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Network political ecology: Method and theory in climate change vulnerability and adaptation research

Trevor Birkenholtz
Rutgers University, USA

Abstract
This paper argues for the development of 'network political ecology', drawing on the insights from regional political ecology and recent advancements in network theories of scale, to meet the challenges of investigating the meso-scale problem of vulnerability and adaptation to climate change. 'Network political ecology', attentive to scale as socio-ecologically produced and grounded in a regional resource use system, is one such approach that fills this gap in middle-range theory necessary to understand the complex processes through which vulnerability manifests and adaptive capacity is produced. This method is exemplified through the case of groundwater-dependent irrigating farmers in Rajasthan, India.

Keywords
adaptation, climate change, India, method, network, political ecology, vulnerability

I Introduction

Intensive and extensive methodological approaches to the study of vulnerability to social-ecological change generally, and to climate change specifically, have co-evolved from such traditions as Natural Hazards (Cutter, 1996; Kates, 1971; Mitchell, 1989) and Political Ecology (PE) (Blaikie and Brookfield, 1987; Watts, 1983a); and Human Dimensions of Global Environmental Change (HDGEC) (Adger et al., 2009; Eakin and Wehbe, 2009; Eakin et al., 2009; Kelkar et al., 2008; O'Brien et al., 2004) and Sustainability Science (Crona and Hubacek, 2010; Kates et al., 2001), respectively, among others.[1] While both stem from Natural Hazards research, *intensive* (idiographic) approaches, such as PE, focus on local particularity and social power relations situated within multiscalar political-economic processes and offer keen insights into local socio-ecologically differentiated vulnerability and adaptive strategies, including mediating structures. Conversely, *extensive* (nomothetic) research approaches, such as HDGEC, typically yield generalizable and policy actionable insights but say little about local social power processes that mediate vulnerability, leading to unintended policy effects (see Crate and Nuttall, 2009, for a discussion; O'Brien et al., 2007). This is even the case despite the recent infusion of social science perspectives into extensive research, drawing on coupled systems (Reynolds et al., 2007) or social-ecological systems (Ostrom, 2009) approaches, but

Corresponding author:
Department of Geography, Rutgers University, 54 Joyce Kilmer Ave, Piscataway, NJ 08854, USA
Email: trevbirk@rci.rutgers.edu

which do not internalize processes of social power, decision-making, or capital flows (Turner and Robbins, 2008).

Since climate change induced social-ecological perturbations will likely produce meso-scale effects (Agrawal, 2008; IPCC, 2007) yet be mediated by multiscalar processes, an investigative approach is needed that can extend intensive methods spatially to multiple sites and longitudinally over time within an affected region. Neither approach on its own is positioned to address this challenge, leaving a surprising gap in middle-range theory of climate change vulnerability research, which is also needed to frame policy debates and interventions (Agrawal, 2008). 'Network political ecology', developed here by drawing on the insights from regional political ecology (Blaikie and Brookfield, 1987; Walker, 2003) and recent advances in network concepts of scale (Rocheleau, 2008; Rocheleau and Roth, 2007; Sayre, 2005), is one such approach to address this challenge.

This paper attempts to bring the above literatures into productive conversation in order to yield novel insights into the investigation of vulnerability and adaptation in climate change research. Here, Sayer's (1984) distinction between extensive and intensive methods in social science research is relevant for human-environment investigations. Extensive methods attempt to test relationships and identify patterns through an array of statistical methods such as correlation, regression analyses, creation and analysis of indices (such as for 'adaptive capacity'), and geospatial analyses. The focus is on the scientifically falsifiable examination of numerous cases of some event, with validation provided by entropy maximization of the model. The approach is further substantiated by replication of the study in other places or time periods. Extensive research may be performed in both local (Sustainability Science) or broader (HDGEC) contexts, but as a mode of explanation is primarily informed by quantifiable extensive methods (Sayer, 1984).

Intensive methods, on the other hand, attempt to examine how particular processes work in particular cases and to understand the patterns that they create. This approach focuses on causal factors that enable some processes or actors to effect social and/or ecological change, and the contingent character of these interactions (a rejection of entropy as a goal). Rigor is ensured by corroboration rather than replication. As I shall argue, these approaches do and need to overlap in examinations of vulnerability and adaptive potential. But to date most research investigating vulnerability to climate change and informing policy debates stems mostly from extensive approaches originating in the environmental sciences (O'Brien et al., 2007). If intensive approaches want to inform these debates beyond the so-called anecdotal, they need to broaden their empirical and geographic scope.

The paper makes two central claims. First, intensive approaches could be extended spatially and methodologically to achieve a mode of explanation that is both particular and generalizable. Second, intensive approaches are better situated to methodological extension than extensive approaches are to intensification because extensive approaches are poorly positioned to incorporate qualitative processes, such as social power relations that cannot be quantified, as a central mode of explanation (see Sayer, 1984: 176, 246), which is necessary to understand causality in local vulnerability and adaptive potential (pp. 176, 246). Therefore, case studies performed through the lens of frameworks such as Sustainability Science (Kates et al., 2001) will not achieve a detailed understanding of the political-economic constraints to adaptation or of different accounts of vulnerability. Indeed, much of the research in the HDGEC tradition recognizes the limitations of their analyses due to local social heterogeneity, including social power relations, which might frustrate the portability of their empirical claims and the veracity of policy

recommendations (Eakin and Wehbe, 2009; Eakin et al., 2009; O'Brien et al., 2004). This limitation should not be seen as a negative, necessarily. All approaches have particular limitations. Indeed, intensive approaches are not ontologically positioned for positivist empirical generalizability of social-ecological systems. Rather it should be seen as a point of entry and potential synthesis. The danger to intensive approaches in not engaging in this debate is not only their potential policy irrelevance, but that terms such as *vulnerability*, *adaptive capacity*, or *resource scarcity* (such as with water supplies) become decontextualized or simplified (Scott, 1998) leading to yet more failed technical solutions (Li, 2007).[2] The paper argues that there is a need, therefore, for intensive approaches to extensify (spatially, longitudinally and methodologically) in order to speak to the role of locally situated particularity and broader connection in vulnerability and adaptive potential to address the meso-scale problem of climate change.

