Change in innovation paths: a critical event analysis

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Abstract
This research focuses on the cyclic nature of innovation and the number of events that occur during these innovation cycles. A multiple case methodology was undertaken where commercialisation and technological innovation paths were mapped and events counted. To test for the differences in the number of events during self-reinforcing periods versus reactive periods, a multiway frequency analysis was used. Our results indicate that significantly more events were required for self-reinforcing periods and that the type of innovation case was also an important discriminator.

Introduction

Early new venture development processes are characterised by large levels of change, uncertainty and learning. These processes, while important for establishing new endeavours/projects, are under researched due to their complexity and non-linear disequilibrium of the innovation (Lichtenstein, 2014). Actors working within such contexts need the ability to observe the results of different processes and alter their actions to incorporate learning processes (Araujo & Harrison, 2002; Thrane et al., 2010). Agency is an important process in how sequences of events within an innovation path are likely to be co-created based on feedback loops. Positive feedback loops are likely to reinforce past processes, while negative feedback loops are likely to drive new processes of disequilibrium and exploration (Lichtenstein, 2014; Arthur, 1994).

These change processes are difficult to work through and have been termed "uncontrollable" (Van de Ven, 2017). They consist of nonlinear cycles of divergent and convergent activities (Van de Ven, 2017). Additionally, new ventures are likely to have greater levels of uncertainty, and effectual logic is more likely to be useful in coping with high levels of uncertainty (Perry et al., 2012). Also, during these early processes of development, ventures are likely to organise and conduct experiments, aimed at reducing or controlling uncertainty (Lichtenstein, 2014).

This study investigates early innovation processes that occur within new ventures. In particular, how fluctuations across innovation paths are influenced by the events occurring along the paths and how negative and positive feedback loops and uncertainty or stress levels affect the outcomes. Therefore, our research question is: What are the associations between types of innovation paths, number of events occurring along those paths and event cycles?

Theoretical development

Innovation paths

Innovation paths have been researched from multiple perspectives and across numerous different disciplines: economics (e.g. Arthur 1989, 1994); entrepreneurship (e.g. Van de Ven et al., 2008); and management/ marketing (e.g. Sydow et al., 2009; Dobusch & Schüßler, 2012; Bergek & Onufrey, 2013; Purchase et al., 2017). This research categorises these different approaches under four broad themes.

First, the path dependence perspective, which focuses on Arthur's (1989, 1994) initial work on increasing returns and path dependence. This perspective highlights that increasing returns result in early lock-in decisions focusing on technology adoption. Thus, decision making may be suboptimal due to self-reinforcing mechanisms and the lack of exploration. It is from this perspective that the term "history matters" emerged, and that technology adoption is not necessarily driven by mechanisms that industry can control and foresee. Most of the research following this perspective focuses at the industry or technology levels, rather than focusing on individual organisations or actors.

Second, the path creation approaches build from some of the notions of path dependence, but have differences in that they highlight the importance of current decision making processes and agency (Garud et al., 2010). Consequently, actors are *"not only embedded in social systems but are also co-constructed by such systems"* (Editors, 2010, p.734). Here the role of agency (Araujo & Harrison, 2002), often neglected in path dependent approaches, is considered important and improvisation, cocreation, and temporal flexibility are included (Makkonen et al., 2014). Most of the research following this perspective focuses at the organisational level.

Third, entrepreneurial researchers considered innovation as a journey following non-linear dynamics. In particular, Van de Ven et al. (2008), through their Minnesota studies, have considered early innovation development as chaotic processes (Cheng & Van de Ven, 1996). Van de Ven and colleagues identified cycles of convergence and divergence (Dooley & Van de Ven, 2017), through evolutionary processes. These cycles are driven by external forces, internal focus, self-organising activities, resource investments, and unit restructuring. Focus is either at the individual or at the organisational level.

