Infrastructure transitions toward sustainability: A complex adaptive systems perspective

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Abstract

To ensure infrastructure assets are procured and maintained by government on behalf of citizens, appropriate policy and institutional architecture is needed, particularly if a fundamental shift to more sustainable infrastructure is the goal. The shift in recent years from competitive and resource-intensive procurement to more collaborative and sustainable approaches to infrastructure governance is considered a major transition in infrastructure procurement systems. In order to better understand this transition in infrastructure procurement arrangements, the concept of *emergence from* Complex Adaptive Systems (CAS) theory is offered as a key construct. Emergence holds that micro interactions can result in emergent macro order. Applying the concept of emergence to infrastructure procurement, this research examines how interaction of agents in individual projects can result in different industry structural characteristics. The paper concludes that CAS theory, and particularly the concept of 'emergence', provides a useful construct to understand infrastructure procurement dynamics and progress towards sustainability.

Key Words

Sustainable Infrastructure, Engineering Asset Management, Infrastructure Delivery, Procurement, Complex Adaptive Systems Theory

Biographical Notes

Professor Kerry Brown holds the Mulpha Chair in Tourism Asset Management and is a professor in the School of Tourism and Hospitality Management at Southern Cross University, Gold Coast, Australia, where she is also Director of the Research Centre for Tourism, Leisure and Work. Her main fields of research are public management and employment relations. Other principal research foci are collaboration, networks and industry clusters; capability, strategy, management and policy for infrastructure and asset management; work-life balance and negotiation, and employment relations. She has co-authored two books and published over 50 articles in scholarly journals.

Craig Furneaux has recently been appointed as a Postdoctoral Research Fellow at the Australian Centre for Philanthropy and Nonprofit Studies, and is finalising a PhD at the School of Management, QUT, examining the procurement of engineering assets. He has undertaken numerous research projects related to infrastructure public policy issues in Australia, covering such topics as BIM, eBusiness, OH&S, procurement, and sustainability.

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Introduction

Proficient and effective provision and stewardship of physical infrastructure is a key activity of government (Lædre, Austeng, Haugen and Klakegg, 2006). A critical part of this process is to first ensure that the assets purchased either through purpose-built design, or as ready-made products, are appropriate to both the required task and operations, and importantly, to the way that the task or operation should be carried out to support the underpinning values of society. Consequently it is crucial to fit within the value framework as espoused by the citizenry and government, and state actors need to devise the appropriate policy and institutional architecture for this purpose. The institutional arrangements for the effective procurement of engineered infrastructure assets, the way in which these arrangements contribute to sustainability of infrastructure assets, and how changes are adjusted and adapted over time are the focus of this research. Procurement of infrastructure assets in a way that offers the best opportunity to develop the purpose and operation of the asset is an important but often neglected part of the life cycle process. We argue that this part of the asset life cycle can be investigated to give insights into the progress towards a sustainability agenda.

Infrastructure procurement is outlined as a way to focus on and explicate transition in relation to a more sustainable infrastructure system. While sustainability is a concept that resists easy achievement, particularly by single firms or policy prescription, the progress towards sustainability, as suggested by Kemp and Loorbach (2003) can be assisted by adopting a transition management approach. Transition management, with its locus of attention on long-term generational change, is a way of shaping those transformational changes occurring within society driven by the values and aspirations of citizens (Rotmans, Kemp, and van Asselt, 2001). It is contended that Complex Adaptive Systems (CAS) theory, with its emphasis on how systems are created and recreated by ongoing interaction of those agents operating within sets of rules of the system, provides a useful construct to understand the dynamics and outcomes of procurement systems at the industry level and infrastructure industry dynamics, and to assess the possibilities for managing such transitions towards sustainability.

Transitions, Complex Adaptive Systems and Sustainability

Sustainability in its broadest sense is about progress, through the creation of economic, environmental and social capital, towards meeting present development needs and ensuring future development requirements can be met (Kemp and Loorbach, 2003). Dasgupta and Tam (2005) acknowledge the difficulty in achieving sustainability for infrastructure systems as these are distributed networks over large distances, have impacts that are significant but dispersed, and have multiple and often conflicting stakeholders.

Rotmans, Kemp and van Asselt (2001) use a case study of transition to a low emission energy supply in the Netherlands to show that transition management may create the trigger to shift to sustainable development, however, while the role of public institutions in driving change is acknowledged, the major impetus to change is argued to be the citizenry (society). The study by Rotmans, Kemp and van Asselt (2001) indicates that multiple and conflicting layers are implicated in the transition to sustainability, but conclude that the social milieu is the key to impelling transitions.

