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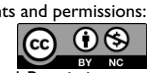
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Ordering theories: Typologies and conceptual frameworks for sociotechnical change

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Abstract

What theories or concepts are most useful at explaining socio technical change? How can – or cannot – these be integrated? To provide an answer, this study presents the results from 35 semi-structured research interviews with social science experts who also shared more than two hundred articles, reports and books on the topic of the acceptance, adoption, use, or diffusion of technology. This material led to the identification of 96 theories and conceptual approaches spanning 22 identified disciplines. The article begins by explaining its research terms and methods before honing in on a combination of fourteen theories deemed most relevant and useful by the material. These are: Sociotechnical Transitions, Social Practice Theory, Discourse Theory, Domestication Theory, Large Technical Systems, Social Construction of Technology, Sociotechnical Imaginaries, Actor-Network Theory, Social Justice Theory, Sociology of Expectations, Sustainable Development, Values Beliefs Norms Theory, Lifestyle Theory, and the Unified Theory of Acceptance and Use of Technology. It then positions these theories in terms of two distinct typologies. Theories can be placed into five general categories of being centered on agency, structure, meaning, relations or norms. They can also be classified based on their assumptions and goals rooted in functionalism, interpretivism, humanism or conflict. The article lays out tips for research methodology before concluding with insights about technology itself, analytical processes associated with technology, and the framing and communication of results. An interdisciplinary theoretical and conceptual inventory has much to offer students, analysts and scholars wanting to study technological change and society.

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Introduction

Despite being opaque to the uninitiated, theories can serve as important heuristic devices that enable researchers to make sense of large amounts of data; such frameworks also offer roadmaps for how to carry out empirical research (Jackson, 2005). Sartori (1970: 1034) put it well when he wrote almost fifty years ago: 'We badly need information which is sufficiently precise to be meaningfully comparable. Hence we need a filing system provided by discriminating, i.e., taxonomic, conceptual containers. If these are not provided, data misgathering is inevitable; and statistical, computerized sophistication is no remedy for misinformation.' Turnheim et al. (2015) agree when they write that a structured dialogue among practitioners of different approaches is needed to better understand processes and pathways of sociotechnical change. Similar calls for more inclusive, comparative, cross-disciplinary research have come recently from many researchers (e.g. Castree, 2016; Sovacool et al., 2015; Stern et al., 2016; Viseu, 2015; Webster, 2016).

But proclamations for theoretical breadth in the study of sociotechnical change raise an obvious question: Which theories offer the most explanatory power or seem to be the most applicable? More precisely, this study asks: What theories or concepts are most useful for the goal of explaining the adoption, use, acceptance, diffusion or rejection of new technology? How can – or cannot – these frameworks be integrated? To provide answers, the first part of the study presents the results from 35 semi-structured research interviews with experts who also shared more than two hundred articles, reports, and books on the topic. This material led to the identification of 96 theories and conceptual approaches spanning 22 identified disciplines, distilled into fourteen theories deemed most relevant. The second part of the study explores the topic of theoretical integration by creating two typologies of theories. We argue that theories fall into five main analytical strategies and areas of focal attention (agency, structure, meaning, relations, and norms) and four main underlying groups of underlying assumptions and goals (functionalist-institutional, culturalist-interpretivist, critical-humanist, and conflict). In doing so, we move beyond the classic social theory triangle of agency, structure, and meaning – or the three 'I's of interests, institutions, and ideas – that often guide the analysis of empirical focus. Instead, we expand on these ideas but also offer two additional categories of analytic strategy: those that are intentionally relational across categories, and those that are normative and offer criteria by which to assess the positive or negative impact technology can have on society or a particular group. The article also offers some tips for analysts concerning research methodology and triangulation before it concludes by offering insights about the study of technology and the framing and communication of results.

The article seeks to make two contributions. First, for scholars and theorists, it attempts to broaden conceptual debates and discussions that often risk 'bias' and 'epistemological monism' (Castree, 2016), 'disciplinary chauvinism' (Sovacool et al., 2015), or 'methodological unawareness' (Sartori, 1970: 1034). When thinking about technology,

the academy needs to move beyond science, engineering and economics as preferred 'cognitive resources' (Martello and Jasanoff, 2004: 4). Second, for researchers and even for students, the project attempts to provide a toolkit or menu from which researchers can 'order', but it also proposes strategies for ordering, selecting, and synthesizing diverse theoretical options.

Research methods and terms: Interview protocol and defining 'theory'

The primary data collection tool for this study was semi-structured research interviews with knowledgeable experts about technology and social science theory. The lead author conducted full-length research interviews with 35 scholars listed in Appendix I during late 2015 and early 2016. In terms of the interview process, only two completely open-ended questions were asked: What theories or concepts are most useful at explaining the adoption or diffusion of technology, and how can these be integrated, if at all? A follow-up question at the end of the interview asked for supporting articles, reports, books and other sources of data for further information, which have been integrated into the analysis and cited below, when relevant. Interviews ranged in duration from 20 minutes to four hours, with a mean time of about 45 minutes. Most interviews were done face-to-face (n = 21), although others were done as part of two workshops (n = 10) and a few (n = 4) were done via telephone. Any theory or concept mentioned by participants was recorded in Appendix II; those mentioned more than 10% of the time across all respondents were synthesized into a short-list of fourteen theories discussed in the later part of the paper.

Thus, there is an element of 'grounded theory' to the study in that only concepts, approaches, and theories 'grounded' in the interview responses are mentioned here (Strauss, 1987). The aim is not to present all possible theories and concepts, of which there are probably hundreds, but instead to present those argued as most relevant or useful by interviewees and the material they shared. Respondents were not corrected when they gave incorrect or incoherent information or did not produce an answer that was an obvious fit with the research question. All answers were treated as equally valid. This same approach was utilized with how respondents described theories and concepts – statements were taken at face value.

The nonrandom sample relied upon for primary data is limited in several ways. First, although the interviewees listed in Appendix I come from over a dozen disciplines, the sample was confined primarily to researchers in the social sciences, with an emphasis on behavioral science, transition studies, energy studies, transport studies and innovation studies. Although researchers located primarily in cultural studies and related humanities fields were not included as part of the sampling frame, theoretical frameworks that are prominent in these fields and that interviewees mentioned (e.g., Discourse Theory, Social Justice Theory) were included. Second, the interviewees represented diversity in terms of institutions – coming from 29 separate universities and a few research institutes spread across eight countries – but the sample focused on the category of 'experts', mostly senior and eminent researchers. Some junior scholars, to whom some in the network pointed as doing 'cutting edge' work,

were also included. The sample thus made it possible to develop a picture of what is considered important from the perspective of highly cited scholars familiar with various theoretical debates and frameworks. Third, the sample is limited demographically, and to some degree it is moderated by the first author's personal networks, training in science and technology studies (STS), and contacts as a journal editor. Because the researchers are located primarily in organizations in Europe and North America, the full global range of work on technology and society is not included. Furthermore, those researchers who were unavailable for interviews happened to include a cluster of researchers known for their work on some of the theories. Finally, the sample is weighted toward men, as is the broader referent research network of researchers in these fields. Therefore, this analysis should not be interpreted as representing the full diversity of approaches to social studies of technology; rather, it is an analysis of what a nonrandom or 'convenience' sample of leaders of the field, or a network of people with prominent field positions, perceive to be important theoretical frameworks. In the comparative analysis of the theories, we discuss some approaches that are missing from their perceptions of important theories. Because the results of the exercise are limited by who was interviewed, the goal of this study is to create an illustrative rather than exhaustive catalogue of theories.

Again, the central goal of this study was to explore *theories* related to technology and society, especially the patterns of adoption, diffusion, and technological change. Thus, the core unit of analysis for this study is a 'theory', but within the academic literature (and throughout the research interviews) no consensus presented itself as to what constitutes a theory or differentiates theories from concepts or heuristic devices. For example, Wagner and Berger (1985) noted that the word 'theory' covers everything from 'commentaries on the classics' to 'causal modeling', and Abend (2008) even offers eight different definitions of 'theory' utilized within sociology, including explanations of social phenomenon and observing and contemplating.

A wide range of distinctions is evident in some of the most proximate literature, such as grand versus middle-range theories (Merton, 1948, 1967), models versus frameworks (Geels, 2010), and meta-theories and theory frames (Rueschemeyer, 2009). Alexander (1982) suggests a continuum, offered in Figure 1, from general presuppositions, models, and concepts to laws, correlations, and methodological assumptions. Doty and Glick (1994) argue that at its most basic level a theory specifies a consistent relationship between independent and dependent variables; at more complex levels, a theory must satisfy more advanced criteria, such as being decomposable into constructs or ideal types (often first order and second order), specifying the relationship among these constructs, and enabling those relationships to be tested or falsified.

A relational approach to theory can draw attention to actors and conflicts, and dominant and subordinate positions within a scientific or cultural field, and thus can examine how habits and skills become ingrained in theoretical preferences forming a researcher's *habitus* (Bourdieu, 2004). Those interactions produce preferences for a theoretical framework or topical area, which can align with broader ideological and social divisions (Bourdieu, 1988). STS is not immune from such homologies (Hess, 2011); for example, in programs in the history and social studies of science and technology in the United States, a taste for research on topics such as the environment and

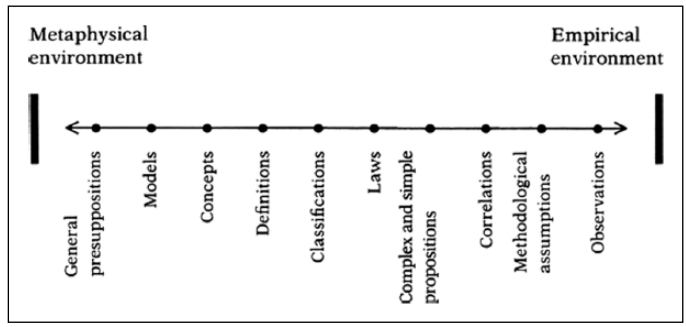

Figure 1. Metaphysics, empirics and a continuum of scientific components (from Alexander, 1982).

democracy is higher among scholars in non-elite programs with a focus on technology than among those in elite programs with a focus on history (Hess, 2013). Thus, the difference between a theory and ideology is not so easy to trace. Theories can serve as expressions of disciplinary culture or even as mechanisms of socialization. Because of these dynamics, it is important to pay attention to theoretical frameworks and problem areas that are missing in the data set that is analyzed here.

In summary, there is no agreed upon definition of theory, nor agreement on what the boundaries and relations are among theories or between a theory and non-theory (Mintzberg, 2005). There is no 'sure to please standard' (Eisenhardt and Graebner, 2007) or universal approach to theory building (Gioia and Pitre, 1990: 584). To be as inclusive as possible, this study there defines theory broadly. This approach also situates the study in line with Abend's (2008) plea to commit to 'ontological and epistemological pluralism'. The term 'theory' therefore captures any theoretical construct, conceptual framework, analytical tool, heuristic device, analytical framework, concept, model or approach relevant to technology and society. The lines among these are rhetorically porous, and some theoreticians even use categories such as 'meta-theory' or a 'material-semiotic method' (Latour, 2005).

A few other definitions are in order. By looking at technology and society, the study sought to investigate theories of how technological artifacts or systems change, such as how new technologies become widely disseminated or embraced by users. Sometimes this is referred to as 'diffusion', 'social acceptance', 'market acceptance', 'technological transition', 'community acceptance', or 'commercial acceptance' (Sovacool and Ratan, 2012; Wuestenhagen et al., 2007). Other times it refers to 'sustainable innovation', which Johan Schot (interview with lead author, 2016) defines as

> The introduction of a new product, a good or service, or a new process that has significantly improved characteristics or intended uses.

In still other cases, other phrases were employed to describe diffusion, usually words such as 'adoption', 'attitudes', or 'support' (Huijts et al., 2012). These all refer to

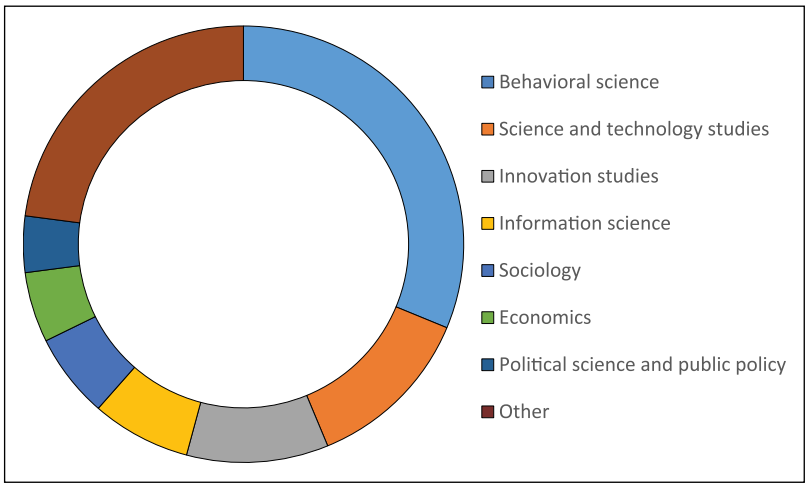

Figure 2. Academic discipline for selected theories (n = 96). 'Other' disciplines include history, organization studies, political ecology and geography, transport studies, business studies, communication studies, conflict resolution, consumption studies, development studies, energy studies, ethics and moral studies, legal studies and jurisprudence, linguistics and semiotics, marketing, and mathematics.

essentially the same thing, namely, people adopting or using technology, rather than resisting or inhibiting the use of it.