Lastly, and again coming from a non-linear dynamics perspective, generative emergence considers innovation paths as an emergent process through which human agency plays an important role, thus differentiating it from a complex adaptive systems perspective embedded in the physical sciences Lichtenstein (2014). Here, innovating organisations go through five phases: 1) disequilibrium organising; 2) stress and experiments; 3) amplification to a critical threshold or event; 4) new order through recombination; and 5) stabilising feedback. Our research focuses on the ‘disequilibrium organising’ and ‘stress and experiments’, which are aligned with overcoming uncertainty, while ‘new order through recombination’ and ‘stabilising feedback’ are similar to converging to a more certain path. There are common threads with the cycles proposed by Van de Ven (2017), which are adopted in this research: e.g., the notion of cycles, how new ventures work with uncertainty and non-linearity of the overall innovation process.

Each of these approaches have resulted in a rich literature around innovation paths, but have often focused on (i) different levels; (ii) different methodological approaches; and (iii) different results, due to different emphasis placed on various constructs (e.g. history, agency, change processes). Yet, there are similarities in ideas of paths, event sequences, change and uncertainty. This research draws mainly on the non-linear cyclic approaches, on notions of multiple innovation paths (Thrane et al., 2010; Bergek & Onufrey, 2013) and considers a cyclic process of experiments. As our focus is along the paths, we follow the approach of Thrane et al. (2010) and Purchase et al. (2017) where two types of innovation paths are examined: commercialisation and technological. Commercialisation paths align with the development of the business, while technological paths align with the development of the core technological product/ service.

Feedback loops, changes and uncertainty

While there is little doubt that new innovative ventures face high levels of uncertainty and constant change processes, what drives these change processes is an under-researched topic. Feedback mechanisms play an important role in influencing change processes. Feedback loops drive learning processes and are important in how new ventures use knowledge to organise their processes (Dobusch & Schüßler, 2012).

Positive feedback loops (self-reinforcing mechanisms/increasing returns) highlight that the processes currently being undertaken are driving positive outcomes and indicate early gains (Arthur, 1994). Thus, new ventures will continue working in the same direction and may even allocate more resources towards reinforcing previous positive returns. This positive reinforcement reduces uncertainty and focuses resources and energy towards building on previous good results. Negative feedback loops (decreasing returns) highlight that the processes currently undertaken are causing negative outcomes, resulting in increasing stress and may lead to a flurry of experiments in an attempt to reduce uncertainty by solving the issues (Lichtenstein, 2014). Upon reaching a threshold event that overcomes the problems highlighted, the new venture recombines resources to stabilise the feedback to positive outcomes (Lichtenstein, 2014).

Cycles along innovation paths

This research focuses on three descriptions of cycles along innovation paths: convergent/divergent cycles (Van de Ven, 2017; Dooley & Van de Ven, 2017); self-reinforcing and reactive event sequences (Araujo & Harrison, 2002); and generative emergence (Lichtenstein, 2014). Van de Ven (2017, p.40) described a convergent process as *“an integrating and narrowing process of exploiting a given direction”* and a divergent process as *“a branching and expanding process of exploring new directions”*. Araujo and Harrison (2002, p.7) defined reactive event sequences as *“initial disturbances*

…that shift the path.. into a new direction and not one that necessarily reinforces the first move", while their description of self-reinforcing event sequences is similar to that outlined in path dependence. By the same token, Lichtenstein (2014) portrayed innovation processes of disequilibrium as consisting of high stress and experimentation. These processes are followed by a threshold event that leads to re-combination of resources to a new order. That may be "triggered" to cycle back to disequilibrium.

The common thread across each of these descriptions is that we have two types of events: a) events that "trigger" high levels of uncertainty through negative feedback loops, e.g. divergent processes, reactive sequences and disequilibrium; b) events to reduce (or control (Perry et al., 2012)) these high levels of uncertainty, such that a new way is found, which "triggers" convergent processes/self-reinforcing mechanism and order. The motivation of this work is to understand this cyclic pattern and the events that occur within each of the cycles.