This research takes up the theme of managing transitions to a more sustainable future by tracking the changes to operations according to new collaborative forms of procurement arrangements. Such fundamental shifts from the prior competitive approach to more collaborative arrangements and models of project governance can be viewed as a major transition in procurement system arrangements. Further, the appropriateness of two concepts from CAS theory — the interaction of agents according to ‘rules’ and the concept of emergence — are examined as a possible way to better explain transitions in the procurement of infrastructure within a sustainability framework. In its broadest sense, such changes in infrastructure procurement reflect the shift from New Public Management

(NPM), with its emphasis on the use of market mechanisms to achieve efficiencies (Hood, 1991), towards more collaborative approaches to service delivery, such as those underpinning network governance arrangements (Keast ,Brown and Mandell, 2007). It is contended that as traditional forms of procurement in a market context resulted in a fragmented industry afflicted by chronic litigation (Dubois and Gadde, 2002), the application of rules and the concept of emergence can explain the change to more collaborative forms of procurement. The research considers the question: what does CAS theory inform us about how transitions are able to accommodate a focus on sustainability? This question is examined by using the study of the change from competitive procurement to collaborative procurement regimes. The methodology undertakes an meta-analysis of three cases of infrastructure procurement regimes (phases over time) and describes and analyses the change over time to determine the ways that agents interact with each other, and the emergent order which results from such interaction.

CAS theory holds that multiple interactions between agents result in structural changes of the system at an aggregate level (Dubois and Gadde, 2002, p.630). This concept is particularly relevant for understanding how transition to sustainable infrastructure might occur. The change to infrastructure sustainability is a structural change that requires the interaction of agents to coalesce around both technical change to achieve sustainable physical infrastructure, as well as social change to reflect social values of sustainability as drivers of change. Citizens may demand a focus on sustainability and start to act as agents in an infrastructure system to have this intent captured in 'new rules of the game' such as lowering emissions, carbon offsets, clean technology implementation or changes to pollution policy and laws. However, the rules of the system may also be set at the strategic level, by government or by overarching governance bodies. The possibility of change to sustainable infrastructure is examined in this context.

Klijn and Teisman (2007) argue that the governance system and its environment are constantly changing and that complexity theory helps to explain the way that agents, systems and environments interact and produce change. In particular we argue the concept of *emergence* within CAS provides a key theoretical construct to understand the aggregate effect that individual project governance arrangements can have upon the structure of specific industries, which in turn impact individual projects. Changes in projects then have an effect on the system, operating as a feedback loop. Emergence is understood here as the interaction of agents in the system that eventually produces a relatively stable macro structure (Holland, 1998; Tang and Youmin, 2006). It is in this area of emergence that CAS theory is held to provide a powerful extension to the advances already made by transition theory for addressing sustainability as the interaction of agents influencing technological and public values change to deliver sustainable infrastructure (Loorbach and van Raak, 2005; Kemp and Rotmans, 2001).

Applying the concept of emergence to transitions in the rules underpinning infrastructure procurement requires an examination of how the interaction between agents involved in individual projects (infrastructure asset procurement in this study) influence the structural characteristics of the industry they are in. In order to explain this dynamic more fully, first transitions theory and CAS theory within a sustainability context are reviewed, focussing particularly on the concepts of emergence and interaction. The utility of *emergence* as a construct to understand changes that project governance arrangements can have at the industry level in infrastructure procurement is then demonstrated. Further, it is shown that agents interacting with the rules of the system could produce the conditions for new types of infrastructure systems and it is at this juncture that the change to sustainability becomes a possible future scenario.

The next section describes and interrogates the concept of CAS. This theoretical concept is outlined and analysed for its relevance to infrastructure procurement systems. In following sections the implications of using CAS theory for understanding the potential for a shift to sustainable infrastructure are then explored.

Complex Adaptive Systems (CAS)

CAS theory is derived chiefly from biology and seeks to understand the behaviour of populations of animals on given landscapes with Kauffman (1995) and Holland (1998) as key authors. Recently this theory has been incorporated into strategic management literature, through organisational ecology (Hannan and Carroll, 1992), and into public policy literature (Klijn, 2007). Two elements of CAS theory that are then relevant for the analysis of infrastructure and the transition to sustainability are emergence and agent-rule interaction as these relate to explaining the way new systems might come into existence, and distinguish among the many interactions in a system the genesis and type of rule change that tips the 'old' system into a 'new' system. The concept of emergence is of interest in this research due to the utility of the construct of managing transitions in infrastructure procurement. Interaction rules are an important element as these set the parameters according to which agents may interact.

According to CAS theorists, the structure of a system results from the interaction of agents according to rules, both formal and informal. These rules are devised to provide an overarching framework for the way in which agents may interact with each other. This approach is acknowledged by Klijn and Koppenjan (2006, p.143) when they argue that institutions in their role of providing stability and rules, are useful for determining behaviour and providing a mechanism for co-operation. Smith and Stacey (1997) note that network, hierarchy and market governance modes are the main ways that public and private agents interact in public policy systems. Keast, Mandell and Brown (2006) argue that in network arrangements agents will interact primarily via rules of collaboration; in hierarchical arrangement, agents interact according to rules of control; and in market based arrangements agents interact according to rules of competition. Thus the rules of interaction between agents are different depending on the dominant governance arrangement which is in place: network, hierarchy or market.