The paper continues in five further sections. In the next part, I introduce extensive approaches to vulnerability most typical of research being conducted under the umbrella of Human Dimensions of Global Environmental Change (HDGEC), Sustainability Science, and Resilience frameworks. In the third section, I analyze intensive approaches to the same and their examination within work that broadly can be termed Political Ecology (PE). Necessarily, space limits preclude an exhaustive review of these literatures. Instead, these sections lay out the central insights, strengths, and weaknesses of these approaches. In the fourth section, I examine political ecology's origins as a regional science to develop and introduce the strengths of a 'network political ecology', attentive to scale as socially and ecologically produced. In the fifth section, this approach is exemplified through a case from Rajasthan, India, where the author's current research investigates the interaction of a 'regional resource-use system' (Dove and Hudayana, 2008) of groundwater-based irrigation, with the projected meso-scale impacts of climate change variability on that resource-use system, while internalizing related agrarian perturbations. The paper concludes with a discussion of the possibility for network political ecology to repoliticize the vulnerability and adaptation debate by informing extensive research and policy discussions.

II Extensive approaches: focusing on 'impact vulnerability'

Extensive (nomothetic) approaches to the investigation of vulnerability and adaptation reflect research mainly from Sustainability Science, HDGEC, and Resilience frameworks, and to a lesser degree (in terms of the number of studies performed) from work descending from climate change science specifically. Research from this latter perspective centers on a 'scientific framing' of climate change (O'Brien et al., 2007: 77), focusing on the 'problem of human impacts on the global climate system' (Kasperson et al., 1995; O'Brien et al., 2007: 76). It generally poses a question similar to the following: what impact will climate change induced perturbations have on social-ecological systems and economies? This work initially concentrated on 'outcome vulnerability',[3] which is concerned with the projected impacts of climate change on a particular exposure unit, often imagined as the nation state (Brooks et al., 2005; Downing, 1991; Haddad, 2005). Vulnerability, therefore, is the result of negative impacts of rising greenhouse gas emissions on biophysical systems.

All three approaches, however, attempt to identify vulnerability to perturbations and quantify the availability or potential of adaptive capacities to mediate them. Here vulnerability is 'the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt' (Adger, 2006: 268). Recently incorporating 'social change' as a factor, this

definition traces its lineage to first generation natural hazards research that focused on biophysical changes as the cause of risk, and on vulnerability as exposure to risk (Kates, 1971), and has a direct connection to approaches such as 'Sustainability Science' (Kates et al., 2001), which closely integrates with the environmental sciences. The focus is on developing suitable metrics for vulnerability that incorporate human well-being and the relative, perceptual, and perpetually changing character of vulnerability at multiple scales (Adger, 2006: 274; see also Polsky, 2004). The ontological reality of scale is seldom problematized (Sayre, 2005).

Exemplifying the recent incorporation of social well-being through similar methods, O'Brien et al. (2004) have taken up the problem of temporality and multiplicities of vulnerability by focusing on the relative distribution of vulnerability to multiple stressors or what the authors' termed 'double exposure' (trade liberalization and climate change risks) at the subnational level in India (O'Brien et al., 2004: 312). They focused on the district level to examine which districts were most likely to adapt to drought conditions as a result of climate change. The authors incorporated the local through 'ground truthing' or local case studies in three of the districts projected to be most affected by climate change and market liberalization, but with the least adaptive capacity (see also Garg et al., 2007; Kelkar et al., 2006, 2008). The work identified areas in need of further investigation of the particular conditions under which vulnerability manifests, but was less sanguine in its examination of local processes, including social power, longitudinally (offering a snapshot of vulnerability in one point in time).

Similarly, Eakin (2005), drawing on O'Brien et al. (2004), examined the way that market liberalization and climatic risk circumscribed household decision-making in Mexico. In doing so, the author identified a number of 'key resources' associated with local adaptive capacity but recognized that these will not necessarily lead to effective management of changing patterns of climate risk, which she recognized were related to the local power of various agents (see also Bebbington, 1999). The work further detailed coping strategies and pondered on the degree to which these strategies may be negatively impacted by particular local social power relations and policy approaches, such as 'adaptive capacity building' (Brooke, 2008; Folke et al., 2005; Pahl-Wostl, 2009). But the approach did not attempt to explain the impact of social power relations on coping strategies, including adaptation. So, too, adaptive capacity building is essentially an apolitical concept stemming from Putnam's (1995) work on 'social capital', where all 'social connection' is seen as positive. Several have problematized the notion that social connection is always positive (Li, 2005; Natter and Zierhofer, 2002; Rocheleau and Roth, 2007; Zimmerer and Bassett, 2003), while others have drawn on the more theoretically elegant, but difficult to index, version from Bourdieu (1977) (see also Jeffrey, 2001) or perhaps Sen (1990)[4] (see also Blaikie et al., 1994). In this way extensive approaches may be either spatially extensive or local in character but of *extensive* methods (e.g. nomothetic – reliance on quantifiable metrics as the primary mode of explanation, rather than ethnographic detail, which is used to inform background contextualization).

The latest extensive approaches to the study of vulnerability and adaptation have built on these recent shifts to include the local by adopting frameworks for the examination of social-ecological systems (Eakin and Luers, 2006; Ostrom, 2008, 2009; Ostrom et al., 2007), particularly the notion of ecosystem services and resilience from ecology (Adger, 2000; Daily et al., 2009; Eakin and Wehbe, 2009; Folke, 2006; Lambin, 2005; Lawrence et al., 2010), and similar notions from land change science (Lambin, 2005; Lambin and Ehrlich, 1997; Messerli et al., 2009), water science (Braden

et al., 2009), and land architecture and Sustainability Science approaches focusing on threshold changes or tipping points (Kates et al., 2001; Turner, 2010). Resilience 'refers to the magnitude of disturbance that can be absorbed before a system changes to a radically different state as well as the capacity to self-organize and the capacity for adaptation to emerging circumstances' (Adger, 2006: 268–269). Resiliency has been incorporated from the ecological sciences (Berkes et al., 2003), which abstract social-ecological systems from the political-economic relations in which they are embedded, prompting a submission of vulnerability as ultimately contextual (Kelly and Adger, 2000; O'Brien et al., 2004) and the limits of ecological frameworks to explain local social-ecological processes (Lawrence et al., 2010). This is a rationalist view of institutions (Ostrom, 2005, 2009) that leads to a focus on social capital and its derivative 'adaptive capacity building', which can be indexed and then addressed in technical and managerial terms (Li, 2007) rather than leading to the questioning of the structure of resource allocation or issues of social justice, human security, and equity. Therefore, climate change vulnerability and adaptation science needs to find new ways to incorporate the local to complement these existing approaches, including the causal processes that mediate vulnerability and adaptive capacity, which extensive (HDGEC and Sustainability Science) approaches do not claim to explain (Adger, 2006: 275).

