colorado River. While this period encompasses non-drought years, Cohen attributes the reduction to a combination of plumbing codes and measures taken by water utilities to respond to a decade-long drought. Moreover, several other cities have since exhibited striking declines during the drought, influenced by the growing perceptions of shortage risk. Las Vegas, Nevada is the prime example of this trend with a 37% reduction in per capita water usage from 2002, the onset of the drought, to 2015 with drought and water shortage risk as primary motivators for behavioural changes and with the establishment of a conservation programme run by the Southern Nevada Water Authority, a regional water utility (Fleck 2016).

The city of Albuquerque, New Mexico (population of 556,000 in 2013) draws water from both the Rio Grande and, via an inter-basin transfer, the Colorado. A combination of drought and the threat of litigation to protect endangered species has spurred water conservation programs and triggered household conservation; total water use has dropped by 24% over the past 20 years (as of 2015) while population has increased by 25%. Changes in outdoor water use are a prime source of the savings (see Figure 4 for the decrease of vegetation within the urban centre associated with conversion of turf to native landscaping).

As with irrigation water use, the conservation progress can be attributed to a combination of changes in norms as awareness of drought and water shortage risk grows, coupled with rule changes and incentives created by increasing water rates and rolling out rebate programmes to remove turf lawns (Fleck 2013). In short, the reduction in per capita water consumption in cities has been attributed to a combination of independent action (behaviour change), local collective adaptation efforts (changing water prices by municipal water utilities, approved by city councils) and in some cases, regulation by state authorities (conservation targets in the case of Arizona) (Cohen et al. 2011). Independent adaptation efforts have also prompted the need for collective adaptation by municipal water utilities, city councils and related decision-makers. Rapid declines in per capita water con-