Innovation events

As indicated, events are the generators for path dynamics. Consequently, this research also focuses on critical events (Halinen et al., 2013) that may influence major changes in the innovation process, such as instigating the convergent and divergent cycles (Dooley & Van de Ven, 2017). These events have been conflated with constraining/ enabling factors (Dooley & Van de Ven, 2017); self-reinforcing mechanisms (Arthur, 1994; Dobusch & Schüßler, 2012); critical threshold events (Lichtenstein, 2014), and critical events (Purchase et al., 2016; Purchase et al., 2017; Halinen et al., 2013).

Research Problem

This research examines cycles along technological and commercialisation innovation paths in three distinct cases. A special interest is on how critical events occurring along each path are associated with the cycles that repeat over time. A number of propositions/hypotheses guided our analysis:

H1: The frequency of critical events influences the cycles of event sequences.

H2: Commercialisation innovation paths require a combination of decisions and resources (measured as events) to achieve convergence or stabilisation periods.

H3: Over time, the number of events decreases if they are on a pathway with reduced uncertainty.

Methodology

A longitudinal multiple case study approach was used to trace the events surrounding technological and commercialisation innovation paths. The use of multiple case studies allows each innovation path to be investigated within its unique context; enables the researchers to analyse the critical events; makes possible investigation of the changes along innovation paths and is an established theory development method (Eisenhardt, 1989; Welch, 2000; Dubois & Gadde, 2002; Halinen & Törnroos, 2005). Multiple case study methods improve on single case study design by offering greater explanatory power through analysis of common general patterns and issues across cases, while explaining differences between cases (Aabeon et al., 2012).

Case data was used to define events and to highlight their impact on the evolution of the innovation paths differentiated in two categories: technological and commercialisation. For example, critical events may trigger feedback loops that influence which cycle occurs along the innovation paths. The frequency and timing of cycles are important for the innovation path. The analysis that was undertaken uses a log-linear type of model, the Multiway Frequency Analysis (MFA). This decision was made based on the type of data extracted from the cases (non-parametric) and on the fact that we explore the relationships among three or more discrete variables. MFA is similar to the χ^2 test of association and develops a linear model of the (ln) of expected cell frequencies. MFA starts with higher level associations and 'trims down' the non-significant relations, before sequentially testing lower-level effects (Tabachnick & Fidell, 2007). More information is offered in the Data Analysis section.

Case description

The three cases selected are renewable energy start-ups in Australia. They were chosen because they all focused on a single industry, renewable energy, however they began from different business models. Case 1 (C1) is a university spin-off organisation initially focusing on the solar energy marketing. This is a small company which now focuses on innovation and licensing of their technology, rather than production. Case 2 (C2) is a diversified private organisation that focuses on wave energy technology. C2 is the largest out of the three cases and has focused on raising capital from the stock market and systems development for generating electricity. Case 3 (C3) began as a private funded venture, focusing on battery technology. C3 is currently listed on the stock exchange and has had multiple marketing strategies over the years, although the technology has remained fairly stable.

Data collection

Data is collected from two main sources across a period of four years: (i) face-to-face semi-structured interviews; and (ii) publicly available secondary data (including newspapers, professional magazine articles, Australian stock exchange announcements and websites). During the initial interviews, interviewees were asked to describe the story of their innovation journey, which allowed for unanticipated data to emerge and new questions to be incorporated into future interviews. In the annual follow-up interviews, interviewees were asked to provide updates to the changes that have occurred over time. Interview data was collected annually in Case 1 from 2013 to 2017; Case 2 from 2013 to 2017; and Case 3 from 2014 to 2017. Secondary data was collected continuously from 2013 to 2017.

Data analysis and results

The data analysis consisted of the following four steps:

1. Defining the critical events;
2. Development of technological and commercialisation innovation paths;
3. Analysis to determine the cycles in the innovation paths;
4. Conducting a Multiway Frequency Analysis to test the hypotheses.