This returns us to extensive approaches to vulnerability and adaptation that produce correlates of vulnerability without necessarily examining the underlying causes (other than acknowledging local factors, such as social power, which may inhibit adaptive capacity building). For instance, in attempting to capture the dynamics of specific variables as important factors influencing variability (not determinants), Adger writes 'specific variables do not necessarily measure vulnerability directly [they measure correlation] . . . hence, a leap of faith is required between vulnerability of a key variable (whether physical or social) and other elements such as ecosystem services or well-being'. This 'leap of faith' is the interstice where causal processes operate. Due to the focus on correlation and quantification more generally, it is not possible for extensive approaches to incorporate intensive methods of causality, which rely on qualitative evaluations of social processes (Sayer, 1984). Instead, intensive approaches must extensify to capture the particularity of the general conditions of vulnerability and adaptive responses and the character of their spatial connections. In other words, to understand causality in vulnerability and adaptive capacity at the local level, we need an intensive approach (Sayer, 1984) capable of extensifying. Once performed, extensive approaches can then draw on intensive 'regional' investigations to 'truth' their models (rather than the other way around).

III Intensive approaches: focusing on 'access vulnerability'

Intensive approaches to vulnerability and adaptation also descend from natural hazards research (Hare et al., 1977; White, 1973, 1974), grounded in cultural ecology and cybernetics (Rappaport, 1975; Turner, 1989), but later critiqued through a political economy perspective (Cutter, 1996; Watts, 1983a, 1983b). Similar to extensive approaches to vulnerability today (in the sense that they do not examine social power relations explicitly), early natural hazards research 'pragmatically' examined human 'exposure and response to environmental perturbations' as an outcome of rational actors, focusing on the 'factors important to the response of the systems to stress, rather than on those relating to its cause' (Watts, 1983a: 240–241). Contemporary intensive approaches in PE, however, originate from political-economic critiques of early hazards research that focused on the biophysical correlates of risk and

exposure. Watts (1983a: 246) redirected hazards research to the examination of vulnerability as an outcome of the 'character of ... production and in particular the current vulnerability of rural producers to environmental hazards *for which they are conceptually prepared*' but to which they are unable to respond due to their marginal position vis-a-vis local social power relations and in broader political-economic processes (see also Forsyth, 2003: 195). This approach is largely an 'access model' of vulnerability (rather than the extensive 'impact' model) taken up by political ecologists that continues through the present (Blaikie et al., 1994). It generally poses a question similar to the following: in what way will climate change induced perturbations affect social structures that currently mediate vulnerability? Drawing on Sen (1990, 1999), Blaikie noted:

> vulnerability [is] ... the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard. It involves a combination of factors that determine the degree to which someone's life and livelihood is put at risk by a disaster of identifiable event in nature or in society. (Blaikie, 1994: 9; also cited in Forsyth, 2003: 198)

Further, access to resources is critical in determining who precisely is vulnerable. Drawing on Bourdieu, Blaikie et al. (1994) argued (see also Bryant, 1998):

> access involved the ability of an individual, family, group, class or community to use resources which are directly required to secure a livelihood. Access to those resources is always based on social and economic relations, usually including the social relations of production, gender, ethnicity, status and age. (Blaikie et al., 1994: 48)

Therefore, accounts of vulnerability differentiated by multiple axes of difference lead to and necessitate different types of policy responses (Forsyth, 2003: 199). Extensive approaches are poorly positioned to internalize local social difference (see above), particularly power relations, as a mode of explanation and, therefore, policy based on these results will be unable to address them.

The PE tradition over the past decade has produced a number of intensive vulnerability and adaptation case studies applicable to the study of climate change. Setting a research agenda, Bryant (1998) distinguished marginality and vulnerability. The former is an everyday, ongoing process and is cumulative and unequal, such as soil erosion or salinization, where often the poor are the most affected (p. 84). The latter is more episodic, such as with flooding events, but where the marginal (who are also the poorest) are *positioned* to be most affected. Recent research has shown that contemporary vulnerability may be rooted in colonial relations and exacerbated by development programs (Pelling, 1999) and that who is vulnerable changes over time with shifting assets, environmental change and policy reforms (Muldavin, 2000; Neuburger, 2000). So, too, Mustafa (2005) has focused on the social structural and power/knowledge basis of vulnerability, identifying their constraints to adaptation, while suggesting several pragmatic solutions missed in other accounts (see also Collins, 2009, 2010; Mustafa, 2002). Finally, discourses of environmental risk have been shown to exacerbate vulnerability for the most marginal (Rademacher, 2009), while others have linked neoliberalism to gendered vulnerability (Harris, 2009; Page, 2005; Sultana, 2009).

PE, Sustainability Science and HDGEC approaches to vulnerability are largely in agreement that a complex set of factors influences vulnerability, but PE focuses on the persistent factors that lead to differential exposure to hazards ('starting point vulnerability') based on particular situatedness (e.g. class, gender, age, education, access to resources). Extensive approaches (e.g. HDGEC or Sustainability Science), on the other hand, begin with the creation of indexed variables (e.g. income or educational attainment, and land-cover change, respectively) and focus on explaining their

relationship with other variables (Turner and Robbins, 2008: 302) thought to relate to vulnerability or adaptive capacity. Moreover, Sustainability Science, in particular, focuses on the interaction of 'subsystems' of coupled human-natural systems in producing vulnerability. Therefore, intensive approaches begin with processes and end with the patterns that they produce, while extensive approaches begin with describing patterns and end with inferring (or correlating) processes. This is not to argue that PE approaches fail to recognize the capacities that non-human processes have to effect social-ecological change (Bakker and Bridge, 2006; Birkenholtz, 2009; Robbins, 2001; Whatmore, 2002), but that intensive approaches typically begin with social process (broadly defined, increasingly in the Latourian sense[5]) rather than biophysical, recognizing that a focus on the latter may actually make people more vulnerable (e.g. REDD programs that remove producers from their land in order to preserve forests for 'additionality' requirements under the CDM). While both types of studies make important contributions, there is need for an approach that offers reasonable generalizability, while maintaining explanations of local social processes that affect differential vulnerability and adaptive potential.