Cilliers (1999, p. 143) explains that order emerges out of interaction according to rules without the intervention of external forces on the agents (a process also known as self-organising). The emergence of a higher order structure from lower order interaction is held to be one of the key properties of CAS (Holland, 1995). Daneke (2005, p. 95) argues that "the primary feature of social systems thinking is its focus on those elements that 'emerge' from the interactions of agents and institutions". As Rhodes (2003, p. 63) points out "Emergence is the term used in CAS theory to describe the phenomena of patterns at a higher level of abstraction that arise from interactions among lower level agents". Notions of self-organisation have parallels in institutional theory with its idea that structures emerge from the interaction of agents as they interpret and use institutional rules (Teisman and Klijn, 2008). Consequently, according to CAS theory, for infrastructure procurement systems, the nature of the industry structure arises out of the dominant agent interaction rules. Thus, a different industry structure is likely to emerge depending on whether the dominant interaction was based on collaboration, competition or control.

It is important to note, that the rules which govern agent interactions are not static however, and are subject to change. Change, or adaptation as it is defined in CAS, occurs due to changes in the environment, the choices of agents and often a dynamic feedback between the two. Xi (2006, p. 189) observes that the "capacity for self-organisation is a property of complex systems which enables them to develop or change internal structure spontaneously and adaptively in order to cope with, or manipulate, their environment". When the environment of the system changes, so does the behaviour of agents and as a result, the behaviour of the system as a whole such that the system learns and adapts to the new environment (Lewin and Regine, 2003). CAS can also evolve over time through the entry, exit and change of agents, as well as changes in the linkages between agents (Anderson, 1999).

From a public policy perspective, Klijn and Teisman (2007) note that both the governance system and its environment are constantly changing, and argue that CAS theory helps to explain the way that agents, systems and environments interact and produce change. Klijn and Koppenjan (2006) also contend that change in

institutions is problematic as prior interactions, standpoints and relations of power become embedded in institutions. In the case of infrastructure procurement, such rules are interaction rules according to, and governed by, the policy arrangements devised by government actors. CAS theory holds that such interaction produces change not just within a network, but also in relation to how multiple interactions between agents produce an outcome at an aggregate level (Dubois, 2002, p. 630). In other words, if the interaction rules were to change, then the higher order structures could also change. It is this area of evolution, emergence and adaptation which CAS theory is held to provide a powerful extension to the advances made by network governance (White, 2001).

In summary, agents in complex systems interact according to rules. Over time this interaction results in higher order structure. However, the rules are not static and have the capacity to change over time. Changing the rules by which agents interact, according to CAS theory, will result in a change in the industry level. In order to foster a transition to sustainability, then identifying and altering the way agents interact should result in a change in the system which supports the transition to infrastructure sustainability. Before this is explored in more detail, a brief discussion of transitions and the relationship between CAS and transitions is needed.

Complex adaptive systems and transitions

Transitions in policy arenas are often marked by short periods of radical change, followed by long periods of stability known as punctuated equilibrium (Loorbach and van Raak, 2005). Transitions are also often marked by concurrent developments in a number of domains or arenas, which can either inhibit or accelerate change in other arenas (Martens and Rotmans, 2005). Kemp and Rotmans (2001) determine that a transition is a move from one dynamic equilibrium to a new dynamic equilibrium characterised by both speedy and deliberate developments as a result of interacting processes, and involves innovation as a key aspect of the societal subsystem.

Like complex systems, transitions are viewed as a multilevel construct. At the macro level is the set of societal expectations; the meso level contains patterns of institutions, artefacts, rules and norms assembled and maintained to perform economic and social activities; and the micro level comprises the individual specific actors (van der Brugge and Rotmans, 2007).

While complex systems are made up of agents interacting according to rules, such interaction results in complex and emergent patterns — not all of which can be attributed to the action of any one actor or elements of the system (Holland, 1995). van der Brugge and Rotmans (2007, p. 253) argue that regimes are complex adaptive systems: “an island of relative stability embedded in a changing landscape and not always capable of adapting due to its interdependencies between its actors and artefacts”. However, the multilevel nature of CAS would suggest that the interaction at the micro level, according to rules set at the regime level, can affect the macro level over time.

According to transition theory, transitional changes do not have a predetermined outcome, but instead have a variety of potential outcomes. The transition to stabilisation is “the desired pathway in achieving sustainable development. However, the complexity of the interaction processes limits control over societal developments which may lead to less desired pathways, such as the lock-in, the backlash or the system breakdown” (van der Brugge and Rotmans, 2007, p. 255). While rules are seen as key elements in CAS, they are relatively under-examined in transitions research. Additionally, the impact of making significant changes to the rules is unlikely to be determined beforehand, with a number of possible outcomes from the changes in the rules. The goal of this research is to make explicit the system transitions in a particular public policy arena — procurement of engineering assets — by focussing on the rules, how these rules change over time and the impact that these changes have on the system overall.

As noted earlier, within CAS theory, the behaviour of agents is seen to be determined by a collection of rules (Holland, 1995). Understanding the rules of a CAS is vitally important as these rules are held to determine agent behaviour. Gell-Mann (1994) contends that the capability to create rules distinguishes CAS from other complex systems such as galaxies. The first step to understanding the dynamics of a system is to identify the rules which underpin how the system operates (Rhodes and MacKechnie, 2003).