Results: Probing theoretical concepts

Although the 35 final interview participants for this study came from only 15 stated disciplines, they recommended 96 distinct theories. In turn, the 96 theories represented 22 disciplines or areas of interdisciplinary inquiry, including behavioral science, business studies, communication studies, conflict resolution and project management, consumption studies, development studies, economics, energy studies, ethics, history, information science and management studies, innovation studies, legal studies and jurisprudence, linguistics and semiotics, marketing, mathematics, organization studies, political ecology and geography, political science and public policy, science and technology studies, sociology and transport studies. As Figure 2 reveals, across the whole sample the disciplines with the most identified theories were behavioral science (31%), science and technology studies (13%), and innovation studies (10%). Again, these simple statistics are presented only to help frame the analysis; the results are much closer to a 'probe' than a comprehensive survey, because the sample of respondents is not uniform (Collins and Evans, 2015).

Of the 96 theories mentioned, only fourteen were articulated by more than ten percent of the expert respondents as important (see Table 1). These fourteen theories are described in more detail in the subsections that follow. The fourteen subsections follow the same structure: the source of the theories and their underlying assumptions or intellectual history, the core concepts, the contributions the theory tries to make, and the acknowledged limitations.

Table 1. Most frequently mentioned theoretical approaches (respondents = 35).

No.	Name	Frequency mentioned by respondents (n)	Frequency mentioned (%)
1	Sociotechnical Transitions	15	43
2	Social Practice Theory	14	40
3	Discourse Theory	10	29
4	Domestication Theory	9	26
5	Large Technical Systems	9	26
6	Social Construction of Technology	9	26
7	Sociotechnical Imaginaries	7	20
8	Actor-Network Theory	7	20
9	Social Justice Theory	7	20
10	Sociology of Expectations	6	17
11	Sustainable Development	6	17
12	Values Beliefs Norms Theory	5	14
13	Lifestyle Theory	4	11
14	Universal Theory of Acceptance and Use of Technology	4	11

Sociotechnical Transitions

The theory of 'Sociotechnical Transitions' is sometimes called the 'Multilevel Perspective' (MLP) on socio technical transitions and innovation (Geels, 2002; Geels and Schot 2007a; Schot and Geels, 2008). Borrowing from a mix of disciplines, including history, evolutionary economics, institutional theory and STS, the approach suggests that diffusion or transitions occurs through interactions among three levels: the niche, the regime, and the landscape. The niche refers to a radical innovation that is emerging to gain diffusion or adoption, to move from invention and innovation to viable market introduction (Grin et al., 2010). The regime refers to the incumbent sociotechnical system that the niche is potentially affecting or replacing; such regimes contain cognitive, regulative, and normative institutions (Geels, 2004). The 'landscape' refers to exogenous developments or shocks (e.g. economic crises, demographic changes, wars, ideological change, major environmental disruption like climate change) that create pressures on the regime, which in turn create windows of opportunity for the diffusion of niche-innovations. Figure 3 illustrates how the three scales interact.

A key term of art within the framework is that of a 'transition pathway'. Analytically, the claim is that different kinds of interactions among niche, regime, and landscape result in different kinds of alignments. Geels and Schot (2007b) construct a typology based on combinations between two dimensions: the *timing* and *nature* of multi-level interactions. This leads them to distinguish four transition pathways: 1) *technological substitution*, based on disruptive niche-innovations that are sufficiently developed when landscape pressure occurs, 2) *transformation*, in which landscape pressures stimulate incumbent actors to gradually adjust the regime, when niche-innovations are not sufficiently developed, 3) *reconfiguration*, based on symbiotic niche-innovations that are incorporated into the

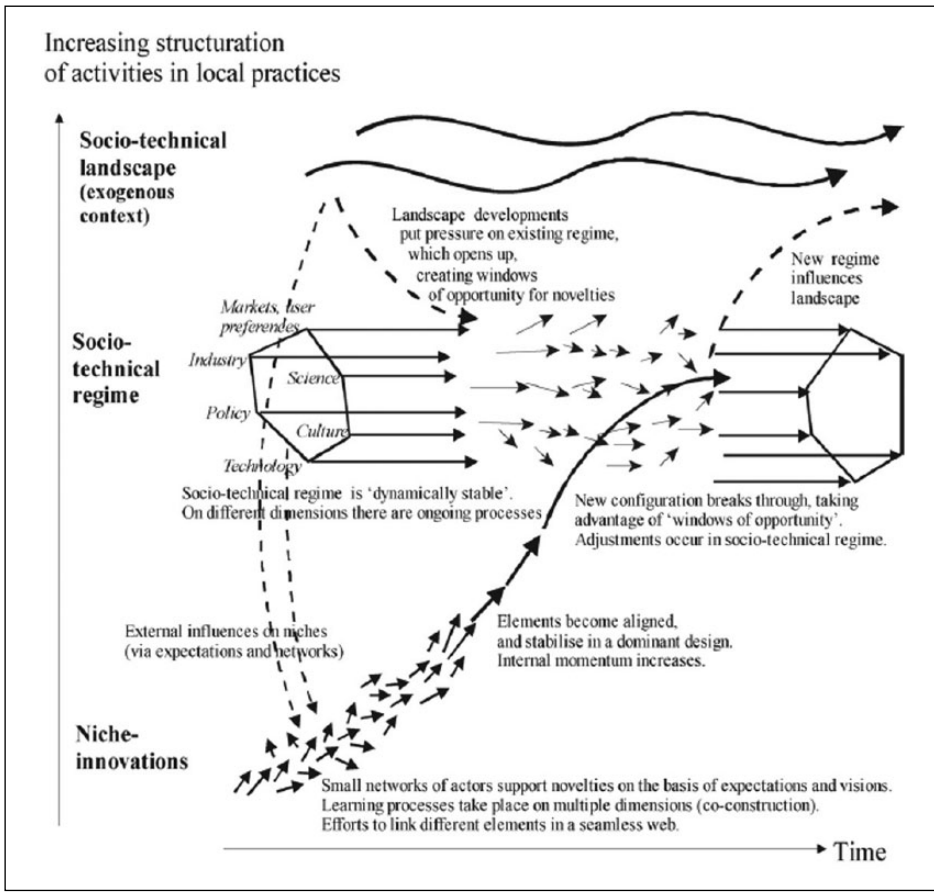

Figure 3. Niches, regimes, and landscapes in sociotechnical transitions (Source: Geels and Schot, 2007b).

regime and trigger further (architectural) adjustments under landscape pressure, 4) *de-alignment and re-alignment*, in which major landscape pressures destabilize the regime when niche-innovations are insufficiently developed; the prolonged co-existence of niche-innovations is followed by re-creation of a new regime around one of them. The implication is that transitions can be conflictual – many niches fail – and that existing sociotechnical systems and infrastructure can dominate and suppress threatening innovations.

A significant benefit to the theory is its emphasis on interactivity and dynamic interactions among the three levels of niches, regimes, and landscapes. As Johan Schot (interview with lead author, 2016) describes it:

> A central finding from the MLP is that transitions happen only when niches are built up sufficiently to change or challenge a regime, usually through indicators such as deep and broad learning, deep and broad networks, or robust and specific expectations. Such acceleration of

> niches can create tensions or help to destabilize existing regimes; the sociotechnical landscape can also create pressures attuned to change. The key is the interaction between all three levels: the niches, the regime, and the landscape.

A second benefit is the theory's focus on learning and co-evolution, which challenge overly linear explanations of change. Instead, transitions come about when multiple dimensions and levels coalesce simultaneously. The theory also focuses on size, stability and structure: Niches and regimes are about networks of actors that subscribe to particular rules, but these are constantly shifting in their scope, scale, maturation, and effectiveness. Also, successful niche innovations need what Adrian Smith (interview with lead author, 2016) calls 'protective spaces' where experimentation and development of new technologies can take place within a supportive environment. Expectations can also play a role in articulating a future in which particular socio technical configurations are featured (Rolffs et al., 2015).

Despite its utility, and the fact that the theory was the most popular among all respondents, some point to its shortcomings. Geels (2011) identifies no fewer than seven major criticisms (which he uses to further elaborate the MLP) including that it excessively downplays the importance of agency, that it is biased towards bottom-up change models, and that it possesses a flawed epistemology and explanatory style. Wells and Lin (2015) further argue that the transition process occurs over geographic space, but the definitions offered by the theory of landscape, regime and niche are ambiguous in nature. For example, is a city with a million people a landscape or a niche? They argue that it can be both depending on context. Geels (2011) mentions that frequently the category of landscape is used as a catch-all for whatever doesn't fit into a niche or regime, rendering it a 'residual garbage can'. Shove and Walker (2010) criticize the MLP for being too focused on structure and not looking at elements such as agency or human needs. Steinhilber et al. (2013) write that although the theory 'has been a powerful tool in helping understanding of how and why changes occur in the social application of technology, there has been a relative neglect of how embedded regimes may have diverse evolutionary pathways including non-change'. This complements the thinking of Gordon Walker (interview with lead author, 2016), who claims that:

> The sociotechnical transitions literature has a lot of power, particularly in understanding historical transitions. It is very good in looking back at the processes involved in past transitions. It comes a bit unstuck when it tries to look forward and propose processes of change and agency, or offers itself as a management tool. Future change mechanisms require different theories.

A final criticism is that the MLP does not always adequately explain issues of politics, power and hegemony in explaining how transitions occur (Smith et al., 2010).

Social Practice Theory

Social Practice Theory – also called by some 'theories of practice' – was the second most frequently mentioned approach. Shove et al. (2012) state that it attempts to explain 'why people do what they do', by noting that behaviors are driven by beliefs, values, lifestyles

and tastes that express personal choice. The theory is recursive in the sense that it suggests that human action and social structure are mutually co-constructed. As Shove et al. (2012) argue, the theory is relational because social practice theory 'aims to comprehend and even then transcend the dualisms of structure and agency, determination and voluntarism'. At its core sits the notion of a 'practice', a type of behavior that is routinized much as is a habit, but that also links together bodily activity, mental activity, and things and their uses. Allison Hui (interview with lead author, 2016) argues that:

> Social practice theory starts with the idea of a practice. Something like driving is a practice that involves people and materials and knowledge and skills about using. Focusing on practices forces analysts to move back and forth between those things, not just consumers and what they are thinking, or a piece of technology, but how they circulate. Skills are being continually deferred and reframed, resulting in an interactive, complex and dynamic process that is continually performed.

Shove et al. (2012) decompose practices into elements, entities, performances, and carriers. Elements are recognizable and often material items that enable or constrain individual action; entities are things spoken about and skills drawn upon when doing an activity; performances encompass the immediacy of doing or the pattern provided by the practice as entity; and carriers are individuals that host or undertake a practice, most often people but sometimes other things like automobiles or computers.

To make sense of this complex nature of practices, social practice theorists (Ropke, 2009; Reckwitz, 2002; Shove et al., 2012; Watson, 2012) have argued that analysts must investigate at least four topics:

- Materials (sometimes called 'materialities'), meant to include things, technologies, tangible physical entities and other material objects,
- Competences, meant to include skills, habits, knowledge, tacit knowledge and technique,
- Meanings, meant to include ideas, symbolism, aspirations, and other cognitive dimensions, and
- Connections, meant to describe how certain practices emerge, persist, shift, or disappear over time.

This last constituent part of connections is meant to convey temporality to practices, showing how they change over time. As Matt Watson (interview with lead author, 2016) clarifies:

> Of course socio technical transitions are important, but my concern is to emphasize how the changes comprising transitions always come down to changes in social practices. Practices sit at the center of it all, and what happens in terms of rhythms, routines, and recursive reactions has significant implications for the system as a whole. … What is exciting now is work moving beyond individual practices to look at bundles or complexes of practices that lets practice theory move beyond the immediacy of action and to also tackle large social phenomena, like socio technical systems. This is about recognizing that many things we do, including sustainable consumption, energy use, eating food, or driving occur only in relationship with multiple other practices. New

> concepts have emerged over recent years to signal this shift – complexes of practices, constellations of practices, systems of practice. The terminology will hopefully settle out, but what matters is they represent moves to comprehend how apparently large social phenomena are made from the same social stuff, produced, reshaped and reproduced through social practices.

So, unlike the MLP, which places technology at its heart, Social Practice Theory zooms in on the actions of people.