The examples of intensive research outlined above have led to conceptually and theoretically generalizable insights but have focused less on empirical generalizability, even at the regional or meso-scale level. And very few case studies in the PE tradition have examined vulnerability and adaptation to climate change specifically, instead focusing on the politics of greenhouse gasses (Bottrill et al., 2010; Howarth and Foxall, 2010), carbon offsetting (Bumpus and Liverman, 2008; Lovell et al., 2009), discourses of climate change (Boykoff and Goodman, 2009), or local perceptions of climate change and variability (Battaglini et al., 2009; Byg and Salick, 2009; Hageback et al., 2005; Rangan et al., 2010; Vedwan and Rhoades, 2001). Research that can incorporate the importance of social structure, human agency and the environment in either producing or mitigating vulnerability is needed (McLaughlin and Dietz, 2008). PE has a regional tradition of research that could be reinvigorated with recent advances in network thinking to meet the methodological demands of investigating vulnerability and adaptation to climate change perturbations situated relationally within existing socio-ecological networks of vulnerability and adaptive structures.

IV Extending intensive methods: 'network political ecology'

The challenge, therefore, for intensive research is empirical generalizability, while the challenge for extensive research is empirical particularity of social process. The investigation of climate change induced variability requires a method capable of examining the particular while also striving for generalization, at least at the regional policy level. Specifically, it needs to be capable of examining the regionally specific social-ecological effects of climate change and the longitudinal, multiscalar character of the social structures that mediate vulnerability. 'Network political ecology', drawing on the insights of regional political ecology and network theory, is one such approach that is positioned to extend intensive methods.

Many scholars have argued recently for expanding intensive approaches in research on vulnerability and adaptation to climate change (Crate and Nuttall, 2009; Magistro and Roncoli, 2001) or for integrated perspectives (McLaughlin and Dietz, 2008). PE's long tradition of 'regional' research (Black, 1990; Blaikie and Brookfield, 1987; Walker, 2003) uniquely positions it to inform this debate. Initially focused on 'regionally-based accounts of land degradation' or land-cover change (Turner, 1999), early work viewed socio-economic organization as hierarchical, leading to the 'chain of

explanation' approach (Blaikie and Brookfield, 1987). More recently, the framework has been credited with illustrating political-economic contradictions of global character: 'regional political ecology' draws 'attention to macro-level irrationalities in political-economic processes and policies, which can only be resolved through resource degradation at the local-level. The former can be termed the "contradiction" in the regional resource-use system and the latter can be termed its fix' (Dove and Hudayana, 2008: 737). Focusing on the interaction of a 'regional resource-use system', such as groundwater-based irrigation, with the projected meso-scale effects of climate change variability on that resource-use system, is an entry point for the future study of climate change related vulnerability.

Recent advances in the regional optic have come from the Global North (Robbins and Fraser, 2003; Schroeder et al., 2006), including the American West (McCarthy, 2002; Walker, 2003) and from growing topics of concern, such as HIV/AIDS (Blaikie, 2008; Blaikie and Barnett, 1992; Robbins and Bishop, 2008), while more traditional regional policy and access to resources concerns continue (Blaikie and Muldavin, 2004; Robbins and Fraser, 2003; Robbins et al., 2009; Turner, 2009). Robbins and Fraser (2003), for instance, explained regional land-cover change as a result of local political-economic processes, drawing into question extensive approaches' forest transition models. They explained this shift in terms of economic restructuring such as 'consumption through ecotourism' and industrial production that produced both 'pristine sites of conservation' and degraded monocultures, respectively. This is in contrast to the 'forest transition model' from Land Change Science that viewed this transition as the modernist outcome of urbanization and industrialization, and the disintensification of agriculture. Therefore, in this account an understanding of regional land-cover change was built from the local to the regional, rather than through the regional perspective of extensive Land Change Science.

Arguing for a return to research drawing on the 'regional political ecology' framework, Walker (2003) concluded that PE research in the Global South focused primarily on 'local-scale studies', which led to an emphasis on specificity and difference, and possibly the policy-relevant marginalization of the subdiscipline. He further argued that we ought to rethink the explanatory power that comes with regional PE, along with the demands of the optic to situate 'local-scale social dynamics' within broader-scale processes, leading to mutually constitutive socio-ecological change (see below). Without considering network approaches, he focused on the 'region as a mediating scale' (p. 13) between local and global processes, while also arguing that 'regional frames should not be merely accepted as given' but that a focus on the region opens the door to comparative approaches, such as between different resource-use systems (see also Beinart and Coates, 1995). Regional PE also offers the potential for a different kind of comparative approach: a bridging concept between extensive and intensive approaches.

Studies adopting regional PE frameworks continue to grow in the Global South. This work has drawn on the 'chain of explanation' approach, including the largely abandoned notion of scalar hierarchies, to examine multi-scalar political and economic change around HIV/AIDS (Robbins and Bishop, 2008) or to test the veracity of the Theory of Himalayan Environmental Degradation (THED) (Blaikie and Muldavin, 2004). Implicitly engaging in regional PE, Turner (2009) drew on longitudinal ethnographic fieldwork with regional herders in Mali to produce a picture of regional (dryland West Africa) socio-ecological change, highlighting the (limited) flows of 'extra-regional trade' and framing future policy needs. Similarly, Birkenholtz (2009) has shown how the aggregated cropping decisions of tubewell

irrigation partnerships led to regional-scale groundwater and cropping pattern change. This research exemplifies both the need for a regional scope of explanation, based on a 'regional resource-use system' and the explanatory power of longitudinal, mixed-method fieldwork (see also Robbins et al., 2009).

Two dominant views of the region that emerge from this body of work include the region as economic, ecological, and political continuity, and the region as mediator of multi-scalar processes, while reflecting the aggregate distinctiveness of individual places (Walker, 2003: 21). What these approaches to regional PE are missing is a way to bring the overlapping and divergent views of the region together, including the processes that are constitutive of the region and the uneven vulnerability to these processes, which a network ontology can illuminate.