Rules and the challenge of engineering asset procurement

Rules are an important element of a CAS (Holland, 1995). Rules are devised and then applied by matching a given situation to those rules (March and Simon,1993, p.8). From a public policy perspective:

> "...making sense of contemporary public administration then, requires and understanding of the complex ecology of institutions, actors, rules, values, principles, goals, interests, beliefs, powers and cleavages in which it operates" (Olsen, 2005, p. 7).

Holland (1995) contends that rules can be classified into two main types — rules which regulate the action of agents and rules about the system itself. This point is supported by Klijn (2006; 2007) suggesting that in public policy systems there are rules which focus on the policy arena itself (arena rules), and those which relate to the interaction of agents in a system (interaction rules). These two 'layers' of rules offer a way of understanding the different drivers of change, as change may be affected from the top down through the adoption of arena rules and also from the bottom up as part of the interplay of interaction rules.

Since the state is the agency through which the 'rules of the game' are established and enforced, the state controls to an important extent the institutional environment by determining how agents interact (arena rules) (Vanberg and Buchanan, 1986, pp.217-218). However, CAS theory suggests that by changing the interaction rules, government can change the way the dynamics of the system create different ordering within the system. This aspect is especially interesting for understanding the possible shift to sustainable infrastructure as government may choose to devise rules that compel agents to adopt new approaches. For example, in a study of sustainable transportation, Patil, Herder and Brown (2010) found that stability of policy environment was a critical success factor in adopting alternative fuel for transport, along with availability and cost of new technology.

Two key sets of rules relate to decisions concerning the institutional arrangements (interaction rules) involved in delivering the engineering asset and in decisions concerning the project or asset itself (system rules). The structure of agents interacting in governmental arenas has been of growing concern to public policy researchers — particularly those researching the various modes of governance: hierarchy, network and market (Keast ,Mandell and Brown, 2006). Boisot and Child (1999) argue that these different organising arrangements are the main mechanisms by which agents in CAS cope with complexity. Markets, hierarchies and networks have been acknowledged as the fundamental modes, operating as 'ideal types', of interaction between organisations (Rhodes and MacKechnie, 2003). As modes of social organisation, these are located at the level of governance and fit within Geels' (2002) conceptualisation of the landscape of systems.

Table 1 provides an overview of these different modes of governance and sets out the interaction framework within which each mode operates to best and least effect.

Table 1 Summary of forms of organisational interaction (Adapted from Keast, Mandell and Brown, 2006)

Relationship to Organisational Archetypes	Core dimension	Concept of working	Objective	Logic	Drawback

Market	Competition	Working against	Best cost	Competition keeps price down	In markets where competition is weak — leads to opportunistic behaviour
Network	Collaboration	Working with	Best relationships	Collaboration reduces conflict/ realises complex projects	In situations with low complexity — not worth the establishment costs
Hierarchy	Control	Working for	Best quality, certainty	Control ensures quality	Where outcomes are difficult to specify and therefore measure — control difficult to ensure

Hierarchy involves the establishment of vertical chains of accountability and is primarily focussed on control; markets involve the exchange of goods and services with competition as the underpinning logic; and networks involve various types of negotiated outcomes with collaboration a key logic. Keast, Mandell and Brown (2006) note that these are archetypes and in reality a mix of the three modes of governance is typical in a given set of arrangements. However, Smith and Stacey (1997) argue that the mix or interaction between the formal (hierarchy) and informal (network) systems produces emergent order, which may or may not be in line with the intentions of those in authority.

While the notion of networks, markets and hierarchies as modes of governance is not new (Polyani, 1957; Rhodes, 1997), recent work has focused on the optimal mix of modes of governance in order to deliver services and products (Provan and Kenis, 2008), and the importance of different types of networks for different situations (Keast, Brown and Mandell, 2007; Provan and Kenis, 2008) (see Table 2). However, it is contended that these archetypal forms provide fruitful ways of examining interaction in procurement systems.

Table 2 Summary of governance rules and their effect on individual projects (Adapted and extended from Eriksson, 2008; Rowlinson, 1999; Boisot and Child, 1999)

Governance Dimension	Competition	Control	Collaboration
Performance criteria			
Speed	Low (if all phases are tendered)	High	High
Cost	Medium	Low	High
Variations	Medium – High	Low	High
Certainty	Medium	Medium	Low
Client involvement	Low	Medium	High
Project phases			
Specification	By supplier or client	By client	Joint specification
Bid invitation	Open bid	Closed bid (invitation), government delivery	Negotiated process
Bid evaluation	High weight on price	High weight on certainty	High weight on ‘soft’ parameters
Contract	Formal comprehensive	Formal/government	Informal,

		trading enterprise	incomplete
Compensation	Fixed price	Penalty clauses	Incentives
Performance evaluation	By the client	By the client	By the supplier
Complexity			
Relational and cognitive complexity	Medium	Low	Medium – High
Business environment complexity	Best when relatively stable (predictable)	Best when stable (little change)	Best when high uncertainty
Complexity in delivering infrastructure	Medium complexity	Simple tasks	High complexity

According to CAS theory there is a trade-off between the various options that agents can take in their interactions (Kauffman, 1993). For example, construction relationships can be characterised as either a low trust competitive route or a high trust cooperative route (Korczynski, 1996). However, high trust is likely to have high costs as the relationships take longer to develop and there is little to guide the project by way of highly specified contractual arrangements. As is shown in Table 2, for organisations, as interaction arrangements move towards collaboration they are likely to move away from control and competition. These alternative modes of governing relationships involved in the delivery of services can influence the outcome of the network (Klijn and Koppenjan, 2006). Thus collaboration in a project that requires a low cost, non-negotiated solution is likely to fail as collaboration entails a high cost, negotiated solution suited to situations of high complexity.