One contribution Social Practice Theory attempts to make is to explain that what people do is never simply reducible to attitudes or choices, or indeed to anything simply individual or rational. Instead, 'doing' something is almost always a performance. Another contribution relates specifically to technological diffusion. Gordon Walker (interview with lead author, 2016) remarks that:

> Social practice theory de-centers technology, and it explicitly recognizes processes of change and always sees them as deeply integrated with social processes and very often mundane everyday shared conventions of living and doing and working and so on. It's very powerful and often says technology is just a piece of a bigger story. You don't start from the technology; you start with the activity or practice and see how multiple technologies and materialities are integrated into practice entities and in practice performances.

A final contribution is that practices can come to mutually align, depend upon or support each other, creating 'systems' or 'circuits' of practice. Marianne Rygaug (interview with lead author, 2016) emphasizes that:

> I have always liked the term 'circuits of practice' because it shows how practices are interrelational, related to one another. They affect other practices, like an evolving ecosystem.

These circuits of practice can both empower or constrain technological diffusion.

Social practice theory is not without its critics. One drawback is that it tends to treat many practices as the 'same' despite variation over time or even space. Tim Schwaren (interview with lead author, 2016) cautions:

> Social practice theory is very good about practices over time, less so about space, spatial differentiation, and spatial structure.

John Urry (interview with lead author, 2016) claims that practice theories tend to overemphasize agency and downplay structure:

> Social practices can be trivial, it's systems change that matters.

The approach does not always therefore adequately describe broader systemic forces affecting technology. Lastly, Maouzelis (1993) writes that approaches centering their analysis on social practices often disconnect themselves from the actors that produce them, reflecting a view that practices do not have a single creator, but rather a class or group of articulators. This implies that social arrangements have no overall author, leading to what Maouzelis terms a risk of the 'death of the subject'.

Discourse Theory

Discourse Theory or discourse analysis integrates concepts from a very wide range of disciplines. For analysts working in this area, the term 'discourse' means a 'historically emergent collection of objects, concepts, and practices' that 'mutually constitute' each other to cohere into stable meaning-systems (Doulton and Brown, 2009). A discourse refers to a collective way of comprehending the world that is consistent with the broader use of the culture concept in various fields.

Situated at this interdisciplinary nexus, a variety of themes is apparent. Discourse analysis attempts to unveil the 'thought collectives', 'regimes of truth', or 'grids of intelligibility' behind how people, or institutions, think and act. Foucault describes this intersection as the ritualization of power into a truth regime and contends that '[e]ach society has its regime of truth, its "general politics" of truth: that is, the types of discourse which it accepts and makes function as true; the mechanisms and instances which enable one to distinguish true and false statements' (Foucault, 1980: 131). According to this view, the process of adopting a new technology is not about a singularly coherent system of ideas and beliefs with unified ideological schemes. Instead, narratives of technology and diffusion are replete with contradictions and are continually (re)produced and negotiated as people experience them (Rafey and Sovacool, 2011). Analyzing sociotechnical discourse, then, often requires examining the 'argumentative structure in documents and other written or spoken statements' that provide insight into the interplay of language, identity, policy and technology (Hajer, 1993: 44).

Viewing technology through a discursive lens has significant benefits, understanding technology as more than instrumental, black-boxed objects. Discourses do not simply describe human relationships with material artifacts but actively structure these relationships by way of models of and for action. Thus, discourses do not merely float ephemerally like ghosts around various technologies or their actors, but instead are situated within specific organizations, crystallizing into practices and ways of reasoning (Escobar, 1995). Hajer (1993) likewise argues that narratives cohere into a sort of 'discursive coalition', which ties institutions and ideas together around particular shared conceptions of reality. Discourse Theory reminds us that discourses define possibilities and frame problems, simultaneously forming the context in which phenomena are understood and presenting solutions to the problems that result.

Notwithstanding its utility, researchers have also noted the limitations of Discourse Theory. Because it looks at the interface of technology, language, and meaning – as well as how the material world becomes tied to institutions, decision-makers, and even ideology and hegemony – discourse analysis can lack coherence (Hajer, 1995). Discourse analysis can also become trapped in descriptions of systems of meaning rather than providing explanations of how and why the systems change. Another limitation is that competent analysis of discourse demands an interdisciplinary understanding that many scholars lack, even in teams. For example, Hajer (1995) suggests that a comprehensive discourse analysis of acid rain would require expertise in mathematics and economics (cost and abatement techniques), science (ecology and biology), social repercussions (sociology and history) and ethical questions of fairness

and attribution of blame or responsibility (philosophy and law). Lastly, because discourse analysis is about deconstructing thoughts and language, a legitimate question arises as to when it ever ends, when deconstruction can stop.

Domestication Theory

Arising from STS, as well as anthropology and consumption studies, Domestication Theory describes how particular technologies or technological artifacts become integrated into daily routines and lifestyles, how they enter people's lives, and what symbolic meaning they come to possess (Haddon, 2011). Or, as Silverstone claims, domestication involves human agents learning to digest and appropriate a technology: 'a taming of the wild and a cultivation of the tame' (1994: 12). New technologies become domesticated, a process of transformation that goes from seeing an artifact as radical, exciting, unfamiliar or possibly even dangerous, to seeing it as routine, mundane and an ordinary part of life.

The theory posits that the process of domestication involves four sequential parts or phases: appropriation, objectification, incorporation and conversion (Silverstone and Hirsch, 1992). Appropriation occurs when an artifact, product, or process is sold to an individual or household that becomes its owner. Objectification is the process of that owner beginning to use the technology, placing it in a particular place or on display. Incorporation is the technology becoming more integrated into everyday life, routines and practices. Conversion happens when that technology starts to shape relationships with users and people outside of the household, i.e. by expressing a particular lifestyle or status symbol. Lie and Sørensen (1996) further demarcate three relevant activities: cognitive work, which includes learning about the artefact and the development of new competencies, symbolic work, which refers to sense-making and the articulation of new interpretive categories, and practical work, in which users adjust everyday routines and practical contexts.

Domestication Theory can reveal the complicated cultural dynamics in which users come to own, use, modify and appropriate technology. This is a helpful antidote to frames of thinking that look at products in technologically or economically deterministic ways, such as Rogers's (1976) diffusion of innovations theory. Furthermore, the theory is useful for its emphasis on the 'moral economy of the household', a special space where technologies are mediated and adapted within the home, in contrast with larger technological systems (Silverstone, 2006). Lastly, the theory can examine the catalysts and aspirations leading people to adopt or use a technology in a particular way, but also constraints and pressures that inhibit adoption (Haddon, 2011).

Weaknesses of the approach include a tendency toward reductionism. As Silverstone and Haddon (1996: 3) comment, 'Design and domestication are the two sides of the coin of innovation. Domestication is anticipated in design and design is completed in domestication'. This takes the limited view that adoption can be reduced to the two dimensions of technical design and user adoption, and it ignores broader, more structural elements of politics or infrastructure. Furthermore, if the strength of Domestication Theory rests on giving context to the decisions made by users and adopters, then a drawback is that one can always add more context (Haddon, 2011) creating an

ever-moving target. Similarly, Domestication Theory's focus on households is inhibited by the fact that the home is not the only place where sociotechnical change occurs. Technologies that bridge the public-private divide, such as computers at the office or public phones or radio, don't fit neatly with the theory.

Large Technical Systems

The theory of Large Technical Systems (LTS), also called by some the 'social science systems approach' to technology (Hirsh and Sovacool, 2006), offers an approach to explaining how humans organize and consolidate disparate materials or functions to maximize the efficiency of a given technique, process or goal. Systems are 'coherent structures comprised of interacting, interconnected components' ranging from simple machines, such as a power generator or a telephone, to regional electric supply networks and massive telecommunications complexes (Hughes, 1983: ix–x). In other words, systems are comprised of related parts and components that become ordered, integrated and coordinated. These components are connected by a network, or some type of structure, that allows each node to be centrally controlled. When these different constellations of components align, systems successfully diffuse.

LTS theory suggests that to achieve such operations and control, diffusion is a simultaneously social and technical process in at least two senses (Hughes, 1987). First, systems require social institutions and technical artifacts to function. For example, the electric utility system contains social institutions such as regulatory bodies and financing firms. At the same time, it encompasses technical artifacts such as electric generators, transmission substations, and cooling towers. Second, systems possess both physical and immaterial components. The electric utility system refers not just to material artifacts such as steam turbines and distribution wires but also to immaterial or epistemic elements, such as the knowledge needed to repair a broken generator or to construct a new transmission line. Hughes uses this epistemic element of the electric utility system to explain why such systems vary among geographic regions: the different sociotechnical environments in Britain, Germany, and the U.S. produced distinct types of electric utility networks.

The LTS approach helps to reveal that technological artifacts must be understood in their societal context and that the different values expressed by inventors, managers and users shape technological change (Giere, 1993). This makes it a theory with broad applicability. Richard Hirsh (interview with lead author, 2016) explains:

> People have employed and added to Hughes' systems approach for decades, but overall it remains a general methodology that I believe can be used, justifiably, for explaining the interaction between many actors involved in the creation and management of large technical enterprises. Some academics have argued that the approach remains too all-encompassing to be truly beneficial. But I think its great benefit is simply to emphasize that the motivators of technological change extend beyond the technical realm and have origins in the social world. Too often, technoscience practitioners and scholars do not understand this basic truth.

Furthermore, LTS emphasizes momentum or path dependency. A system's ability to continue along a given path results from the actions of numerous stakeholders, such as educational and regulatory institutions, outside investors, and industry workers and managers

(Cowan and Hulten, 1996). In concert, these elements promote business as usual and the outward show of a large degree of momentum. In other words, 'future choices were shaped by those who chose first' (Kirsch, 2000: 12). Dijk and Yarime (2010) argue that such path dependence can arise from both changes in consumer preferences (on the 'demand side') as well as changes in technology (on the 'supply side'). In addition, the theory's focus on system evolution highlights the interoperability of technical (and social) mechanisms. Hughes argues that each module of the system must be designed to interact harmoniously with the characteristics of the others. The theory lastly proposes that LTSs emerge and diffuse though a set of sequential phases: invention, development, innovation, technology transfer, system growth, momentum and style.

Despite its potential to uncover the sociotechnical aspects of diffusion, the LTS approach has not remained immune from criticism. Winner (1993) notes that the LTS and related approaches tend to disregard the dynamics evident in technological change beyond those revealed by immediate interests, problems, and solutions of specific groups, especially system builders. Gingras (1995) argues that conflating the social and technical as 'the same' collapses into the idea that 'everything is in everything.' Grint and Woolgar (1995) comment that the notion that values are 'built into' technology implies that technology can be neutral until such time as political or social values are attributed to it. Attributes such as interests and values are assumed to be straightforwardly available to the analyst, who can ignore interpretive work that goes into rendering the motives of social interests. Rutherford and Coutard (2014) write that LTS thinking – by its nature – emphasizes large, centralized, often supply-side infrastructure but can neglect aspects such as agency or change, as it sees agents as constrained within national and international structures.

Social Construction of Technology

The Social Construction of Technology (SCOT) holds that technology emerges in society as a 'seamless web' (Bijker and Pinch, 2012). Drawn from the sociology of scientific knowledge, SCOT emphasizes that new technologies emerge only in a constitutive nature with individual users and other social factors. SCOT draws heavily from the 'empirical program of relativism' (Collins, 1983), which argues that knowledge – even that previously regarded as true or false – involves material resources, psychological processes and social practices.

Within this framework, four important conceptual elements have been developed: relevant social group, interpretive flexibility, closure and stabilization, and technological frame. A relevant social group includes the actors and organizations that share a relationship with and set of meanings attached to a particular technology (Pinch and Bijker, 1984). Social groups play a critical role in shaping and defining the problems that arise during the development of an artifact; social groups thus give meaning to technology and define the problems facing that technology (Bijker, 1993). Connected to the concept of a relevant social group is interpretive flexibility, which suggests that differing interpretations of technological artifacts are available. Diffusion and technological change become 'heterogeneous' processes because their meaning, rather than being fixed, is interpreted and negotiated by those social groups

connected to them (Klein and Kleinman, 2002). Closure and stabilization occur when a consensus emerges that problems arising in the development of technology have been alleviated. These problems need not to have been solved in the common sense of the word; rather, the relevant social groups have perceived those problems as solved (Misa, 1992). The idea of a technological frame, similar to the concept of paradigm, refers to the system of meanings (e.g., goals, concepts and assumptions) that emerges in the network of relationships; it comprises all elements that influence the interactions within relevant social groups and lead to the attribution of meanings to technical artifacts (Bijker, 1997: 123).

Among the many advantages of SCOT are the ideas that technologies possess heterogeneity or fluidity and that they extend to the cognitive or social domain. SCOT focuses on how relevant social groups share the same sets of meanings attached to particular technological artifacts. SCOT also centers more on the array of values, methods, goals, tacit knowledge, user practices and testing procedures used by a group of practitioners when developing a particular technology. A second major plus is that SCOT has general applicability to many different types of technology. As Bijker (interview with lead author, 2016) puts it:

> To me, SCOT remains highly relevant and perhaps the best tool analysts have to understand the diffusion or acceptance of a new technology. The combination of relevant social groups, interpretive flexibility, stabilization, closure and frame are concepts that I believe have great explanatory power and general applicability. These concepts are technologically agnostic in the sense that they can apply to any artifact or system you can mention, from the pyramids of Egypt to nanotechnology to water filters in South Africa to hand looms in India.