Critically, recent research in this vein has problematized the ontological reality of predefined scale (Mauro, 2009; Neumann, 2009; Sayre, 2005), instead arguing for a scale of research that is produced through particular social and ecological processes. This echoes the stated value of advocates of 'regional political ecology' as an ideal optic for understanding a particular set of social-ecological problems, nested within broader political-economic contradictions. A network approach, however, problematizes the region as both a cause and consequence of these processes (Neumann, 2009). Therefore, advancements drawing on network theories seek to move beyond unidirectional notions of scale to illuminate the shifting spatial and temporal character of driving processes (see also Rocheleau, 2008; Rocheleau and Roth, 2007). Indeed, they have directed our attention to the 'relational and networked quality of the spatial configurations' of socio-ecological dynamics, where 'networks of actors (human and non-human) transcend single spatial scales to produce new relational [socio-ecological] spatialities' (Neumann, 2009: 403; see also Natter and Zierhofer, 2002; Sneddon, 2003; Swyngedouw, 2007; Zimmerer and Bassett, 2003; cited in Neumann, 2009). In advocating this approach for the investigation of nature-society relations, Rocheleau and Roth (2007) highlight the power of network approaches to bridge disciplinary divides, to illuminate the ever complex connections between local and transnational social-ecological change and to understand complexity. Drawing on these insights would allow for examination of the spatially and temporally shifting relationship (degree and terms of connectivity) between processes of social power, the production of social-ecological territorial space(s), territorial mobility (migration) and ecological change so that they may be reconfigured to reduce vulnerability and enhance adaptive capacity.

Specifically, a network ontology demands an examination of 'type of connection (+ or –), terms of connection, strength of connection, structure of network and position of actor within the network' (Rocheleau and Roth, 2007). This approach recognizes that not all connections are positive or desirable (contra to Putnam, 1995), but that they are rooted in particular resource-use systems, the biophysical properties of which may be incorporated as agents with capacities to direct change within the network (Birkenholtz, 2009). For instance, we might use this approach to understand farmers migrating from one area to another due to conditions of groundwater decline in their home area, which has undermined their ability to engage in the kind of agriculture in which they have expertise. The farmers migrate with their expertise and practice agriculture in a new setting, altering the 'resource-use system', producing new territories of extraction, and reworking social power relations in both places. Clearly an adaptive practice with new social connections, but what remains unclear is the degree to which vulnerability is reduced or exacerbated and for whom (i.e. the polarity of the connection).

The network is grounded territorially, therefore. 'Territories of extraction can be seen as one kind of rooting' in which analyses may be conducted (Rocheleau and Roth, 2007: 435). Similar to the 'regional resource-use system' highlighted by Dove and Hudayana (2008) and combined with the spatial extent of particular climate change perturbations, such as drought, temperature change, severity and periodicity of weather events, another kind of 'rooting' emerges. For network political ecology, this means a focus on both vertical (hierarchical) and horizontal (non-hierarchical) connectivity in places experiencing a common effect of climate change, understood through their connections to other processes.

The benefits of this approach, therefore, are threefold: (1) it is both positioned to evaluate local social structures and particularity (intensive), while being able to explain causality of socio-ecological change within an area being affected by a common experience of climate change induced variability (extensive) through mixed field methods informed by a network ontology; (2) it illuminates the degree to which different political actors and groups create divergent accounts of risk and vulnerability based on their political, ecological, and economic positionality and the character of their socio-ecological connectedness; so that (3) it enables the examination of vulnerability and adaptation from the specific to the general, incorporating both human and biophysical processes, and yielding more robust policy recommendations as well as new understandings of the scalar linkages between vulnerability, socio-ecological change, and adaptive potential. In short, it bridges *intensive* and *extensive* approaches, filling an empirical, theoretical, and methodological gap in current investigations of vulnerability and adaptation.

The proper scale of analysis, therefore, depends on the research questions being asked and then emerges by following the connections. Returning to the goals of explanation in intensive climate change research, it leads to the question (posed previously): in what way will climate change induced perturbations affect social structures that currently mediate vulnerability *rather* than what impact will climate change induced perturbations have on social-ecological systems and economies? But it also includes gaining an understanding of the strength and directionality (polarity) of connection between vulnerability and adaptive processes by engaging in longitudinal research, including archival work, in multiple sites, from the specific to the general (see also Vayda, 1983), within a particular resource-use system, and the constitutive character of these processes. Research, therefore, must extend intensive methods in order to identify specific vulnerabilities and adaptive practices to climate change induced social and ecological perturbations among socially and ecologically stratified resource users. It must (1) employ household and ecological surveys of users in socially and ecologically heterogeneous sites situated within a common political structure and resource-use system; (2) engage in ethnographic and participatory methods with resource users, development practitioners, and state planners to detail the causal processes that create and mediate vulnerability; and (3) map out these adaptive associations to capture their spatial, social, and ecological character.

This approach is ideally suited for the examination of resources users in a study region within a contiguous resource-use system, a common experience of projected climatic change induced variability, and a history of adaptation within that system by a diverse set of users with differential adaptive potential and stratified socially and ecologically. Next, I draw on ongoing research with groundwater-dependent, irrigating farmers in Rajasthan, India, which exhibits these traits, making it an interesting place to exemplify this methodological approach. So, too, by employing these methods, variables and particular kinds of processes may be identified

that are critical in examinations of climate change related variability elsewhere.

V Network political ecology: investigating vulnerability and adaptation to multiple perturbations in Indian groundwater irrigation

1 Rajasthan, India

This method is being constructed and tested in Rajasthan, India, where there is: (1) a high degree of socio-ecological heterogeneity but where a particular resource-use system is relatively constant, allowing for the examination of differential adaptive responses and livelihood prospects across a range of social and ecological difference; and which is (2) expected to be affected by a common set of climate change induced socio-ecological perturbations, making it prescient in understanding similar processes elsewhere.

Rajasthan is a highly stratified social environment composed mainly of low- and high-caste Hindus (Jeffrey, 2001) and Muslims with differential levels of education (Jeffrey et al., 2008), landholdings, and access to off-farm income opportunities (Birkenholtz, 2009). There are two main cropping seasons. It is also ecologically diverse with the arid west of the state receiving between 18.55 (Jaisalmer District) and 31 (Jodhpur District) centimeters of rainfall per year on average, while the eastern semi-arid part of the state receives between 56 (Jaipur District) and 87 (Chittorgarh District) (Directorate of Economics and Statistics, 2009). This is partly due to the Aravalli Mountains (900 m at their peak) that run from southwest to northeast through the middle of the state, creating a sharp isoline gradient between the east and west, and three distinct agro-ecological zones captured by this study's three study sites (see Figure 1).