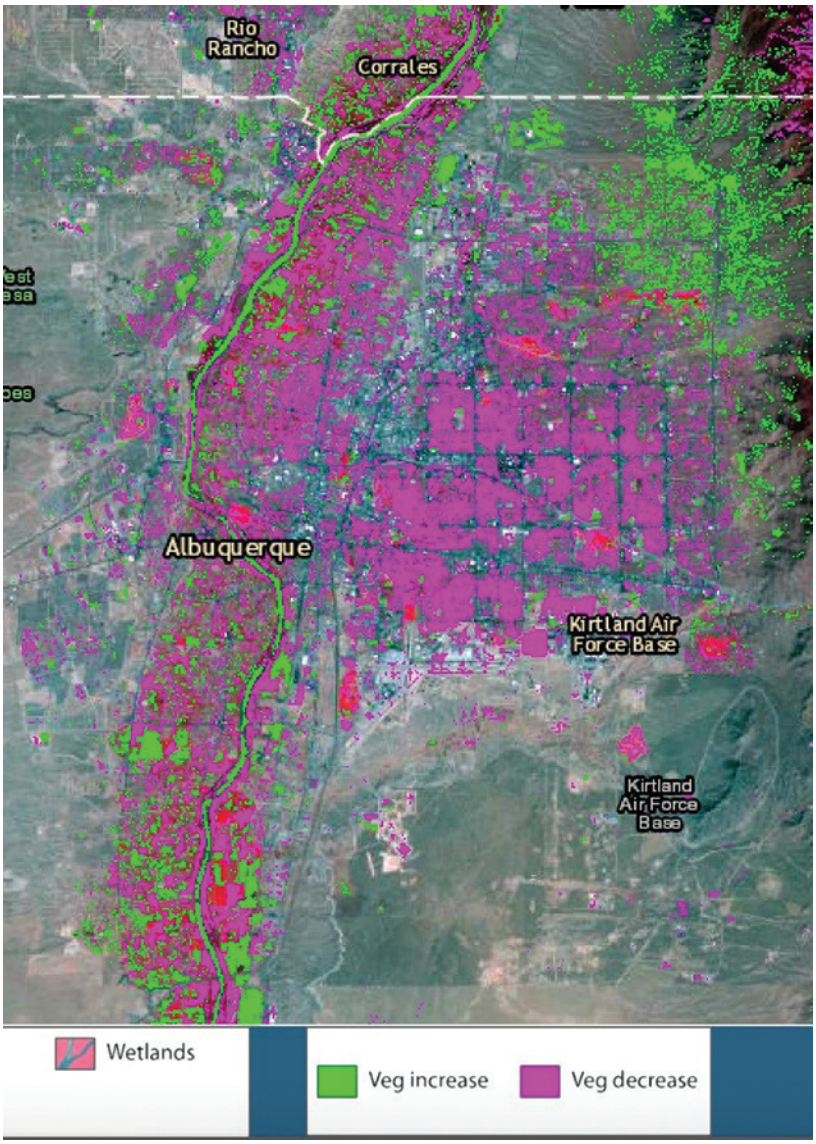

Figure 4: Albuquerque Vegetation Change (Landsat Imagery, Source: ESRI), illustrating the marked reduction in household outdoor water use as one example of the behaviour change and incentive-based programmes to spur independent adaptation in outdoor water use, primarily involving the removal of water-intensive turf landscape in favour of xeriscaping.

sumption have dampened revenues needed by utilities to underwrite the operations and maintenance of municipal water infrastructure. Cities have also become

increasingly involved in state-wide and basin-wide efforts to plan for and adapt to sustained drought and climate change.

5.4. How are social dilemmas and spillovers managed? When do higher level institutions complement versus crowd out decentralised adaptation?

The limits of decentralised adaptation – both through independent adaptation and collective adaptation efforts by self-organised water users and local governments – have been reached in both basins, triggering inter-governmental cooperation and conflict resolution between the US states sharing the two rivers. The trajectories of collective adaptation at the inter-governmental, or regional, level have diverged sharply in the Colorado and Rio Grande.

In the Colorado River, sustained drought has exposed the basin's 'structural deficit' (Reclamation 2012): the imbalance of supply and demand caused by historical overallocation of water supplies at the basin level. Water apportionment between the states is governed by the 1922 Colorado River Compact and a suite of subsequent laws, court cases and operational rules collectively known as the 'Law of the River.' The Compact was established based on the wettest 20 years on record, committing 110% of the long-term average annual supply. This imbalance was historically buffered by a reservoir storage of four years of average annual runoff, until long-range supply and demand intersected for the first time in the mid-1990s. This milestone, coupled with the onset of sustained drought in 2000, left basin stakeholders vulnerable to the system-wide effects of drought. The recognition of the inevitability of institutional change, as well as exasperation at its slow pace, triggered a sequence of basin-wide interstate and international agreements to complement the adaptation at the farm, household, irrigation district and municipal levels (Kenney et al. 2011). These transboundary adaptations were highlighted by three agreements dealing with water supply variability: the 2001 interim surplus guidelines, 2007 interim guidelines for shortage and the 2012 international agreement (minute 319, which was updated and extended in 2017 with minute 323) extending shortages rules to cover Mexico (Fleck 2016).

Underpinning these agreements was the development of a network of actors, supported by joint monitoring and modelling (Garrick et al. 2008). The suite of collaborative inter-governmental agreements was negotiated on an interim basis and in the shadow of threats by the federal government to take over if the states failed to act, illustrating the federal role in complementing local efforts rather than crowding them out (Fleck 2016). Paralleling these efforts were a series of pilot efforts by cities, irrigation districts, state governments and environmental nongovernmental organizations (ENGOS) to conserve water, negotiate agricultural-to-urban transfers, adopt interim rule changes and conduct joint studies to assess adaptation options for both drought and chronic water scarcity conditions. Contrasted with the counterfactual – that drought and shortage would trigger protracted legal 'water wars' (Reisner 1986) – the trajectory of adaptation and assignment appears consistent with the subsidiarity principle and the emergence

of adaptive efficiency through incentivising local adaptation and strengthening complementary, higher level institutions to address cross-border externalities, conflict resolution and economies of scale (Garrick 2015).