Furthermore, SCOT helps to reveal how some technologies come to express 'low inclusion', 'obduracy', or 'endurance', that is, how they can come to be perceived as a 'take-it-or-leave-it choice'. This aspect of stabilization contributes to path dependence because users feel forced to accept, rather than to abandon, a system (Hommels, 2005). A final contribution of SCOT is that it understands diffusion or technical change as a socio-cognitive process with evolutionary characteristics. The initial variety of meanings attached to an artifact is reduced through inter-group selection processes and build-up of a shared cognitive frame, usually through a process of variation and selection (Grin et al., 2010).

That does not mean that SCOT is free from reproach. Grin et al. (2010) advance at least three criticisms. First, its focus on agency, practice, social groups, and frames tends towards voluntarism and often-heroic storylines that may obscure other aspects of power or structural embeddedness. Second, SCOT downplays the issues of the impact of a technology on society because of its efforts to open up the black box of upstream development. The heightened focus on design and immediate use is associated with less attention to issues such as extended adoption or impact over time. Third, while SCOT helps highlight flexibility and even the contingency of local practices, it does not as adequately explain larger patterns or commonalities that occur at more aggregated or system-wide levels. Bijker and Pinch (2012) admit that the question of where human agency ends and where nonhuman agency or technological

agency begins is difficult to address. Moreover, they ask that researchers avoid normative statements and refuse to articulate judgments as to whether a given technology is good or bad; instead, they commit to an 'ontological agnosticism' (Bijker and Pinch, 2012: xxiv) – lacking an explicit connection to issues of morality or justice.

Sociotechnical Imaginaries

Having roots in political and social theory as well as STS and discourse analysis, Jasanoff and Kim (2009: 120) originally defined Sociotechnical Imaginaries as 'collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technological projects'. A more recent definition refers to 'collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology' (Jasanoff, 2015a: 4). Sociotechnical Imaginaries differ from Discourse Theory because the latter usually focuses on language whereas the former emphasizes action and performance with materialization through technology. Imaginaries are less explicit and accountable than policy agendas, and unlike narratives, they more directly serve explanatory or justificatory purposes. Imaginaries instead are instrumental and futuristic; they project visions of what is good and worth attaining.

Sociotechnical Imaginaries research prioritizes a focus on the three 'M's of materiality, meaning and morality. In terms of materiality, the theory emphasizes that technologies themselves can act as physical forces that constrain action or enhance an experience. In terms of meaning, technologies can provoke radically different reactions from different stakeholder groups, and in terms of morality, technologies can often have negative impacts on society. Jasanoff notes that the concept 'cuts through the binary of structure and agency: it combines some of the subjective and psychological dimensions of agency with the structured hardness of technological systems, policy styles, organizational behaviors, and political culture' (2015a: 24).

Viewing sociotechnical change in this manner has advantages. It focuses on cultural meanings and the common narratives that vibrant societies often have about who they are, where they have come from, and where they are headed, usually through the interplay of positive and negative imaginations – utopia and dystopia. The theory rejects political determinism and the thought that politics or action is always purposively rational, and it emphasizes a performative element to technology that 'unlike mere ideas and fashions, sociotechnical imaginaries are collective, durable, capable of being performed; yet they are also temporally situated and culturally particular' (Jasanoff, 2015a: 19). Another strength is that by exploring how sociotechnical projects travel from imagination and conception to realization, the analysis of imaginaries helps to uncover the process of extension, where particular narratives or ideas gain traction, acquire strength, and cross scales (Jasanoff, 2015b).

These advantages come with some admitted disadvantages. As with discourse analysis, the study of imaginaries can become limited to descriptive cultural analysis rather than including the full interplay of actors, social structures, and institutions in the explanation of sociotechnical change. Furthermore, research on imaginaries can look forward

or backward; some can erase or reinvent the past, others can look entirely to the future, sometimes the distant future. This dialectic between past and future is difficult to capture. Another problem is one of scale: where does an imaginary end, and where does it in fact begin to differ spatially or by different stakeholder groups? Although research on imaginaries can help to tease apart the relationship between collective formations and individual identity, the line between the two is not always bright. Finally, imaginaries have an inherently subjective element, making them fragmented or unique: one person's utopia can be another's dystopia (Sovacool and Ramana, 2015).

Actor-Network Theory

Actor-Network Theory (ANT) seeks to offer an explanation for how scientific or technical objects (usually called 'artifacts') are integrated with social relations. ANT proposes that the social alliances in which technology are constructed are bound together by the very artifacts they create, which in turn have agency in heterogeneous, sociomaterial networks (Latour, 1999). ANT examines the facts, machines, people and bureaucracies that must be aligned, molded and disciplined to create technological development and acceptance. Latour (2005) writes that ANT investigates the nature of actions related to technology, the nature of objects and hardware, and the nature of facts and knowledge. Thus, it is a relational 'sociology of associations' or a 'sociology of the social.'

Although less structured and less systematically laid out than some of the other theories mentioned in this study, one can infer at least two key themes within the ANT literature relevant to technological diffusion and change: network assemblage and translation. By focusing on the relational aspects among engineers, inventors, analysts, politicians, artifacts, manufacturing techniques, marketing strategies, historical context, economics and social and cultural factors, an assemblage highlights that technology emerges and diffuses through an interstitial milieu of material objects and immaterial epistemologies. Neither inevitable nor static, technological change is the product of complex relations of alliance and conflict among divergent actors and their interests. As network assemblages gain credibility or solidify, they move through what Callon (1986) terms the process of translation: problematization, framing an assemblage as a vital way of addressing some pressing problem or fulfilling a social need; interesessment, the strengthening of the network between actors and other support structures; and finally the enrollment and mobilization of allies that anchors them to the network.

One of the recognized strengths of ANT is that it emphasizes the importance of human-nonhuman symmetry – i.e., the inclusion of nonhuman actors in treatments of science and technology. For example, a study of the French electric vehicle included electrons, motorists, accumulators, researchers, manufacturers, government departments and engineers all as 'actors' (Callon, 1985). By doing so, the author intended to create a radical reconceptualization of how social scientists conceive the social and the technical. More abstract than systems theory, ANT assumes that sociotechnical networks subsume science, technology, and other categories. ANT is also skeptical about the existence of any stable social structure, and instead it sees a constantly open-ended interaction among a multitude of actors (MacKenzie, 1999). Additionally, similar to the concept of stabilization in SCOT, ANT recognizes how sociotechnical networks become more obdurate and less reversible over time (Hommels, 2005).

Perhaps the most significant criticism of ANT is that it is too abstract, and it is difficult to tell where a network ends and others begin. Latour (2005) acknowledges that ANT has been accused of two sins: extending politics everywhere, including the inner sanctum of science and technology, and being so indifferent to inequalities and power struggles that it offers no critical leverage. Longstanding concepts in the social sciences – such as social structural categories of class, race, and gender – disappear. By depicting society as a network of networks, analysis of structural inequality and technology becomes practically invisible (Hess et al., 2017). Another shortcoming is that the central concept of actor or actant remains 'an anonymous, ill-defined and indiscernible entity' (Callon, 1999: 192). Within ANT scholarship, a person, a plant, a machine, a weather system, or even a germ are all referred to as 'actors' (Whittle and Spicer, 2004). By looking closely at the organizational outcomes from technical systems, ANT is less useful for understanding how or why similar technologies can be interpreted or used in different ways (Bijker and Law, 1992).

Social Justice Theory

Contemporary Social Justice Theory intertwines aspects of earlier religious and naturalist conceptions of justice. It possesses at least four logics: distributive justice, procedural justice, cosmopolitan justice and justice as recognition (Sovacool, 2016). Modern notions of 'distributive justice' deal intently with three aspects of distribution: what goods, such as wealth, power, respect, food or clothing, are to be distributed? Among what entities are they to be distributed (e.g., living or future generations, members of a political community, or all humankind)? And what is the proper mode of distribution – is it based on need, merit, utility, entitlement, property rights, or something else? Modern notions of 'procedural justice' emphasize an entirely different aspect of justice: who gets to decide and set rules and laws, which parties and interests are recognized in decision-making? By what process do they make such decisions? How impartial or fair are the institutions, instruments, and objectives involved? Procedural theories of justice are all oriented toward process – with the fairness and transparency of decisions, the adequacy of legal protections, and the legitimacy and inclusivity of institutions involved in decision-making. 'Cosmopolitan justice' theorists argue that justice principles – such as those from distributive and procedural justice – must apply universally to all human beings in all nations. Cosmopolitan theories of justice acknowledge that all ethnic groups belong to a single community based on a collective morality. 'Recognition justice' scholarship challenges the predominantly accepted discourse of distribution and procedure, suggesting a terminology of distributive vs. post-distributive (or recognition) aspects of justice. Table 2 provides a summary of these different applications.

The benefit of a justice-centered approach to sociotechnical change is relatively direct and simple: It asks us to think about technology and systems as more than simply hardware, and in moral or judgmental terms. Put another way, we need to reframe or repoliticize what technologies are (Sovacool et al., 2016). Technologies can be mechanisms of resource extraction that transfer wealth from developing countries to developed ones, or systems of segregation that separate negative harms from the positive attributes across

Table 2. Constituents of Modern Social Justice Theory.

Concept	Definition	Major influence(s)
Justice	The act of being morally right or fair, and providing equal rewards for equal merit	Plato, Socrates, the Bible, Thomas Hobbes, John Locke
Distributive justice	Equitable distribution of social and economic benefits and burdens within and across different generations	John Rawls, Ronald Dworkin, Brian Barry
Procedural justice	Adherence to due process and fair treatment of individuals under the law	The Magna Carta, Edward Coke, Thomas Jefferson
Cosmopolitan justice	Universal respect for individual human rights regardless of one's identity	Immanuel Kant, Charles Beitz, Amartya Sen, Martha Nussbaum, David Held, Thomas Pogge, Peter Singer
Justice as recognition	Tolerance and respect for the vulnerable or otherwise marginalized	Nancy Fraser, Gordon Walker

different classes of consumers. Thus, new technologies can transfer what were once customary public resources into private hands, concentrate political power, facilitate human rights abuses, become intertwined in national discourses of revitalization or national security, and validate distinct approaches to economic and social development. Social justice theories also point to the empirical problem of analyzing structural inequality, a problem that is often absent from other approaches to technological systems.

Not all streams of justice scholarship align with each other. Some forms of justice, such as those based on human rights (cosmopolitanism) or recognition, argue for a hierarchy of principles. They are based on a 'lexical' or 'lexicographical' ordering of needs so that the most vulnerable – those already marginalized or those threatened by human rights abuses – must be totally satisfied before one addresses other injustices (Gordon, 1980). By contrast, distributive justice theories tend to be about the utilitarian analysis of costs and benefits, whereas procedural theories say less about distribution and are almost entirely about process (Sandel, 2009). Moreover, many of these justice themes are anthropocentric; they put the (justice) needs of humans above say other nonhuman species. Lastly, absolute or deontological forms of justice theory do not respect cultural relativism, treating all humans and therefore culture as the same, holding humanity to an absolute notion of morality, insensitive to local variation or preference.

Sociology of Expectations

The Sociology of Expectations (sometimes called 'expectation studies' or the 'sociology of anticipation') assesses how visions or expectations about future benefits affect and structure technology. The theory posits that expectations are a key part of the process of technological innovation rather than a latent or unintended side effect (Borup et al., 2006). As Harro Van Lente (interview with lead author, 2016) puts it:

Table 3. Visibility and maturing in expectation 'hype cycles'.

Phase of cycle	Visibility
Technology trigger	Low
Expectations peak	High
Trough of disillusionment	Low
Slope of enlightenment	Improving
Plateau of productivity	Level, modest

> Expectations analysis is not psychological but sociological: expectations provide a force that cannot easily be ignored.

Expectations of technology are a common resource and in this sense structure its development, providing legitimation, coordination and guidance (Van Lente, 1993, 2012). Nightingale (1998) calls technological optimism and fantasy an elemental part of the 'cognitive' dimension of innovation. Selin (2008: 1891) adds that 'the expectations, hopes, fears, and promises of new technologies are not set apart from, nor layered on top of scientific and technological practices, but are, rather, formative elements'.

A variety of concepts currently ground this theory. One is the notion of a rhetorical vision: advocates of a particular technology will often hold shared fantasies about it. These will have specific dramatic elements such as plot lines, stories and characters. This act of providing a narrative enables groups of people to come to a 'symbolic convergence' about that part of their common experience (Sovacool and Ramana, 2015). Another is the notion of a 'promise – requirement' cycle. Promises and expectations of emerging technologies become part of an agenda-setting process that germinates into a requirement for engineers and other actors, giving them a 'mandate' to develop 'their' technology (Bakker et al., 2011). As Gordon Walker (interview with lead author, 2016) adds:

> The sociology of expectation is both a different and important approach – it gets into understanding the power of ideas and discourses, and how they become embedded in actions.