These sites were chosen for their social and ecological diversity, but where groundwater irrigation and state institutions are a constant in Jaipur, Chittorgarh, and Jodhpur Districts, the latter two of which have been subject to significant groundwater irrigation expansion between 1994 and 2007: 46% and 101%, respectively. Over the same period, Jaipur District's groundwater irrigation rose only 3% as it was already heavily served, being one of the first areas in the state to receive electricity and tubewells since the Green Revolution. Indeed, groundwater irrigated area in Jaipur actually declined by over 10% between 2001 and 2006 due to groundwater overdraft and as a result of a severe drought in that district in 2005–2006, during which Chittorgarh District received *record high* rainfall and Jodhpur was *above* the long-term average. Precipitation is highly variable even within years, therefore. So, too, irrigation quality is suffering in all three districts due to increased mineralization and salinity associated with groundwater overexploitation.

Rajasthan also has been subject to market-led reforms (Oza, 2006), reductions in crop subsidies (O'Brien et al., 2004), and heavy investment by international donors that are transforming the agricultural sector along free market principles (Asian Development Bank, 2007; World Bank, 2005). This is leading to contradictions in the resource-use system, such as a nomadization (Robbins, 1998), corruption in natural resource management (Robbins, 2000), groundwater contamination (Bakore et al., 2004), gendered marginalization (O'Reilly, 2004), and shifts from commercial to traditional crops (Birkenholtz, 2009). Mirroring production conditions that resource-dependent populations throughout the Global South are facing, these contradictions are networked within shifting climate change related physical perturbations.

The IPCC predicts increased unpredictability in precipitation throughout northern India (IPCC, 2007), even though monsoon precipitation patterns were formally recognized as

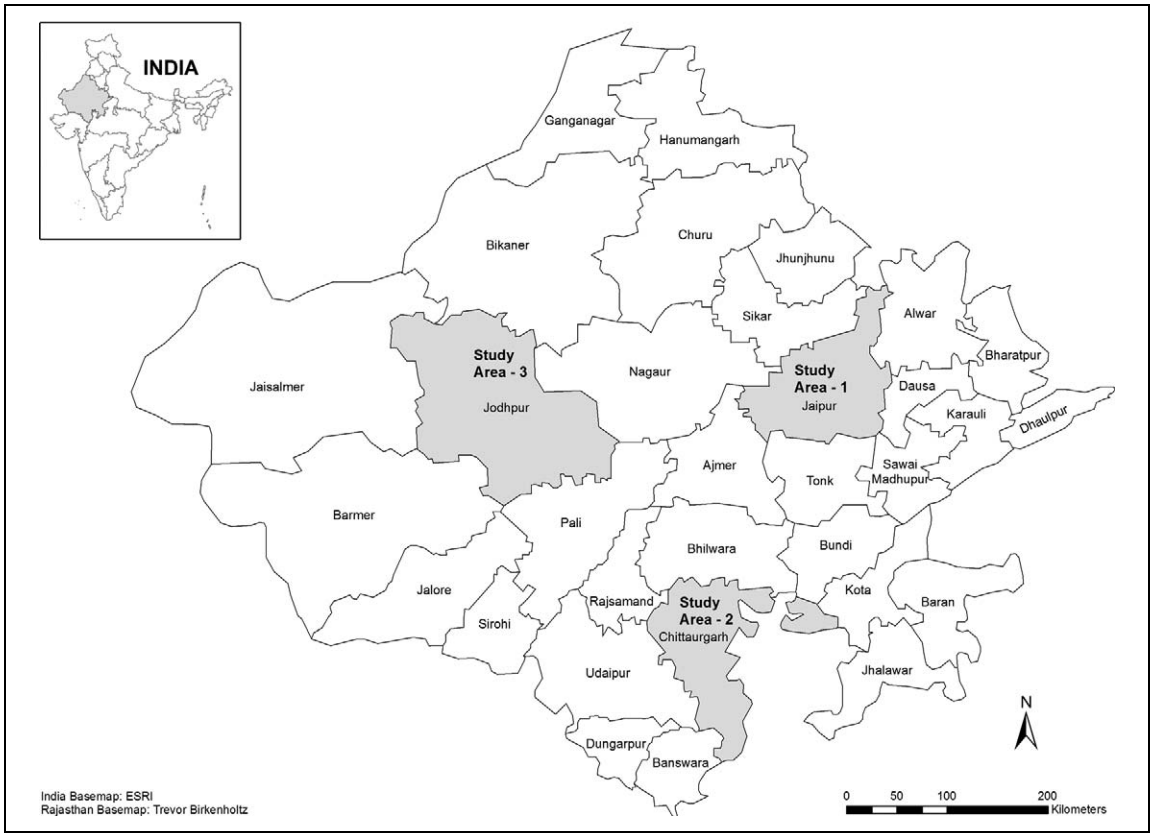

Figure 1 Study region: Rajasthan, India, with representative study areas

unpredictable in this region since before the colonial period (Indian Irrigation Commission, 1903) leading to numerous forms of adaptive practices and social institutions (Birkenholtz, 2008, 2009). Though models are in disagreement about the precise character of rainfall pattern change, increased seasonal, spatial, and episodic (more dry/flood events) variation is 'very likely'. This will exacerbate runoff, which is expected to increase by up to 40% by 2090–2099 compared to 1980–1999 levels (IPCC, 2007: 49), leading to a reduction in groundwater recharge, which is in a current state of overdraft by 410 million m^3 per year (Government of Rajasthan Groundwater Board (GORGB), personal communication, 2006). Moreover, average ground-level temperatures are expected to rise by 3.5–4.5°C by 2090–2099 (IPCC, 2007: 46), reducing soil moisture and increasing evaporation and evapotranspiration rates, increasing the need for irrigation (Shah, 2009). This is problematic as today 39% of Rajasthan's net sown area is rain fed, while much of this (the *khariph* – summer season – crop) is also dependent on supplemental groundwater irrigation. So, too, most *rabi* (winter) season irrigation is reliant on groundwater recharge as over 71% of Rajasthan's 6.5 million gross cultivated hectares is groundwater irrigated (Directorate of Economics and Statistics, 2009). This is particularly alarming as recent analyses of NASA's GRACE (Gravity Recovery and Climate Experiment) satellite imagery have shown that between 2002 and 2008 northern India, including Rajasthan, had the highest regional groundwater

depletion rates in the world even though *rainfall was above normal for the period* (Tiwari et al., 2009). Given these conditions, particular emphasis must be placed on investigating the degree to which different political actors and groups create divergent accounts of risk and vulnerability, based on their political, ecological, economic, and spatial positionality.