The experience in the Rio Grande contrasts sharply with that of the Colorado at the basin scale, despite the success story of Albuquerque noted above. The basin is governed by two different international agreements – a 1906 Convention and the 1944 Water Treaty between the US and Mexico – in part because it contains major tributaries originating in the US (Upper Rio Grande) and Mexico (Rio Conchos) as well as the portion of the river comprising the international border between Texas and four Mexican states. The discussion here will focus only on the Upper and Middle Rio Grande, whose water is shared (from upstream to downstream) by the states of Colorado, New Mexico and Texas, and governed by the 1938 Rio Grande Compact – an inter-governmental agreement to apportion water supplies among the three states, and analogous to the 1922 Compact dividing the waters of the Colorado River among the seven US states. The Rio Grande Compact was developed in response to a Supreme Court case and established a proportional water sharing rule, including a scheme for accruing credits and debits to help cope with climatic variability and droughts; Schlager and Heikkila (2011) have pointed to this as an example of 'congruence' between the rules and the local conditions, supporting the allocation of water resources among the states that has broadly been viewed as fair, particularly after the resolution of disputes between Colorado and the downstream states (Vandiver 1999).

The Rio Grande has not addressed the cross-border externalities tied to groundwater use, however, blurring the assignment and coordination of responsibilities during droughts. The omission of groundwater from the inter-governmental agreements and subsequent conflict resolution efforts has created a situation described as cooperation without trust (Wheat 2015). Most recently, this has led the state of Texas to sue New Mexico for lack of compliance under the Compact due to the impacts of groundwater pumping on the reliability of downstream deliveries from Elephant Butte reservoir. The pending case before the Supreme Court has been described as a 'battle over jurisdiction and authority,' demonstrating the controversies over the assignment of governance responsibilities (Las Cruces Sun-News 2016).

Decisions at the state and federal levels have been a key source of mistrust between the states and locally, fuelling complaints that state and federal agencies have crowded out local solutions. In the context of the ongoing drought and pending Supreme Court case, for example, the attorney general of New Mexico nullified an agreement negotiated by the city of El Paso and two irrigation districts in New Mexico and Texas, which aimed to resolve the dispute over groundwater locally (Wheat 2015).

A suite of ambitious adaptation efforts have occurred locally in the Rio Grande, such as the investment in irrigation efficiency (Middle Rio Grande Conservancy District), water use metering (Elephant Butte Irrigation District) and the voluntary establishment of a new sub-district in the San Luis Valley of Colorado to

limit groundwater pumping to pre-empt state-level regulations (Cody et al. 2015). Nevertheless, the lack of trust between states and between the state and local water users within New Mexico has prevented a range of management changes that could offer win-win outcomes and improved reliability, such as the conservation of water in upstream water storages to reduce evaporation and increase flexibility to manage water for non-consumptive instream purposes (e.g. fisheries, recreation, hydropower). The pending litigation before the Supreme Court has stalled the development of collective-choice arrangements for inter-state coordination. The Upper and Middle Rio Grande exhibits evidence of successful self-governance, but without the higher level institutions needed to address cross-border externalities associated with groundwater and to coordinate regional drought adaptation measures (such as reservoir re-operations).

5.4.1. Adaptive efficiency and trajectories of institutional performance: how do independent and collective adaptation affect adaptive efficiency?

A comprehensive assessment of adaptive efficiency as recommended in the prior section is beyond the scope of this illustrative comparison. Nevertheless, the initial evidence in the US portion of the Colorado River basin suggests higher levels of adaptive efficiency than in the US portion of the Rio Grande River basin. The threat of federal action in the Colorado River reinforced the pre-existing incentives and pressures for decentralised decision-making at the farm, household, irrigation district, municipal, and state levels to address drought-related challenges, supported by multiple formal and informal collective choice arrangements to address interstate coordination challenges. The trajectory of institutional performance in the Rio Grande has been less encouraging and has encountered lock-in associated with the Supreme Court conflicts tied to groundwater pumping. Although decentralised adaptation has progressed in the Rio Grande, the capacity of local actors to self-organize a response to groundwater pumping has been limited, and higher-level institutions in New Mexico do not recognise the rights of local districts and cities to coordinate. Unlike the alignment within the Colorado River basin between decentralised adaptation and inter-governmental coordination, the pattern of adaptation and assignment in the Upper Rio Grande may diminish the incentives for decentralised problem-solving and raise the costs of future adaptation decisions, thereby reducing adaptive efficiency.