A final related concept is that of a 'hype cycle' or 'promise-disappointment cycles', an admittedly simple but visual representation of the ups and downs of technological expectations. Here technologies are seen to move along a path from a trigger to a peak in expectations, then plummeting into a trough of disillusionment before eventually giving rise to a range of somewhat more modest applications, as Table 3 suggests.

The approach has been credited with multiple benefits. At its core, it offers a semiotic and symbolic understanding of sociotechnical change: diffusion is intimately tied to cognitive elements such as values, attitudes and expectations. John Urry (interview with lead author, 2016) argues that such a focus is instrumental in understanding large classes of human behavior:

> By focusing on the unarticulated reasons for why people do things, theories like the sociology of expectation help us better understand the invisible or the innate, things that must be inferred rather

> than directly observed. You can interview people left and right, but never hear the real reason why they fail to adopt a particular technology such as an electric vehicle or a mobile phone.

The approach also helps to explain why planners and promoters will become enthralled by the possible future benefits of a new technology and are willing to accept present costs to realize them. Put another way, they will overestimate the advantages and discount its future costs in the absence of knowledge about current economic or technical compatibility; reality of present risks and costs are discounted by the unrealized possibilities of future gain, something Byrne and Hoffman (1996) call thinking in the 'future tense'. The theory also demonstrates how expectations are continually 'constitutive' or 'performative' in defining roles and in building obligations to support a particular technology. Lastly, the theory helps to explain why many rhetorical visions are strategically contradictory: visions are malleable, allowing actors attempting to build support to avoid discussing technical details that may expose the contested nature of their own agenda.

Although there are parallel accounts, such as the closely related literature on promissory discourses in the biosciences and the more distant literature on the performativity of economics, the first limitation to the approach is that it has been applied so far only to a particular type of discourse, future-oriented deliberations, and also a particular type of technology: novel, new, and emerging artifacts (Borup et al., 2006). This makes the theory fairly narrow in scope and inapplicable to other types of deliberation and to more established, commercially successful technologies. Also, expectation analyses so far describe the expectations but do not assess ways to avoid or minimize the social costs of exaggerated hype (Van Lente et al., 2013). Brown and Michael (2003) highlight the difficulty of generalizing findings from expectations studies because they are so context dependent and unique. As they note, accounts are performative: They serve to enable some technoscientific worlds and to disable others, which means they must always be situated in their own special temporal context. Moreover, expectation narratives vary according to the type of technology being discussed, the strategies of actors, and broader public perceptions.

Sustainable Development

Sustainable Development is an umbrella term for multiple normative criteria used in the fields of development studies, economics, law, legal studies and jurisprudence that are used to assess the pros and cons of sociotechnical change. Influenced by the Stockholm Declaration on the Human Environment endorsed by the international community in 1972 (Strong, 2001), the 1980 World Conservation Strategy (IUCN et al., 1990), and (most famously) the 1987 Brundtland report (World Commission on Environment and Development, 1987), these ideas have become normalized in international and national law. They attempt to evaluate the broader economic, environmental or social impact of technologies as they change and diffuse.

Traditionally defined as balancing two societal goals – satisfying the needs of the present and those of future generations – recent work has argued that sustainable development includes also elements of prudence, intergenerational equity, precaution, responsibility and governance. Environmental prudence refers to the duty of states to

ensure the sustainable use of natural resources. It means that states have sovereign rights over their natural resources, that they have a duty not to deplete them too rapidly, and that they do not cause undue damage to the environment of other states beyond their jurisdiction. Equity can describe the right of future generations to enjoy a fair level of common patrimony, as well as the right of all people within the current generation to have fair access to the entitlement of the Earth's resources (Dobson, 1999; Speth, 2008). Precaution is best exemplified in the precautionary principle, predicated on anticipating harm before it occurs and on preventing or minimizing such harm even when the absence of scientific certainty makes it difficult to predict the likelihood and magnitude of the harm (Raffensperger and Tickner, 1999; Ricci et al., 2003). Good governance, similar to Social Justice Theory, centers on democratic and transparent decision-making processes and financial accounting, as well as on effective measures to reduce corruption and respect for due process.

Like Social Justice Theory, the value to the Sustainable Development approach is that these different criteria demand that analysts evaluate the actual contribution that different technical systems make as they diffuse or could diffuse. Do they do more harm and good, and do they have a particular set of winner and losers? More specifically, the following types of questions can be raised whenever one considers the desirability of a particular technology from a sustainable development perspective:

- Does it injure the environment?
- Does it degrade the social structure of local communities?
- Does it damage traditional culture?
- Does it benefit local economies and utilize local resources?
- Does it provide education or local participation?
- Does it promote efforts aimed at conservation and efficiency?
- Does it foster the well-being of future generations?

While the importance of such questions may appear obvious to some, many assessments continue to ignore the entire range of possible impacts a given technology or sociotechnical system can have on society.

The drawback to such an approach is that it is, of course, ideal – many technologies will satisfy few, if any, of the criteria, and perhaps none will satisfy all criteria. It's also hard to answer these questions without rich, interdisciplinary studies that may be time consuming and costly to implement. The answers will be entirely context dependent on a mix of endogenous and exogenous factors, producing a great variation in whether sociotechnical change is 'good' or 'bad' for sustainable development – it will depend on where as well as when.

Values Beliefs Norms Theory

Values Beliefs Norms (VBN) Theory comes from the domains of psychology and environmental sociology. The theory is in many ways an extension of Schwartz's (1977) work on 'normative influences on altruism' and his later work on the structure of values. Jackson (2005: 45) calls it a 'theory of pro-environmental consumer behavior'. VBN

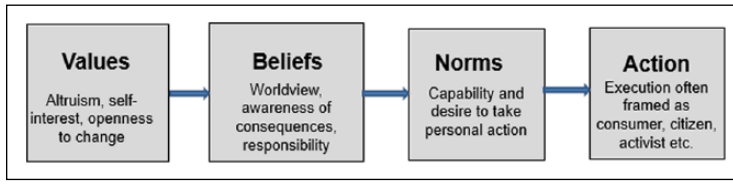

Figure 4. Values Beliefs Norms Theory chain of causal influence.

researchers attempt to describe and account for the various symbolic and reasoned components of consumer choices about the technologies or environmental practices they adopt. The theory situates itself as a strong critique of rational actor theory, arguing that decisions are often not based solely on reasoned action. As Dietz (2015) and Dietz and Stern (1995) note, many consequential actions are the result of habits and have complex motives that do not always reflect a reasoned weighing of tradeoffs, and the influence of values on decision-making is often constrained by what is practical or satisficing.

At the core of the theory are the notions of 'values' and 'norms'. Unlike a preference, a value is a general, non-negotiable principle that causes an actor to prioritize one thing over another; values provide 'a standard for assessing our behavior and that of others' (Jamieson, 2010: 78). Core values rarely change over short time spans, and when they become a factor in sociotechnical change, the importance of all other variables tends to become de-emphasized. Values can be centered on the environment, or biospheric, such as an affinity with nature or harmony with other species; they can be humanistic, such as desiring social justice or equity for all; and they may even be self-interested, such as a desire to protect one's family or to respect one's elders (Steg et al., 2014; Stern et al., 1998). The theory proposes that values affect beliefs, which in turn affect personal norms and action in a sequential fashion (Dietz, 2015), as Figure 4 summarizes.

Among the benefits of the VBN approach is to highlight the influence of descriptive and injunctive personal norms on catalysts for individual action. The theory can also account for variability in values and norms. Paul C. Stern (interview with lead author, 2015) remarks that according to the theory:

> Consumer behavior is strongly influenced by financial costs, government policies, information gathering constraints, social influences from friends, advertising, etc. Depending on the behavior and its context, VBN variables can have greater or lesser importance.

Also, the theory allows for the analysis of a range of values. Altruistic values are generally the most strongly predictive concerning the adoption of environmentally significant technology with the populations and behaviors studied. Motives can also be altruistic, as benefits to others can be prioritized over self-interest (Anable et al., 2006). The theory demonstrates how cognitive processes can serve to influence goal-directed behavior, and it emphasizes the salience that habit and routine can both occasionally have in restricting, provoking, and moderating pro-environmental behavior (Henry and Dietz, 2012).

One potential drawback to the theory is that it is a somewhat simplistic and unidimensional approach to describing and interpreting technological change. Jackson (2005) argues that simplicity makes VBN theory readily applicable to many different contexts,

but as a result its predictive power is limited. For example, in empirical studies explained variance is reported to be below 35%; that is, explained variance changes dramatically depending on the kinds of behavior studied. Furthermore, the theory has much lower explained variance with behaviors that are difficult or expensive. Dietz et al. (2005) note that the theory has also tended to restrict its scope to individuals and the role of citizens and consumers, leaving out other scales of action.

Lifestyle Theory

Lifestyle Theory offers yet another perspective mentioned by respondents. In this context, the concept of a 'lifestyle' can be understood either as a 'way of living' or as an 'indication of an individual's character' (Axsen et al., 2015: 193). Many researchers in economics, transportation and other fields have conducted forms of 'lifestyle analysis' by segmenting consumers based on demographic aspects, such as income, gender, travel patterns or housing type; however, Lifestyle Theory is distinguished as based in sociology and an individual's concept of self. A lifestyle is 'a more or less integrated set of practices which an individual embraces [to] give material form to a particular narrative of self-identity' (Giddens, 1991: 81): Lifestyles come to cement routines, habits, and orientations with an overall unity that 'connects options in a more or less ordered fashion' and eliminate some actions as 'out of character'.

One of the primary approaches of lifestyle analysis is uniqueness: The processes of identification and lifestyle construction will be special to each individual, with most expressing an affinity or preference. Giddens (1991) suggests that in a modern world subject to change and therefore lacking the clarity of traditions, an individual is likely to create a unique identity based on multiple practices and engagements. Closely linked to identity, one's 'lifestyle construction' is a dynamic and ongoing process, with an individual lifestyle potentially changing as a person grows, enters new life stages, makes new friends, and receives feedback – such events or transitions can induce a period of liminality, where the individual is 'betwixt and between' lifestyles and identities, and may be particularly open to considering or trialing a new lifestyle or identify (Turner, 1969). For example, individuals in a state of liminality have been found to be statistically more likely to try out a new technology or to consider the adoption or strengthening of environmentally-oriented values (Axsen et al., 2012; Axsen and Kurani, 2013). A final theme is reflexivity: Individuals create their lifestyles in a reflexive process of managing behaviors while negotiating tensions among conflicting values that can also shift across time or context. Some individuals can sustain a state of relative liminality and are thus open to new lifestyles for much of their lives. Other individuals might be relatively static, habitually enacting their present self-concept through their lifestyles.

One strength of Lifestyle Theory is that it emphasizes that individuals usually engage in multiple lifestyle actions that reflect and perform different aspects of self, and these actions can motivate users to adopt a technology beyond their present dominant lifestyle or identity. Lifestyle Theory can complement other behavioral theories and constructs, e.g. where habit, symbolism, and other non-hedonic factors can play an important role in cognition and therefore technological diffusion. A secondary benefit is that unlike Social Practice Theory, where the unit of analysis is the practice, Lifestyle Theory reorients the discussion back to the individual. However, as Axsen et al. (2012) explain, many

practices are not consciously related to identity, and therefore conscious reflection is context dependent. For example, while purchasing a new vehicle might be a 'high-identity' event, brushing one's teeth on a given morning is likely to be habitual and private, and thus a relatively 'low-identity' behavior (Shove and Warde, 2002).

Criticisms of Lifestyle Theory begin by noting its overly reductionist notion of the self. For example, Atkinson (2007) argues that self-identity for Giddens is too 'internally referential' and that it is too severed from broader external social forces such as kinship or sense of place. Cockerham (2005) comments that lifestyle approaches focus only on individual behavioral patterns rather than actions of many humans in concert, and that they can also fall prey to 'upwards conflation', a flaw whereby focusing on individuals obscures more collective and organizational forms of action. Shove (2010) provides a particularly strong critique of Lifestyle Theory, arguing that unduly individual-focused behavioral theories can further encourage policymakers to neglect the changes in 'structure' (policy, institutions, and culture) needed to stimulate significant pro-environmental and pro-societal changes. Lastly, Korp (2010) warns that by focusing on the merits of individual lifestyle, the theory can 'blame' some individuals by attributing responsibility to those deemed to have inappropriate, unhealthy, or unsustainable lifestyles.

Unified Theory of Acceptance and Use of Technology

The Unified Theory of Acceptance and Use of Technology (UTAUT) is itself an integration of eight other theories, among them Ajzen's (1991) theory of planned behavior, Davis's (1989) technology acceptance model, and Rogers's (1995) innovation diffusion theory. UTAUT was introduced to explain the adoption of new technologies in the workplace, and it appears primarily within management science and information studies, especially looking at the update of computing systems within offices.