In order to understand the causal processes producing particular patterns and associated vulnerability and adaptive potential to climate change induced social-ecological variability, we must begin with local level analyses of the ways that farmers make sense of weather variability and institutionalize coping mechanisms over an extended area within a 'resource-use system', then move towards methods to quantify these systems of adaptation and link them to their socio-ecological effects.

2 Adapting to agrarian perturbations: weather variability, markets, and irrigation

The work presented here relies on a preliminary investigation comprised of household surveys conducted in 2009 (n = 42) and 2011 (n = 36) equally spaced across the three sites, multiple in-depth interviews with farmers and state planners, and analysis of secondary cropping data. Developing a network political ecology approach, the research establishes that (1) farmers rely on multiple local methods for predicting the onset of the summer monsoon, which (2), coupled with social, ecological, and technological constraints and opportunities, inform their cropping decisions, and their adaptive strategies, such as seasonal migration, land sales, loan-taking, and cropping decisions, which were socio-ecologically differentiated across the three sites, leading to (3) recursive socio-ecological change at the regional level and forming networks of association that both enhance and undermine adaptive capacity.

First, research to date has identified 13 local methods of weather prediction, 11 of which focused exclusively on precipitation *timing*, rather than on absolute quantity. These practices are important less for their validity in predicting rainfall than for the reliance upon them for cropping decisions and their socio-ecological effects. Of those surveyed, 91% relied on at least one of these methods in their summer season (*Khariph*) cropping strategies. Crop decisions followed, first, from these predictions and then, second, from an empirical observation of a precipitation event. This event determined the ratio of crops sown and the subvariety chosen in the case of pearl millet (*bajra*), a dietary staple in northwestern India. With a delayed summer monsoon, farmers tended to increase their production of pearl millet of the 'korDaa bajra' variety, meaning dry and unprofitable, yielding only fodder. Commonly cultivated during the winter (*rabi*) season in a drought year, it requires little irrigation and is tolerant of saline groundwater and sodic soils. It also marks a shift away from the market as a way to mitigate vulnerability, a practice which is likely to increase with growing weather unpredictability recognized by 100% of those surveyed and corroborated by official weather observations (Indian Meteorological Department (IMD), personal communication, 2009).

Second, individual cropping decisions such as these, along with structures of agrarian production, including those within the household (Robbins and Bishop, 2008), translate into long-term adaptive practices, and regional-scale land use (McCusker and Carr, 2006) and ecological change. This impacts current and future vulnerability, while providing clues for further adaptive potential. The survey found that 100% of farmers in Jaipur and Chittorgarh Districts formed partnerships for tubewell construction and subsequent irrigation, while 0% in Jodhpur District had such partnerships. In the two former districts, these new institutions permitted farmers to spread risk of tubewell failure, which was high, and construction

costs, which were great. But they constrained the types of crops that could be grown due to their divergent water and timing requirements, impacting adaptive strategies (see also Birkenholtz, 2009). Moreover, smaller farmers had more partners, further limiting their cropping varieties. It remains unclear what effect the yearly shifting of commercial and subsistence crops has on production relations that mediate vulnerability, which future studies will address. But research suggests that it may have negative effects on gendered labor burdens and power relations (Carney, 1993; Carney and Watts, 1991; Carr, 2008; Schroeder, 1999). Smaller farmers also had higher ratios of income to cultivated area than larger farmers (who are more reliant on groundwater irrigation) and engaged in more off-farm employment, which may better position them to mediate various types of exogenous shocks, including market perturbations and unpredictable weather events. Yet smaller farmers are typically unable to redirect the flow of state resources away from the locally powerful.

In Jodhpur District, on the other hand, low soil productivity, necessitating larger landholdings, along with widespread sharecropping (64% of those surveyed in Jodhpur District) and absentee landlordism undermined the potential for irrigation partnerships. This growing system of sharecropping is attracting farmers from neighboring states (Uttar Pradesh) where groundwater has been depleted and from where they bring their own cropping expertise, reworking social relations and ecologies in both places. While these migrations bring up issues of particular resource 'access regimes' (Jepson et al., 2010; Natcher et al., 2009; Ribot and Peluso, 2003), these farmers, once tied to consumer markets in the Delhi region, have expertise in growing vegetables and cucurbitaceous crops (melons and gourds), and are articulating with new regional markets. Pesticide use has increased, as has the production of these imported, yet regional, crops. Future research will focus on quantifying these shifts and testing their relationships, but it is clear that these processes (e.g. migration, irrigation institutions, markets, ecological change, and variability) form dense networks of association which some articulate so as to enhance adaptive capacity while simultaneously undermining the adaptive potential of others (see below).

Third, these agricultural practices, informed by the local weather prediction methods introduced above, as well as barriers to market entry (such as high seed costs) and access to credit and communal institutions, translate into regional-scale land-use change. The area is experiencing wide fluctuations in area under production and productivity of particular crops. For instance, the production of rape/mustard seed increased by 450% between 1994 and 2007 in Chittorgarh District, while groundnut production increased by 217% in Jaipur District over the same period. At the household level, the production and yield of both crops is highly correlated with groundwater quality (qualitatively observed), officially observed yearly rainfall, the number of members in an irrigation partnership to which the farmer belongs, and the proportion of income from off-farm sources. So, too, drastic shifts are occurring in other important crops as well, indicating that farmers are struggling to align production practices and cropping strategies to shifting social, ecological, and market conditions. Longitudinal and recurring household surveys, followed with similar ethnographic methods, will be performed in the future in all three districts to explain these shifts and test their spatial relationships to vulnerability and adaptive practices and institutions. Doing so forms a 'network political ecology' attentive to local particularity and resulting in robust, generalizable, and policy actionable results. The next section illustrates this in an empirically informed network model, which in the future will be based on geographic, quantifiable metrics.