Geels (2004) suggests that socio-technical systems form the functional underpinning of social organisation as these systems involve interaction of both social and technical infrastructures. In this way, transitions need to account for public values as well as technical system aspects. The system rule changes in the procurement of assets demonstrate that rules relating to technical aspects are not sufficient to change the behaviour of agents but that rules relating to social organisation should also be considered.

The implications for the possibilities of a shift to sustainable infrastructure are that the prevailing governance rules and the associated dimensions as outlined in Table 2 can exert considerable influence on the take-up of novel ideas or new modes of operation. Collaboration involves higher costs and requires a high level of trust but is suitable for situations involving high complexity and uncertainty, in which there is scope for the emergence of novel ideas or new modes of operation. The implementation of sustainable infrastructure may be best attempted in this context. Competition and control governance systems achieve lower cost but provide less scope for the emergence of novel ideas and new modes of operation. Hence, unless the technology or equipment to move to a sustainable future can be procured at a low cost, completion and control governance systems provide little impetus to change from the *status quo* and so limit the possibilities of a shift to sustainable infrastructure.

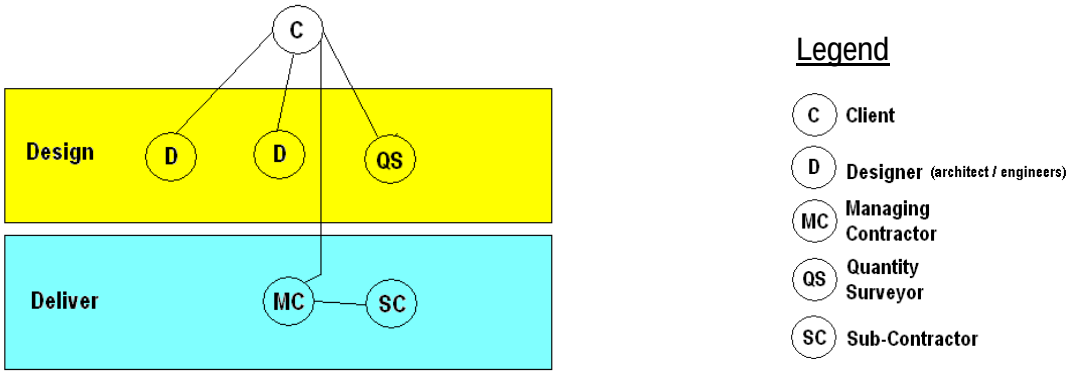
Procurement of infrastructure

Before the introduction of New Public Management (NPM) approaches that sought to instil business management and the rigor of user pays costing into the processes of government, infrastructure was delivered predominantly by in-house labour, with only large and complex projects being outsourced (Furneaux, Brown and Allan, 2008; Furneaux and Brown, 2007). Widespread adoption of NPM in Australia resulted in a significant shift to contracting out of construction services — the competitive model.

Competitive construction procurement systems

For construction projects, the traditional approach to building procurement involved the compulsory competitive tendering of each stage of the construction process in an effort to reduce costs. Figure 1 summarises the typical relationships in a traditional construction contract. As this figure demonstrates, there is little or no interaction between the designer and the builder of the project under such arrangements. In this model, sustainability measures could not be introduced unless there is a cost reduction outcome for doing so. There are long lead times for addressing sustainability and uncertain positive economic outcomes. While positive social and environmental outcomes can accrue to a sustainable model, a values approach will be difficult to implement in a market context (Kemp and Loorbach, 2003).

Figure 1 Traditional approaches to procurement



Dissatisfaction with traditional market approaches led to experimentation with other forms of contract delivery mechanisms — or procurement systems as they became termed.

Collaborative approaches to procurement systems

Institutional differentiation "whether by contracting-out, public private partnerships or bypassing local government for special purpose bodies creates imperatives for interdependent actors to work together" has come to the fore (Rhodes, 1997, p. 48). Alliance forms of contractual relationships are one response; a key distinction between this approach and traditional approaches is that all the members of the construction team are involved in the planning of the project (Furneaux Tywoniak and Gudmundsson 2010) (see Figure 2). The involvement of constructors in the design phase of the project can provide important early advice on the 'buildability' of a given design, and thus reduce changes to plans and contracts, therefore eliminating costs and time overruns. Additionally, the establishment of the alliance may be through pre-qualified supplier arrangements, or through bids by invitation — which together involve a less competitive approach than compulsory competitive tendering.