In its initial form, UTAUT hypothesizes that four main elements – performance expectancy, effort expectancy, social influence, and facilitating conditions – determine whether a user would adopt a new technology in the workplace (Venkatesh et al., 2003). UTAUT proposes that perceived usefulness (performance expectancy), perceived ease of use (effort expectancy), and social influence (norms) affect technology use via behavioral intention, whereas facilitating conditions directly precede behavior. In addition, individual difference variables such as age, gender, experience and voluntariness can influence the four key UTAUT elements. The theory has been augmented with an additional three key elements shown in Figure 5: hedonic motivation (a key predictor from consumer behavior research), price value (a key predictor from economics) and habit (a key predictor from sociology) (Venkatesh et al., 2012). UTAUT theorists also removed voluntariness of use as a moderating factor.

One key benefit to UTAUT is that it is already integrative, synthesizing eight disciplines and concepts. Quantitative studies have confirmed its predictive or explanatory power: Applied to the domain of office computers and information systems, its originators argued that UTAUT explained about 70 percent of the variance in behavioral intention to use a technology and about 50 percent of the variance in that technology's use (Brown and Venkatesh, 2005). As another meta-survey noted, UTAUT 'is believed to be

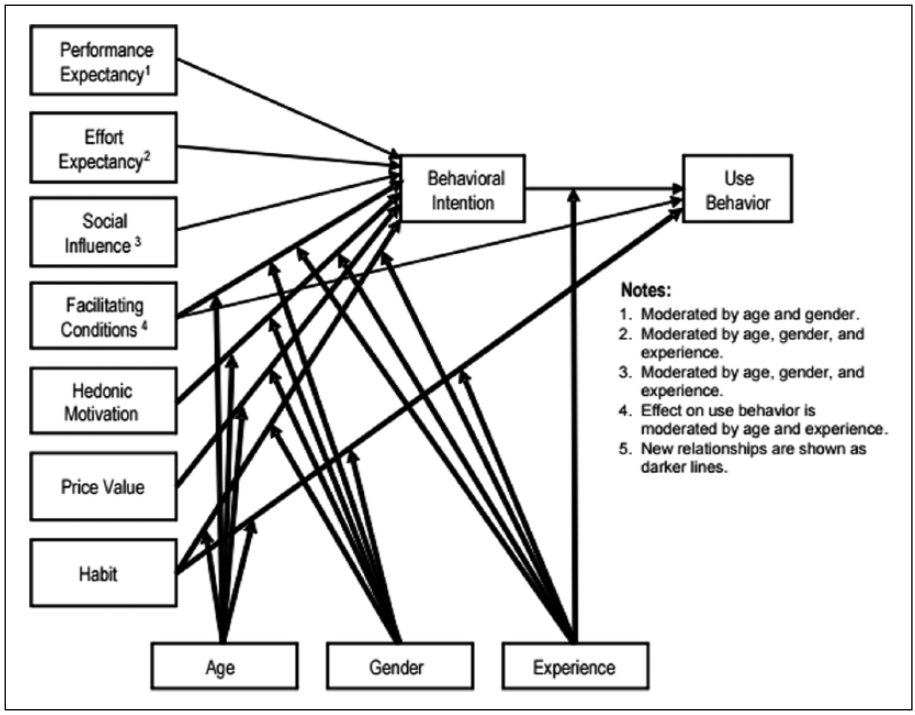

Figure 5. The Modified Unified Theory of Acceptance and Use of Technology (UTAUT).
Source: Venkatesh et al., 2012.

more robust than other technology acceptance models in evaluating and predicting technology acceptance' (Taiwo and Downe, 2013).

This is not to say the theory is without shortcomings. For one, UTAUT relies on a relatively narrow conception of the user, such as the office worker and subsequently the purchaser or adopter of technology. This analytical focus ignores other types of users such as legitimators, inventors or intermediaries (Schot et al., 2016). Also, UTAUT does not readily specify the relative weight and significance of its various constituent elements, nor does it capture qualitative aspects of acceptance difficult to measure outside of formal organizations, such as interpersonal social networks or informal learning (Im et al., 2011; Straub, 2009). Moreover, UTAUT focuses on the adoption of the new, but not the retention of the old – creating somewhat of a deep-seated bias and preference for newness and positive stories of change.

Assembling and disassembling theories: Typologies and lacunae

Continuing to draw from both the original interview material and suggested literature, this section of the paper assembles and disassembles these fourteen theories into two typologies, and it examines lacunae. We use the term 'type' in the sense of Weberian

ideal types (Weber, 1978). The first typology is based on the theory's analytical strategy and empirical emphasis, and the second is based on the theory's underlying assumptions and goals. Although there is overlap between the two approaches, we think it is valuable to discuss both. Finally, the third section discusses elements that may be missing in the fourteen theories.

A typology of analytic strategies and empirical emphasis

In terms of their emphasis, theories can be placed into five categories of where they tend to 'center' their analysis: agency, structure, meaning, relations and norms. The term 'center' is meant to capture that a theory may actually involve elements of multiple types even as it approximates one ideal type most. The term 'agency' covers a range of actors (individuals, organizations and collective actors such as coalitions) and their strategies; 'structure' is used in a broad sense to include macrosocial structure (e.g., class, race, gender) and institutional structure (e.g., social field position); and 'meaning' refers to the semiotic systems (cognitive and normative) that orient action and are changed by it. We use the term 'meaning' rather than 'discourse' to avoid confusion with the Discourse Theory that is one of the fourteen theory categories.

The first set of theories is 'agency-centered', prioritizing the agency of people, individuals, households, or interpersonal decision-making processes as well as those focusing on organizations or stakeholders. According to these theories, agency forms the core unit of analysis, the discussion of motives, and primary scale. Collins (1981), for instance, distinguishes different approaches to agency depending on spatial scales such as individuals, small groups, crowds, organizations and nation-states, as well as temporal scales from seconds and minutes to weeks and months and even years and centuries. Hess (2013: 178) adds that 'agency-based frameworks that focused on constructive or performative processes have come to dominate the sociology of science'. As Figure 6 indicates, agency-centered theories were the most popular in the full sample in Appendix II. According to this classification, four agency-based theories were mentioned most frequently by respondents: Domestication Theory, Values Beliefs Norms Theory, Lifestyle Theory, and UTAUT.

Clearly, agency-oriented strategies of analysis can assume that people are atomistic agents whose action can be explained without deep consideration of structure (Jackson, 2005). Agency-based approaches tend to analyze technology and society independently of social structure or within a constant structure, and they may understand social structure as an outcome of micro-social processes. This focus can create shortcomings and analytical biases, as Jillian Anable (interview with lead author, 2016) explains:

> One significant bias within existing theoretical frameworks is how they privilege both the private consumer (rather than the system) and adoption (rather than usage). There is also a bias towards almost immediate or at least very near term time scales; by definition many theories focus on what people are going to do soon, with a temporality and immediacy to it: a purchase they are about to make, a behavior they need to alter. This creates a series of shortcomings rooted in private consumption rather than other forms or other types of actors,

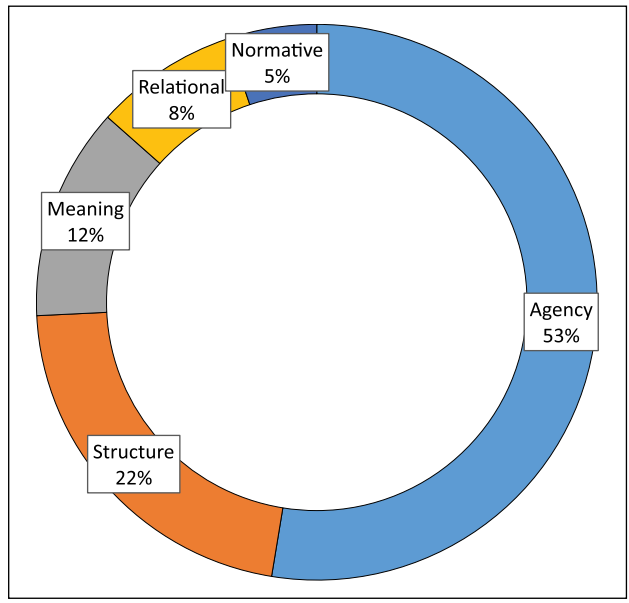

Figure 6. Analytical strategy and emphasis of selected theories among respondents (n = 96).

> focused on early users rather than say second hand purchasers, and emphasizing adoption rather than continued use.

Anable is implying that a broader notion of agency is needed to better illuminate why people use technology.

The second set of theories focus on structure, such as the macro-social, urban, infrastructural, or political environment as their preferred focus. They may also conceptualize structure broadly to include analyses of institutional structure (such as positions of firms in an industry) and relations between technological systems and the natural environment. Although the concept of structure appeared in many of the theories, not many theories could be classified as heavily reliant on structural analysis. One exception is the concept of the landscape in the Sociotechnical Transitions approach, which enables structural analysis that is missing in some of the micro-social theoretical frameworks. Likewise, the analysis of LTS draws attention to societal conditioning factors such as markets and government policy. Mouzelis (1995) notes that the micro-turn in social theory has led to an almost complete neglect of asking questions about bigger entities, reification, or the structural or functional attributes of larger systems. Peter Wells (interview with lead author, 2016) affirms this thinking when he states,

> Many of the things we want to study – technologies, beliefs, values, policies – are embedded in wider social structures and frameworks arising out of other features and pressures.

Marilyn Brown (interview with lead author, 2016) notes that structure-centered theories are needed to offset a theoretical obsession with individual agency. She argues:

> Too much research remains centered on the consumer choice and adoption side of the equation without considering the context of innovation and technology diffusion, which isn't just about information and preferences. As a result of infrastructure investments, consumers in some areas are more able to adopt new technology; this is amplified when multiple products are dependent on a single infrastructure. A good example is credit cards, where you need not only an individual adopter with a card, but retail adopters that will accept them and banks that will process them. In this instance, one needs mutual alignment where consumer adoption is important but so is the broader system. Theories of consumers need to be matched with theories of systems, institutions, and change.

For perhaps these reasons, theories of structure were the second most popular type of theory in the full sample in Appendix II. These theories assume that people are constrained or influenced by external forces frequently beyond their comprehension and control (Jackson, 2005). One structure-centered theory, Large Technical Systems, was prominent within our sample.

These two poles of the theory triangle represent a 'classic divide' in the social sciences with respect to analytical strategies for explaining societal change and social action (beyond the narrower dimension of technology and society). Debates about structure and agency, or the 'paradox of embedded agency', are at the heart of much theory building (Battilana et al., 2009). In the interviews, the topic received much commentary, and we summarize a few of the comments here to show how important the two poles are in the minds of the interviewees. For instance, Paul C. Stern (interview with lead author, 2016) emphasizes that many theories are 'attempts to illuminate parts of the overall system', and Sheila Jasanoff (interview with lead author, 2016) comments that:

> A basic theoretical divide for all social sciences relates to agency and structure. Structure in part determines how human beings behave and interact, but so does agency, which is more manipulatable, mutable, and changing. The key is structure-agency composites, or coproduction. In moments of coproduction, one of the kinds of things that happens is that one's idea of who the human subject is, the subject's identity, changes and with that one's sense of what is mobile and what is fixed and what is changeable and what is not. This existential dance is a reconfiguration of elements that is perpetual and dynamic.

John Urry (interview with lead author, 2016) notes in parallel that:

> Most social science inquiry is about structure or agency, or about things that mediate between the two, the recursive relationship between agency, structure, and practice.

Likewise, Frank Geels (interview with lead author, 2016) states that:

> Within the realm of diffusion, you have two very different families of concepts. One is the family of adoption models, which focus on purchase decisions by consumers and households. Another family is sociotechnical models, which look at the broader system and aspects such as system builders, co-construction and societal embedding of new technologies.

In summary, the distinction between structure and agency represents a continuum of how people act with the broader social and institutional context.

However, such a continuum does not capture the complete range of a theory's analytical strategy and empirical center. The third pole of the social theory triangle focuses on the analysis of systems of meaning. Although all theories to some degree include some analysis of meaning, the theories clustered toward this pole focus on language, symbolism, narratives, performativity, rhetorical visions, and how technologies can co-construct and negotiate meaning for human subjects. The most popular were Discourse Theory, Sociotechnical Imaginaries, and the Sociology of Expectations.

The fourth type was harder to classify; it refers to theories that attempt to apply their focus across agency, structure, and meaning. These hybrid theories are 'relational' or processual, and we put this category in the center of the theory triangle. These approaches may emphasize social relations and interactions, but they also highlight the webs of social structure and meaning in which actors are suspended and which they change through their action (Geels, 2009). Rutherford and Coutard (2014) comment that relational approaches accentuate co-construction and circulation. They see technology and society as co-constructed or coproduced, with no single dimension dictating change by itself; and they see the transfer of knowledge and even the dissemination of artifacts as facilitated by a process of circulation among actors and across geographic scales. Geels et al. (2015) elaborate that relational and processual approaches conceptualize units of analysis as heterogeneous configurations with co-evolving elements, and envision agency as structured by routines, rules, habits and conventions. Furthermore, they address the analytical tension between the reproduction of current systems and normal ways of life ('stability') and the emergence of alternatives that can form the seeds for transition ('change').