6. Conclusion

Drought requires adaptation at a range of levels – from individual to inter-governmental efforts. New institutional economics offers a unique set of insights on the assignment challenge – balancing independent and collective drought adaptation efforts across nested levels of social organisation.

The review above offers three main insights. First, there are opportunities and limitations of decentralised adaptation by individuals, self-organised users' organizations and local governments. The opportunities stem voluntary conserva-

tion and adaptation locally through investments in irrigation efficiency, changes in municipal outdoor water use or periodic groundwater pumping. The limits of decentralised adaptation decisions stem from bounded rationality, which may limit adaptation efforts early in the drought that can forestall more serious consequences later. There are also irreducible social dilemmas linking individual and collective outcomes of drought adaptation. Water conservation during droughts raises the corresponding need for coordination to limit unintended system-wide consequences, such as the effect of groundwater pumping on compliance with interstate and international surface water treaties.

Second, the social dilemmas arising during droughts underscore the need for well-defined property rights, and the development of nested institutions that are well-matched with local conditions. In theory, subsidiarity offers a helpful organising principle for assigning and coordinating roles and responsibilities at nested levels of social organisation. Effective application of the subsidiarity principle depends on capacity for decentralised adaptation coupled with effective coordination institutions to address externalities (e.g. groundwater pumping) and pursue economies of scale (coordinating reservoir operations). Failure to situate individual and local adaptation efforts within nested institutions can lead to unintended system-level consequences, crowding out, mistrust and lock-in. Such consequences are exemplified by the nullification of a locally negotiated, multi-district groundwater agreement in the Rio Grande, fuelling high cost conflict resolution efforts in the US Supreme Court that have stymied further development of coordination institutions.

Third, adaptation decisions deliver temporary solutions but typically carry lasting consequences, which underscores the value of adaptive efficiency as a criterion for evaluating institutional design and performance. Adaptation decisions have consequences for the future and across political borders, which means that the effectiveness of independent and collective adaptation decisions should be assessed in terms of their impact on the costs and benefits of future adaptation decisions.

The analysis also highlights the need for future research that applies the four diagnostic questions introduced earlier to advance our understanding of drought adaptation in large river basins and groundwater systems.

1. What are the scope and the limits of decentralised drought adaptation decisions?

Lesson 1: decentralised adaptation may be necessary or at least desirable but is not sufficient when the severity of drought and spillovers create social dilemmas.

2. How are social dilemmas and spillovers managed?

Lesson 2: clearly defined rights and responsibilities enable adaptation actions at each level, and require appropriate collective choice arrangements (coordination

institutions) to address externalities and economies of scales, including both formal and informal mechanisms.

3. When do higher-level institutions complement versus crowd out decentralised adaptation?

Lesson 3 (a): the assignment of governance responsibilities according to the subsidiarity principle involves congruence between adaptation and local conditions, including coordination institutions when adaptation involves cross-scale interdependencies; (b) incentives for behavioural change, rights to self-organise and external investment in local capacity reduce the likelihood of crowding out decentralised adaptation.

4. How do independent and collective adaptation decisions affect adaptive efficiency?

Lesson 4: (a) decentralisation does not always lead to the best performance over the longer term; (b) assessing different responses to the assignment challenge in terms of adaptive efficiency requires systematic accounting of costs and benefits, specific attention to their distribution across levels of social organisation and over time and a focus on the long-term consequences of adaptation.

Droughts in transboundary river basins expose the interdependency between individual and collective adaptation; new institutional economics, and its diverse theoretical traditions, offers an important perspective on the assignment and coordination of responsibilities, raising a set of questions that caution against simplistic prescriptions about decentralisation.

The review and illustrative comparison here are intended to stimulate future empirical research and theoretical development to advance our understanding of human decision-making and institutional change in the context of droughts and slow-onset disturbances. The diagnostic questions elaborated earlier in the paper provide a basis for characterising and comparing different approaches to the assignment challenge to explore which arrangements enhance or reduce adaptive efficiency in different contexts. The largest barrier to such a research programme will be the need to refine our conceptualisation and measurement of decentralisation, subsidiarity and adaptive efficiency to enable robust empirical analysis and longitudinal assessments. The development of multi-scale observatories of institutional adaptation can support further theory development and empirical evidence.

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