It is suggested that alliance approaches, with their emphasis on innovation and conflict resolution to achieve project goals, may be suited to achieve sustainability as part of an innovative capacity. Table 2 indicated that high cost, high trust collaboration that delivered complex projects under conditions of uncertainty may be best placed to achieve transition to sustainability as the conditions supported experimentation and tolerated higher risk. If transition to sustainability could be achieved at a low cost, however, then market-based approaches could deliver this change.

Figure 2 Alliance approaches

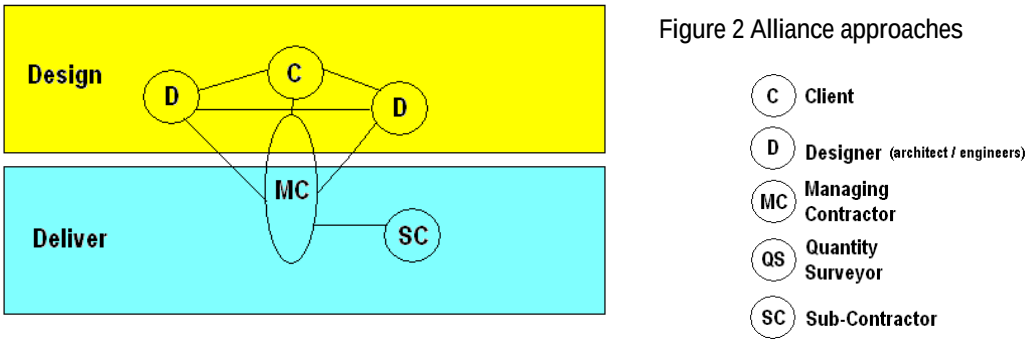


Table 3 summarises the contrasts between traditional and alliance forms of contracts.

Table 3 Comparison of traditional and alliance forms of contracts

Procurement system	Traditional	Alliance
Level of competition initially	Typically high	Low to Medium
Level of collaboration once the contracts are awarded	Low	High

Impact of competition or collaboration interaction rules on market structures

In the work of Rosenkopf and Schilling (2007), 32 network industries were categorised into different types of networks based upon the network structure. Some networks were disconnected with very low connectivity and small size; a second type of network, termed hybrid, had medium levels of density with clusters of nodes identifiable; and finally spider webs were defined by their high network connectivity and large size (Rosenkopf and Schilling, 2007). This study demonstrated that industries have different network structures, although the causes of these differences were not established.

Researchers have begun to argue that procurement can have a positive or negative effect on collaboration at an industry level (Eriksson, 2008; Eriksson and Pesämaa, 2007). Historically, the construction industry in Australia and the UK are considered highly fragmented or loosely coupled industries, often characterised by extensive litigation and high dispute resolution costs. Dubois and Gadde (2002) have argued that the causes of such fragmentation at the market level results directly from competitive, market-driven procurement policies. Over time, the ongoing interaction rules of competition, and conflict would reduce the ties both between industry firms delivering the projects and government undertaking such purchasing. From a CAS perspective, the competition and conflict which resulted from compulsory competitive tendering arrangements would explain the fragmentation and loose coupling at and industry level. The traditional project delivery system is thus a highly competitive process that offers little room for consideration of sustainability issues.

An example of the emergence of aggregate order from micro interactions can be seen from the phases of procurement in the construction industry in Australia.

Phase 1 — Contracting out

Following widespread implementation of contracting out in Australia, much of the contracting of construction work by government was awarded on the basis of lowest price achieved through competitive tendering of each stage of the construction project (design, construction, maintenance). The procurement rules were based on lowest price (cost criteria) and the interaction rules were primarily based on competition (in order to achieve lowest price) (Furneaux, Brown and Allen 2008). According to Masterman (1992) this pursuit of lowest cost via high levels of competition was the predominant method of procurement for most of the 20th century. Dubois and Gadde (2002) found that the construction industry is highly fragmented as a result of the highly competitive nature typical of procurement approaches. High competition, lowest price procurement resulted in fragmentation and litigation at an industry level.

Phase 2 — Increased collaboration and increased non-market contract requirements
The fragmentation and dissatisfaction with outcomes in the competitive model of procurement led to changes to the rules under which contracts were undertaken with a move to a more collaborative approach to procurement particularly with the introduction of more collaborative forms such as alliances. At the same time, government began to introduce a number of additional requirements to procurement contracts in order to achieve multiple policy outcomes. These outcomes included policies such as training for Indigenous people, developing public art and regional development through local purchasing requirements (Austen et al., 2007), as well as Occupational health and Safety (OH&S) compliance systems (Furneaux, Brown and Allan, 2008). These requirements could be expanded to include sustainability measures as part of a government policy regime for contracting. The emergent quality of these new initiatives indicates that policy prescriptions can be adapted to achieve non-market or social purposes and thus align with public values. These can operate to steer the transition to sustainable development.