Many of the interviewees emphasized the value of relational strategies that illustrate social interaction, alignments, and struggles between new and old configurations or that view the world as filled with interacting social groups that have beliefs, interests, strategies and resources. Tom Dietz (interview with lead author, 2016) explains it this way:

> For those of us who have adopted 'this view of life' as Darwin put it, the agency-structure division is not fundamental. Let me start with an individual. She or he makes decisions, but their values, their preferences, their beliefs, their mental models are all shaped by socialization (the long deep) and social context (the immediate). All that depends on where they 'live' in society, on social structure. So do their possibilities, the financial, social, natural, human resources they can bring to bear. But where does all this structure come from? In the population thinking view it is an emergent property of individual decisions, and the actions and interactions that take place. Over time agency, especially the agency of the powerful, gets embedded in laws and other rules, in norms, in the structure of organizations and institutions, etc. I see them as two ways of looking at the same thing: agency shapes structure shapes agency. That is what I mean by evolutionary thinking.

Andy Stirling (interview with lead author, 2016) echoes similar reflections when he argues that:

> The point is to build together diverse ontologies that are not only flat, but 'rhizomic' – each with room for different kinds of 'horizontal' flows and relations. This fits with a 'plural and conditional' approach to the communication of interpretations and recommendations in research – allowing both reflexivity about positioning, without denying what will always, even if not

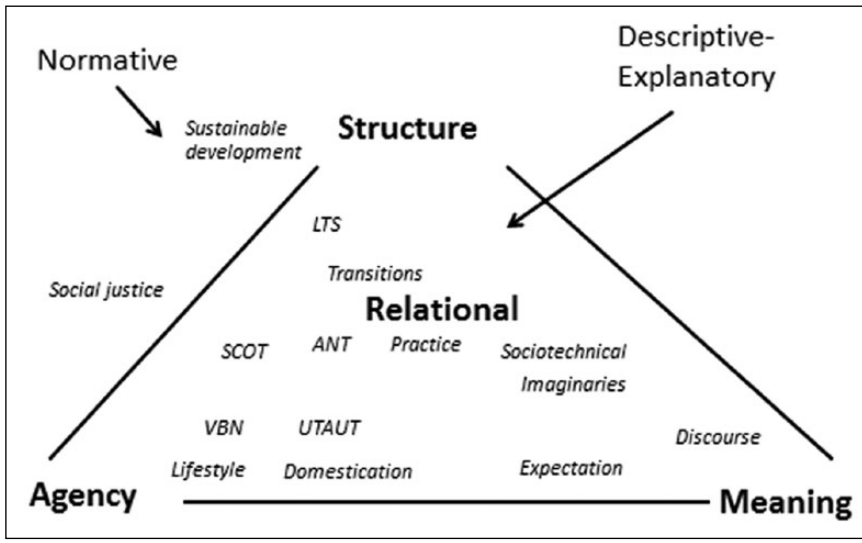

Figure 7. A typology of theories by agency, structure, meaning, relations and normativity. Note: LTS=Large Technical Systems, ANT=Actor-Network Theory, SCOT=Social Construction of Technology, UTAUT=the Unified Theory of Acceptance and Use of Technology, and VBN=Values, Beliefs, and Norms.

declared, be structuring analytic and normative commitments. Relational approaches coming out of Alfred North Whitehead as well as modern scholars like John Law, Bruno Latour, Michel Callon, and Isabel Stingers remind that the patterns being engaged with are more about relations and processes, than neatly-nested categories of things.

This could explain why relational theories accounted for only a small number in the full sample in Appendix II, but some of the most popular approaches were relational and made it into the short list of theories: Sociotechnical Transitions, Social Practice Theory, Social Construction of Technology, and Actor-Network Theory.

Finally, we also classify an analytical strategy as either normative or descriptive-explanatory. Whereas the first four types of theories are inherently descriptive – describing people's agency, broader social or technical structure, language, or recursive relationships – a normative type of theory attempts to answer whether a technology is a net positive or negative for society and individuals. To do so, they often rely on evaluative criteria set by ethics, moral studies, social justice or political ecology. Social Justice Theory and Sustainable Development were the two most often mentioned by respondents. These theories can also emphasize different aspects of the theory triangle; for example, social justice theories can draw attention to microsocial processes and agency. Furthermore, some of the theories classified as descriptive-explanatory can draw attention to moral and policy choices, such as the occasional focus of the MLP on providing both analysis of and guidance for sustainability transitions.

To be sure, the placement of theories across these five types is neither static – theories develop – nor mutually exclusive. Many in fact blur the line, falling across different categories. Figure 7 attempts to situate the fourteen shortlisted theories across a typology

of theory types, showing that many do not fall neatly or entirely inside a category. We also include a distinction between primarily normative analytical strategies (located outside the theory triangle) and descriptive-analytical strategies (located inside the triangle), with the understanding that even the normative theories can emphasize structure, agency, and meaning to differing degrees. The placement of theories with respect to the triangle is based on the authors' analysis of the characteristics of these theories and informed by the comments by the interviewees, and the position represents our assessment of central tendencies in the theories as more-or-less structure-centered, agency-centered, etc.

A typology of underlying goals and assumptions

Our second approach to the classification of theories begins with four ideal types of theory based on underlying goals and assumptions, a typology depicted in Table 4. We draw on but modify the work of Gioia and Pitre (1990), who categorize theories into four main groups: functionalist, interpretivist, humanist, and structuralist. Because few theorists today would likely call themselves 'functionalists', we use the term 'institutionalist' to refer to theories that emphasize the regulative role of norms, values, and cognitive categories as well as organizational settings. We also add the adjective 'critical' to 'humanist' to better specify the type, and we use the term 'conflict', which is widely used in categorizations of social theory, to avoid confusion with the use of the term 'structure' in the previous section.

Table 4. Functionalist-institutionalist, interpretivist, critical humanist, and conflict theories.

	Functionalist-Institutionalist	Interpretivist	Critical Humanist	Conflict
Goals	To search for regularities and sources of disequilibrium	To describe and understand social complexity and multiple perspectives	To describe and problematize assumptions in order to identify potential for change	To identify and modify patterns of domination
Assumptions	Society as a self-regulating system	Society as socially constructed action	Society as historical change and development	Society as a system of struggle and oppression
Topical focus	Norms, values, and institutions	Discourse, practice, and culture	Historical change and cultural difference	Societal conflict
Approaches	Refinement through causal analysis	Discovery through code analysis	Insight through critical analysis	Liberation through structural analysis
Methods	Probing representative samples of subjects	Identifying specific cases, questioning informants	Comparing specific cases or existing research, questioning assumptions	Evaluating historical evidence and structural conditions
Exemplary articulations of theories that fit	UTAUT, VBN	Domestication Theory, Sociology of Expectations	Discourse Theory, Sociotechnical Imaginaries	Social Justice Theory, Sustainable Development

In this matrix, an ideal typical functionalist-institutionalist theory would focus research on systemic stability, equilibrium dynamics, organizations, and institutional settlements punctuated by periods of change and contestation. This theory type seeks to examine both regularities and changes that can be explained causally through generalizing theory, and it seeks to develop theories to characterize structure and process. Structure may be understood as a relatively exogenous phenomenon that is external to and independent of agents, but it is also produced and modified as actors contest normative and cognitive systems. From the list of theories above, the analysis of regulative norms in UTAUT and VBN Theory approximate this type. Features of other theories that emphasize institutional stability include the concept of regime in Sociotechnical Transition Theory and the idea of stabilization in SCOT.

Interpretivist theories are based on the view that people socially and symbolically construct and sustain their own realities, and the goal of theory is to generate thick descriptions, insights and explanations of the complex models of and for action that people share, reproduce, perform, contest and modify. Because this type of theory tends to focus on interpreting the meaningful social action, it underplays the analysis of deeply transformative change. Domestication Theory and the Sociology of Expectations are consistent with the interpretivist type, but Discourse Theory, Sociotechnical Imaginaries, SCOT, and ANT also have elements that approximate this type (e.g., discourse and imaginaries as cultural texts and the concepts of technological frames in SCOT and problematization in ANT).

A critical humanist theory, like the interpretivist type, also begins with social construction, discourse and meaning, but it draws more attention to historical contingency, cultural difference, and temporal and geographical comparison. This theory type also has a more critical or evaluative stance that enables researchers to develop insight about the underlying assumptions of the current social order by pointing to how they once were different, how they have changed over time, how they are different in other cultural or institutional settings, and how they are being imagined for the future. Doing so opens up the horizon of inquiry to appreciation of historical contingency, human agency and the potential for significant change and radical innovation. Discourse Theory and Sociotechnical Imaginaries, when implemented as historical and/or comparative projects, can approximate this type. Likewise, the more historical and comparative aspects of LTS Theory (e.g., work on national styles of technological systems) and Sustainable Development, and the emphasis on sustainability transitions in Sociotechnical Transition Theory, also provide exemplars of this theory type.

Conflict theory is related to the critical humanist type because of its focus on examining underlying assumptions in order to free the imagination to envision societal change; however, unlike critical humanist theories, the focus is more on patterns of structural inequality and institutionalized disparities. The goal of developing generalizable theory also suggests similarity with the functionalist-institutional type, but the conflict type draws attention to systemic sources of instability and conflict rooted in longstanding and durable structures of inequality. Because of the asymmetry of social conflict, theories of this type assume that societal elites tend to control the means of production (and reproduction) of material, social, and cultural worlds. The goal of theory is to reveal, explain, and criticize existing mechanisms of domination. Social Justice Theory and Sustainable

Development approximate this category, and emerging work in Sociotechnical Transition Theory on power and politics in transitions could also approximate this type.

The concept of ideal types allows us to compare and contrast theories by identifying underlying assumptions and goals. Some theories may align with more than one type, whereas others may approximate more closely a single ideal type. Theories can, of course, bring together more than one type operating in what Gioia and Pitre (1990) call a 'transmission zone'. For example, Discourse Theory can focus on radical change and deconstructive criticism associated with the critical humanist type, but it also can involve cultural interpretation. Likewise, Social Practice Theory blurs the line between critical humanist and interpretivist approaches because it both describes and critiques. In contrast, Lifestyle Theory seeks to describe and recognize the subjectivity of preferences, thus approximating it to the interpretivist type, but it also searches for underlying patterns of stability with quantitative methods, a goal that is common with the functionalist-institutionalist type. Sustainable Development Theory can question underlying cultural assumptions through comparative analyses of wealthy and poor countries, and it also draws attention to pervasive structural inequality at a global level, thus bringing together elements of the critical humanist and conflict types. Sociotechnical Transitions Theory often involves historical case studies that point to the underlying potential for radical disruptions, a theoretical goal associated with the critical humanist type, but it also emphasizes generalizing theory, normative regimes, and institutional dynamics, all elements that are approximated by the functionalist-institutionalist type. Figure 8 attempts to visualize these 'transmission zones' and placement of theories, with the understanding that the placement in the figure does not mean that elements of other types are absent. The figure also emphasizes how only a few theories reside solely within a single ideal type.

The use of typological categories that focus on underlying assumptions and goals rather than on analytical strategies provides another lens for thinking systematically about theory choices. Neither approach requires a one-to-one mapping of theories onto a single type; rather, the types can be used as ways of thinking about how each theory may have more than one underlying set of assumptions and goals. Although some theories may come close to approximating one ideal type, others may be best interpreted as an amalgam of two or more types with aspects that exemplify different types.

Lacunae in theoretical selection

Comparative analysis of the fourteen theories also requires some attention to what is missing. Academic fields, like all social fields, can be studied not only as fertile ground for theory development and refinement but also as social fields where some approaches are favored over others. By focusing on a highly visible and well-positioned network of researchers, the study provides a description of what they identify as important theoretical frameworks and problem areas. In general, the dominant or elite networks in a research field also articulate intellectual taste in the field for good theoretical frameworks. Preferences for theory choices discipline the thinking of the field toward some aspects of the theory types and away from others, and attempts to build theory from subordinate networks can be viewed as a challenge if the theories are not aligned with the mainstream view. From this perspective, of the fourteen theories discussed above and the

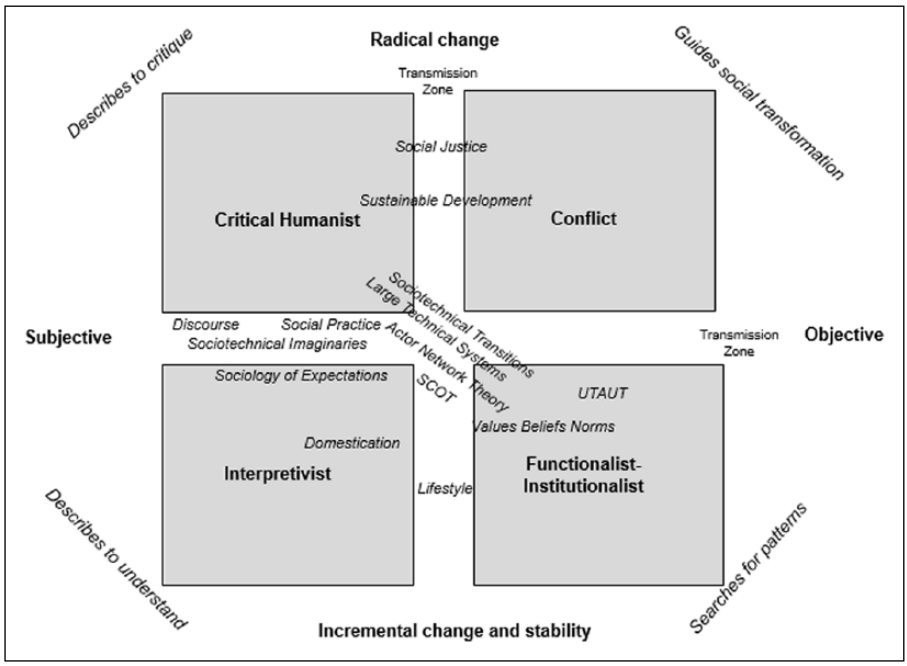

Figure 8. A typology of underlying theoretical goals and assumptions.