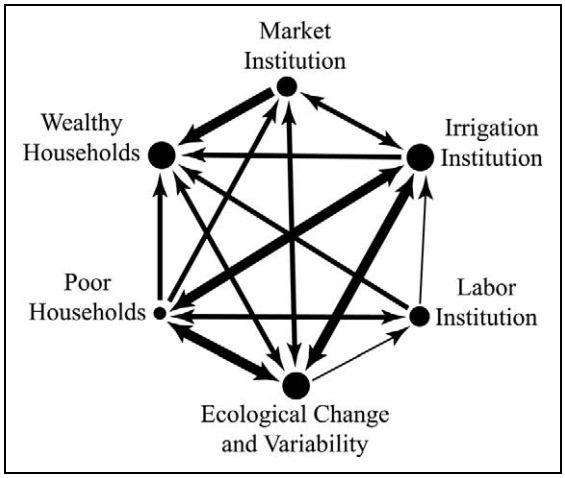

Figure 2 Schematic map of adaptive network
Source: Adapted from Agrawal (2008: 30)

3 Adaptive network mapping

Individual households' adaptive networks are constituted through their particular associations, which emerge from the household surveys and interviews. Relationships, institutions and socio-ecological processes are represented as nodes in the network and their connections are represented by lines of varying width and directionality, indicating a dominantly positive, negative, or recursive connection. This preliminary investigation indicates nodes, connections, and the character of both to vary over space and correlate with agro-ecological zone, but to vary sometimes but not always by class and caste.

Figure 2 is a simplified network model that represents these associations (see also Agrawal, 2008). The schematic links two social groups with three institutions and aggregated ecological change and variability as nodes. The capacity to effect change in the network is represented by node size, while the lines show strength (width) and direction of connection (arrows), indicating the flow of capacity to effect change (social power) and benefits. It shows that, while the poor are active in producing and benefitting from irrigation institutions, they are also more vulnerable to ecological change and variability (due to unreliable access to market and irrigation institutions, for example). The wealthy, on the other hand, accrue benefits from poor households' labor, are less subject to ecological variability due to access to irrigation, and are better connected with and accrue greater benefits from the market. Schematics like this can be used to illustrate the socio-ecological impacts and beneficiaries of targeted development interventions to redirect them towards more socially beneficial outcomes.

In future studies, social surveys will be complemented with ecological surveys detailing groundwater and soil conditions and households will be placed within their adaptive networks using network-mapping techniques provided by GIS and geovisualization software. These will be linked to household survey variables, such as migration patterns, ecological change, and access to irrigation institutions and markets, which will then be coded and weighted to produce a series of vulnerability network maps, modeled after the above, illustrating the breadth of farmers' adaptive networks and enabling an assessment of their relative strength and polarity (Agrawal, 2008; Carrington et al., 2005; Crona and Bodin, 2010; Crona and Hubacek, 2010; Rocheleau, 2008). The maps and the patterns they show will be contextualized with the interview data to yield a robust understanding of connections through which vulnerability is differentially mediated, creating a typology of these relationships, informing future studies.

This brief presentation of research results shows that vulnerability and the adaptive structures and connections upon which farmers' rely to adapt to agrarian perturbations are complex, involving changes occurring sometimes over a large area, but in detailed ways. Current approaches to vulnerability and adaptation fail to be able to explain whether or not these strategies are systemic and the precise ways that they vary over space and between communities, which network political ecology is positioned to address.

VI Conclusion: network political ecology in climate change vulnerability and adaptation research

The network political ecology framework presented here attempts to advance our methodological approach and theoretical understanding of vulnerability and adaptation to climate change. To do so, first, it links existing intensive and extensive approaches by drawing on recent advances in human-environment research on scale and networks. Second, it is driven by the question 'in what way will climate change induced perturbations affect social structures that currently mediate vulnerability *rather* than what impact will climate change induced perturbations have on social-ecological systems and economies?' By prioritizing the former question, network political ecology is effectively positioned to identify and link existing causal processes that affect vulnerability and adaptation with ongoing processes of climate change induced variability.

The approach possesses three main insights overlooked by other frameworks. First, its network ontology positions it to evaluate particular causal socio-ecological processes and place them within their broader recursive relationships, while linking them to their broader socio-ecological outcomes. Second, it illuminates the degree to which different actors (human and non-human) face divergent processes of risk and vulnerability based on the character of their socio-ecological connectedness. Third, taken together, the approach enables the examination of vulnerability and adaptation from the specific to the general, incorporating both human and biophysical processes, and yielding more robust policy recommendations as well as new understandings of the scalar linkages between vulnerability, socio-ecological change, and adaptive potential. In this way, the paper and approach that it advocates informs vulnerability and adaptation research, generally.

The method was exemplified by drawing on ongoing research in Rajasthan, India, with groundwater-dependent irrigating farmers, who are facing a range of agrarian perturbations from socio-ecologically differentiated positions. Grounded in a regional resource use system of groundwater irrigation, the case highlighted the strength of the approach in drawing out the particular conditions under which vulnerability manifests but also the broader causal structures within which adaptive potential is produced, while showing how these processes constituted the domain of inquiry. It further showed that by focusing on the character of the connection(s) between actors, we not only gain a better and more nuanced understanding of the these processes but we are in a better position to inform policy debates.

The paper and approach builds a much-needed middle-range theory for the examination of the meso-scale problem of climate change induced variability (Agrawal, 2008), while internalizing the interaction of existing agrarian perturbations. It has not been argued, however, that we should discontinue intensive (ideographic) or extensive (nomothetic) research in vulnerability studies, both of which continue to yield important insights. Rather, network political ecology should be seen as an approach that complicates the findings of both frameworks, while making its own important contributions to our understanding of these processes.

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Notes

1. We could also include a discussion of intensive contributions from Human Ecology, Cultural Ecology and Anthropology; and extensive contributions from Resiliency research.
2. Latour refers to the meaning of terms which are no longer contested and which have an assumed definition,

cause and set of underlying conditions as 'immutable mobiles'. These are produced by experts, accepted or rejected by locals, and allow centers of calculation to 'act at a distance' (Latour, 1987). This gives them a particular power of (mis)representation, with material effects.

3. Kelly and Adger (2000) term this 'end point vulnerability' as compared to 'starting point vulnerability', which is the focus of much work in the political ecology tradition.
4. These approaches draw on Sen but consider less the political moments of his Rawlsian philosophy – for example, topics like land reform are not addressed.
5. Latour (2005) defines all objects as 'social', where to be 'social' is not a 'domain of reality or some particular item, but rather is the name of a movement, a displacement, a transformation ... an enrollment' (p. 64).

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