However, while the fragmentation of a highly competitive market driven industry was addressed through collaboration, there may be unintended outcomes of the shift to these more collaborative approaches to procurement. Since the introduction of collaborative forms of contracting, together with the increasing social requirements required of contractors in all forms of contract in addition to the actual construction process, there has been a reduction in bids received to undertake construction work in Australia (Austen et al., 2007). Table 4 shows this dramatically:

Table 4 – Reduction in the number of bids for construction Austin 2007 p. 62

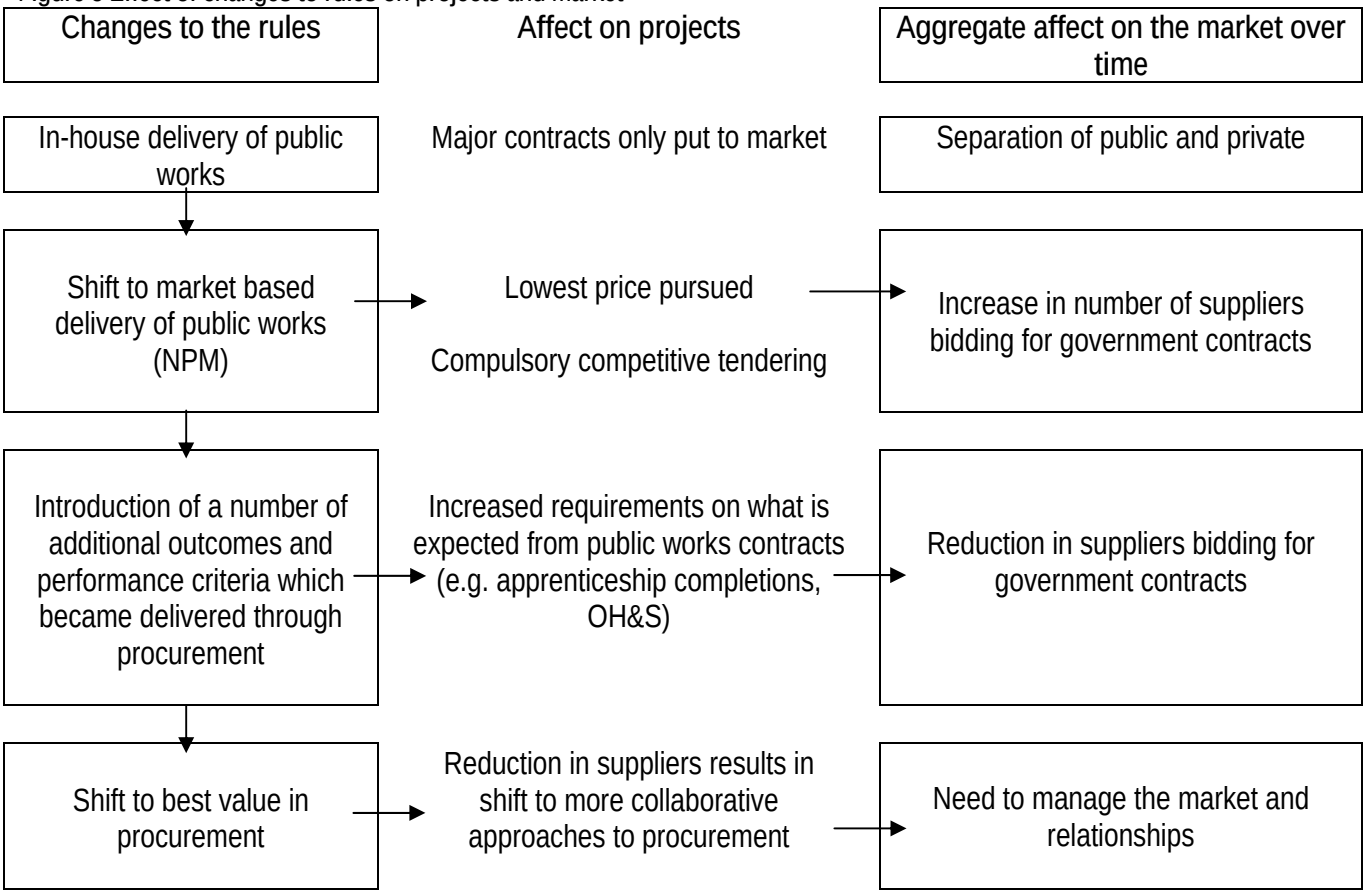
Prequalification Financial Level	Amount	Decline in average # of tender bids
Level 0	$1 to$149,000	22.90%
Level 1	$150,000 to $750,000	50.20%
Level 2	$750,001 to $1,500,000	56.40%
Level 3	$1,500,001 to $3,000,000	60.40%
Level 4	$3,000,001 to $7,500,000	56.40%
Level 5	$7,500,001 and above	26.20%

Phase 3 — 'Managing' markets
A reduction in the number of suppliers has a significant consequence for costs in procurement (Furneaux ,Brown and Allan, 2008). The increasing reliance of government on a limited number of suppliers increases the potential for opportunism in bidding, significantly due to low contestability (Globerman and Vining, 1996). This appears to be already happening in Australia, with significant increases in infrastructure costs due to the high demand for construction services and the relatively small pool of available workers and construction firms with capability to undertake the work (Furneaux, Brown and Allan, 2008).