96 theories in Appendix II, a question of lacunae emerges, that is, a question of what is *not* considered important or what was mentioned with low frequency.

Of the different theory types, the conflict theory type and research that relies heavily on social structure were not mentioned with great frequency. Very few researchers invoke Marx or Marxist perspectives, although we note that there was some discussion of political ecology and geography and the 'varieties of capitalism' literature (categorized as justice-centered and structure-centered research). There was also little discussion of feminist, antiracist, and multicultural approaches to technology and society, even though there is an insightful literature on feminist technology studies (e.g., Layne et al., 2010).

The lack of preference for these theories is probably due to a mixture of factors. The field of research on technology and society, especially in Europe where the sampling was heaviest, has tended to be strongly influenced by research in schools of management and policy, where the focus is on innovation and industrial change as well as on consumers, their preferences, and their values and norms. Likewise, because some of the most prominent feminist multicultural scholars (e.g., Donna Haraway and Sandra Harding) may be viewed more as part of the science side of the field, they may not be highlighted in discussions of leading theories of technology. Furthermore, attention to structural explanation in STS subsided with the emergence of laboratory and controversy studies during the 1980s and the concomitant rejection of more structure-centered versions of the strong program that included social class (e.g., MacKenzie, 1981). However, the lacunae for

these theories is also indicative of the sampling strategy, which focused on a network of highly cited scholars mostly in Europe and secondarily in North America, and focused on social scientists rather humanists and cultural studies researchers. Thus, we interpret the lacuna to be both a reflection of preferences in the research field and a reflection of the limitations of the sample. Yet, it does raise an interesting question for future research: How would a similar study look if the sample were from scholars who work from different perspectives and in the global South?

A second lacuna involves the relative absence of thoughtful consideration of choices of the scale of analysis. With respect to temporal scale, Paul C. Stern (interview with lead author, 2015) notes:

> Many theories addressing human-environment interactions address different aspects of those interactions, often at different levels of analysis and with different temporal scales in mind.

Yet, in the group of fourteen theories, perspectives of multiple centuries or even multiple decades tend to occur only in the justice-centered theories and some work on LTSs and transitions. Attention is needed to the selection of appropriate temporal scale because some theories may be well attuned to periods of rapid change or transformation, whereas others may work best in longer timeframes.

A similar caveat applies to spatial scale. John Urry (interview with lead author, 2016) suggests the need for more self-conscious analysis of spatial scale in a statement that also makes reference to the theory triangle:

> Let the level of analysis determine which theory you use. For households, social practice theory or domestication or social embeddedness or a typology of users will work, since their focus is on individuals. For systems or inquiries related to structure, the multilevel perspective or actor-network theory work well, since they help focus on infrastructure, artifacts, or system builders. For rhetorical visions and processes of legitimation, sociology of expectation and broader patterns of discourse and narrative are useful. For normative questions, you have principles from sustainability or justice.

Anable et al. (2006) take a similar multi-scalar or spatial approach in their review of theoretical concepts applicable to transportation behavior. They classify theories according to whether they are at individual, interpersonal, or community and network levels. With respect to the fourteen theories discussed above, VBN Theory, Lifestyle Theory, UTAUT, and Domestication Theory all revolve around individual and interpersonal levels. The remaining theories are more multi-scalar and cut across community and network scales, in addition to incorporating various theories of change.

Thinking in terms of temporal and spatial scale draws attention to what is missing from many of the theories, including more long-term historical perspectives and spatial levels beyond the local (such as regional, national, transnational and international scales). Transition studies and LTS research work at a higher level of spatial scale than the three levels identified by Anable, and they can offer a complementary perspective. Although the first wave of transition studies was somewhat limited by its focus on national spatial scales, a second generation of work has begun to address other spatial scales and to think

through relations between spatial scale and institutional change (e.g., Coenen et al., 2012, Raven et al., 2012). Work by urbanists and geographers on rescaling, polycentrism and scalar interaction is also important in this regard (Cash and Moser, 2000; Ostrom, 2010).

Eclecticism and implications for theory and methods

The analysis of typologies and lacunae of theories have at least three additional implications for research methodology, derived (again) from a mix of the material and interviewee responses. Note that these suggestions may not apply in all instances and that tensions exist within the material.

First, different theories accommodate (and may incentivize) different methods. For example, some theories are mostly examined through surveys or experiments on individuals and others through historical or case study accounts. Tom Dietz (interview with lead author, 2016) makes this point about data dictating theory when explaining the agency component of VBN theory:

> I accept that VBN has looked mostly at agency, but that is largely because while we have data that gives variation across individuals, we don't have much good data that also gives variation in the social structure in which those individuals are embedded, save for gender, race/ethnicity, and class. The type of data we could get guided our theoretical preference for agency, so to speak. It is a data, not a theoretical, limit, although of course lack of data leads to underdeveloped theory.

Sheila Jasanoff (interview with lead author, 2016) articulates a similar reason when she notes that empirical material and research questions ought to drive theory selection:

> Theories cannot be mixed and matched like clothing accessories. One's research question will determine which theories apply and will also determine methodology and research design. Rather than to start with universal theories, or a smorgasbord of theories to continually digest and modify, the point is to pick a theory that arises out of the material. The theory comes from the material, the material doesn't come from the theory. Things fall into place only when grounded in such an approach.

This could require researchers to avoid wedding themselves to any theory before they begin their investigation, a view that is similar to the 'grounded theory' strategy of Glaser and Strauss (1967) and Strauss (1987) or an openness to the surprises of ethnographic thick description (Geertz, 1979). Although researchers are wise to avoid over-commitment to theory to the point that it biases the interpretation of qualitative data, a variety of strategies can work. In ethnographic, qualitative work, a more flexible approach to theory may be warranted, whereas in quantitative work the goal is often to begin with theories and use data narrowly to test and elaborate hypotheses.

Second, epistemological assumptions matter, and not all theories can be combined or are compatible. Allison Hui (interview with lead author, 2016) notes:

> There is a degree to which mixing and matching is fine, but it is extremely important to recognize the epistemological baggage of different approaches. This recognition is particularly

> crucial to ensure one is using concepts in a way that avoids disconnects and incompatibilities. Some findings cannot be translated or integrated; for instance, those based on economic modeling would not fit well with those deconstructing the legitimacy of such models. It is important to recognize the assumptions and history of those approaches. Some can be used in concert with each other, but others arise from different providence.

The implication here is that a meta-theoretical perspective does not necessarily require that all or many theories be integrated – merely that different representations are accounted for and that researchers think through the match between theoretical frameworks and research goals. This approach could be seen as akin to hypothesis testing, where different theories could be applied to a single research question or topic, and then analyzed for the best fit or strongest exploratory power.

Third, the research community may want to rethink what is typically meant by 'triangulation', traditionally understood as using multiple methods (for example, a literature review plus survey or interviews) to cross-validate results. We suggest that triangulation may be needed not only between data and theory but also across theory types. As Andy Stirling (interview with lead author, 2016) explains:

> Theoretical monogamists or dogmatists remind me of obsolete aristocrats arguing over the maintaining of their 'pure' lineal bloodlines. It is a sign of the blinding effects of power-wielding and privilege-seeking, that it is in fact obvious that no such thing can exist. Even allowing for there always being more covert ('rhizomic'!) connections than typically acknowledged, the basic structures of genetic descent alone and in themselves are fundamentally radically bifurcating and recombinatorial. So – whether established or emergent – discipline-focused pretensions amount at root to little more than vain bids for privilege and power. This is ironic, because despite the prominence afforded to 'rigor' in these rhetorics, some of the earliest and most serious casualties of such syndromes are the robustness and fidelity of the resulting understandings. But such forced kinds of closure are also corrosive in their social effects – the resulting hubris, isolation, entrenchment, and hierarchy militate against the kinds of healthy social communities necessary for high quality knowledge and practice. Pluralism and eclecticism are as essential in the advancing of theoretical understanding as the avoidance of incest is in avoiding genetic disorders. The world is more complex, and knowledge more distributed and relational, than the noisy competitive individualisms of theory-claiming and idea-appropriation find it expedient to acknowledge.

To paraphrase: Deeper understanding may emerge only when different theoretical perspectives are analyzed and juxtaposed, culminating in a sort of meta-theoretical triangulation.

Conclusion

At least four broader conclusions emerge from this analysis of theories of sociotechnical change. Although the sample of experts interviewed was limited, there was remarkable consistency concerning which theories are most applicable to understanding the diffusion and acceptance of technology. These theories not only come from different disciplines and cut across multiple dimensions, they also provide differing perspectives on the question of what technology 'is'. One group of theories sees technology

through the lens of individual users: technology empowers or constrains human agency. Another group sees humans enmeshed in larger structures that shape the opportunities for and possibilities of action, often beyond their control or even cognition. Yet another group sees technologies as mutually constitutive with discourse and language; the discursive power of narratives and visions gives technology co-constructed meaning. Another looks for relations among agency, structure, and discourse/meaning. A final group sees technology as a positive or negative force on society, using normative criteria to determine costs and benefits, as well as their distribution. Taken as a whole, these five groups remind us that technology is polysemic, involving a relational mix of agency, systemic structure, discourse, and normative judgment. Likewise, from the perspective of theory types, most theories can be mapped onto more than one ideal type; many straddle boundaries, or operate in 'transmission zones'.

Furthermore, the fourteen theories discussed in some depth here, and the full 96 theories listed in Appendix II, provide a rich and useful menu that students and other analysts can utilize when they wish to assess sociotechnical change from different perspectives, provided that they also attend to issues of lacunae that we flag above. There is a wide array of possibilities and permutations, and so far comparative theorization or integrative work is rare. Although one must be mindful of the pitfalls of theoretical promiscuity – sheer incompatibility as well as incoherence and inconsistency – there is also great potential in cross-fertilization, or at least in juxtaposing theories and concepts against each other. As our respondents mentioned, integrative theory can be a way to minimize bias and arrogance, best fit a particular research topic or question, tighten concepts through critical thinking, and aid researchers in a quest for meta-theoretical triangulation. (Indeed, some of the most popular theories mentioned by respondents, such as SCOT, UTAUT, Sociotechnical Transitions Theory, Discourse Theory, Social Justice Theory and Sustainable Development Theory, are already deeply integrative). We hope that this article has opened the door to much further engagement and debate about theoretical fits and misfits.

In addition, the breadth of theories identified here serves as a useful framing device concerning how particular disciplines or communities of scholars view the problem of sociotechnical diffusion and change. For example, within behavioral science there is preference for agency-centered approaches, but there appears to be emerging popularity for relational approaches within sociology and innovation studies. In other words, particular disciplines may find particular types of theories more compatible with their epistemic cultures; theories are a useful communication technique that researchers can employ when engaging with specific disciplines and when attempting to receive funding from grants under those research streams (i.e., if talking to a group of psychologists, speak in terms of the agency-centered theories they seem to value). The theoretical menu or toolbox can provide researchers with the resources to improve 'intercultural communication' across disciplines, to speak to disparate communities in a theoretical language they can understand.

Finally, insights from this study point the way toward a future research agenda. We need to continue to reflect upon the dynamism and at times zero-sum game between theoretical complexity and simplicity, between generalizability and predictive power or rigor, and we need to understand better validity across conceptual stretching and

traveling. It may be, as Stern has written, that 'nothing advances theory better than tackling a practical problem by integrating different perspectives' (2014: 3). We need more examination of the epistemological underpinnings of theories and more nuanced ways of comparing, contrasting, and synthesizing them. We need to remain cognizant that theoretical frameworks not only open minds but also close off researchers into particular networks – theories can discipline and socialize in ways that constrain, rather than expand, knowledge. We also need to incorporate theories, concepts, ideas, and data from other perspectives beyond the focus of this study, and we need not shy away from normative questions of efficacy, justice, and sustainability. Theorization and concepts about technology and society are too important and too potentially useful to remain trapped within disciplines or, worse, prone to power-wielding and elitism.

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Supplementary material

Appendices I and II are available as supplementary material on the journal's official website, at http://journals.sagepub.com/home/sss.

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