However, if the emergent outcome of agents interacting in a highly competitive and non collaborative manner is a highly fragmented industry, then the outcome of low initial competition and high collaboration during a project may be a more tightly coupled industry. In loosely coupled systems change is difficult to effect due to the lack of connectivity between agents. In tightly coupled systems change can be difficult to effect due to 'lock in' effects of strong relationships which resist change. While loosely coupled systems are high in diversity and result in a lack of consistency, tightly coupled systems can be characterised with strong institutional isomorphism, as Di Maggio and Powell (1983) argued.

A summary of the changes to the rules of the system, the immediate effect on the project and the longer-term impact on the market is noted in Figure 3 below.

Figure 3 Effect of changes to rules on projects and market



With the rigidity of tightly coupled systems, one of the largest issues of concern is the possibility of a shock moving through the whole system. The transition from a loosely coupled system to a more tightly coupled system is a transition process that needs to be managed as there is potential for significant negative outcomes if a major player fails. Thus both a tightly coupled system and a loosely coupled system have effects that need to be accounted for in different ways. An industry comprised of a mix of strong and weak ties (one which is neither tightly coupled, nor loosely coupled) could offer the best solution, although maintaining the balance between may not be achieved easily. According to Rhodes (1997) these networked relations and structures require a mix of approaches to be successful.

Conclusion

This study extends previous work by positing that the interaction between firms involved in procurement activities has an effect on the structure of populations of organisations and that actors such as government can either shape the landscape or become actors in the interaction. The study investigated the way in which changes in procurement rules influence the system level within the construction industry. It was found that interaction between actors involved in procurement activities results in the emergence of structure at the population level. The research has addressed the question of the way in which the interaction of agents according to rules in procurement systems has resulted in the emergence of aggregate order in the system. Although the study has

focused on understanding how the procurement of infrastructure assets has changed and is relatively small-scale in terms of a transition, the significant shifts in the outlined three phases demonstrate through the depth and breadth of change, these examples can be considered as a transition. The use of an example to illustrate and explore system change in infrastructure procurement does not directly inform our knowledge about sustainability. However decisions and actions in infrastructure procurement that cause change in the way agents interact within the system and in response to policy from government and this has a macro effect on the industry as a whole. This in turn suggests that changes in the interaction rules can also result in changes at a system level, particularly in order to promote the sustainability agenda.

Transitions occur over a long time period, as outlined by Kemp and Rotmans (2001), but transitions also relate to the constant adjustment of rules and consequences of decisions taken in the short-term. The conceptualisation advanced in this research assists in developing a coherent approach to the management of transitions, as it acknowledges the emergent effects of agent interactions according to rules. Critical to the possibility of a shift to more sustainable infrastructure is the shaping of arena rules by governance bodies, especially state actors. These rules however, are not the only drivers of order within a given system. Results from the case study show that changes to a non-market, in-house system to a market based system of procurement by government, driven by the intention to develop robust competition between suppliers in a market, actually reduced the number of agents vying for procurement contracts. The low number of 'competitors' tendering for delivery of infrastructure to government found in phase two shows that emergent order can be created by agents organising within a system rather than being driven by the arena rules of market-based contracting. However, systems also evolve in response to overarching frameworks of these arena rules such that in-house procurement shifted to market-based procurement and then to collaborative procurement. However, both actions and decisions emanating from arena rules and interaction rules may result in unintended consequences and Complex Adaptive Systems theory assists in our understanding of the unpredictability of system change to achieve intended outcomes. Further, and contrary to expectation about the identity and location of agents in initiating change, these shifts were not found to be driven entirely by society and the value choices of citizens but also by broader forces at the governance level.

From the findings of the examples given here, it is evident that changing the rules of the system can affect the system in significant and sometimes unforeseen ways. In order to manage the emergent effects of transitions in the interaction rules, the consequences of such changes need to be monitored, and the resulting structure of the industry assessed. Changes to rules in procurement have highlighted the way in which rules and emergence in procurement may offer insights into developing a sustainable future for infrastructure. Changes to the interaction rules are likely to result in changes to the nature of individual projects, which over time can result in changes to the structure of industries. The third phase shift in procurement demonstrated that in volatile times characterised by ambiguity and highly complex procurement projects, more collaborative approaches were instigated to find mechanisms to deliver successfully these large-scale projects. The action of agents in the system developed rules to build high trust and find new ways to interact based on contracts that were not highly prescriptive and not focused on low cost budgetary regimes. These conditions may offer a way to understand the requirements for a transition to sustainability as sustainability without appropriate low-cost technological solutions will require the creation of a high trust environment and understanding of contested and ambiguous contextual space.

New collaborative forms of procurement arrangements are becoming increasingly prevalent. Such fundamental shifts from competitive to more collaborative approaches to project governance can be viewed as a major transition in procurement system arrangements and can pave the way for sustainability given the combination of values and relational principles of trust and mutuality embedded in such frameworks. However, just as traditional forms of procurement resulted in unexpected outcomes for the industry, the change to more collaborative forms of procurement is unlikely to result in totally embracing a sustainability agenda. Nevertheless it may provide a way of understanding the shifts required to develop this agenda. It is here that the concept of emergence provides a

useful construct to understand the dynamics and outcomes of procurement systems at the level of organisational field or industry level and contribute to our understanding of governability of system transitions towards sustainability.

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