Defining the critical events

Annual interviews and secondary data were analysed to incorporated multiple actor views/perceptions on how each of the innovations developed. To determine the critical events, Leximancer was used to develop a semantic map of the main concepts and their importance across each of the actors (Purchase et al., 2016; 2017). Leximancer uses a learning algorithm to develop clusters of related concepts and themes, which are colour coded, to highlight their overall importance (Smith & Humphreys, 2006). The benefits of using Leximancer include: reducing coder bias; analysing the links between important concepts; and incorporating multiple actor perceptions.

An important feature of multiple case study design is that it enables some form of case comparison (Aabeon et al, 2012). Therefore, a framework of events common across cases was needed to facilitate the case comparison. To obtain coding categories that are both important and relevant to all three cases, the *prominent concepts* for each case were identified and closely examined for their potential associations. These concepts differ across cases due to the different way each of the data sources used language to describe their innovation journey. Leximancer's insight dashboard gives the most prominent concepts for each case, as shown in Table 1.

Table 1: Prominent concepts for each case

Case 1 (BM)	**Case 2 (CWE)**	**Case 3 (RFX)**
Board	Design	Things
Money	Commercial	Doing
Time	Development	People
Company	Funding	Business
Business	Technology	Company
Market	Board	Market
Work	Work	Work
People	Money	Time
Things	Time	Money
Technology	Company	Technology

To examine the associations among prominent concepts across cases, each concept is analysed through its associated text to identify overlaps in their meanings. For example the concept ‘Commercial’ in case 2 was found to overlap with the concepts of ‘Things’, ‘Time’, and ‘Business’ identified in cases 1 and 3. By conducting this analysis across all three cases, the common range of meanings represented by the prominent concepts was derived, which allowed us to develop a common event framework.

Development of technological and commercialisation innovation paths

The events developed above were then coded onto an innovation path, as determined by their direct relevance to the purpose of the innovation path (Table 2). Not surprisingly, commercialisation paths involve more events than the technological paths (419 vs 202). This pattern holds across all cases and has been previously highlighted by Purchase et al. (2017).

Analysis to determine cycles in the innovation paths

Self-reinforcing periods (also known as stabilisation or convergent) are triggered through positive feedback loops, and specific foci/directions are selected in an attempt to reduce high levels of uncertainty. During these periods, resources are expended to confirm the particular direction or focus. Reactive periods (divergent or turbulent) are triggered through negative feedback loops when a specific decision/event (introducing a high level of uncertainty and which needs to be resolved), occurs. During reactive periods organisations explore across multiple possibilities and consider different ways to resolve uncertainty. An analysis of the innovation paths highlighted that Case 1 underwent two cycles of self-reinforcing/reactive periods, while Case 2 and 3 underwent three cycles.

Conducting multiway frequency analysis

In MFA, one of the discrete variables is considered the dependent variable (DV), whereas the others are the independent variables (IVs) and a model is fit if the observed frequencies are closely reproduced. This research uses three variables: 1) case; 2) type of innovation path – commercialisation or technological; and 3) self-reinforcing vs reactive effect (which is also considered the ‘outcome’). The analysis reveals the odds of being in various DV categories as a function of the levels of IV. Whereas we could have included many more categorical variables (e.g. more detail on the type of path), the requirement for independent adequate sample size (5 * number of cells) and expected frequency in all cells (e.g., less than 20% of the cells with frequency below 5), prevented us from dissecting the dataset in more detail and led us to several groupings. For the three variables, we have seven potential associations (one three-way interaction, three second-level interactions, and three main effects). Table 2 presents the summary of the number of events (2 x 3 x 3 MFA), which suggests that if no association was among these factors, the expected frequency per cell would have been 11.5. The number of events varied across cases from simple to double (range 126 to 258), driven primarily by the commercialisation processes.

Table 2: Case data for MFA analysis

Effect		Commercialisation	Technology development	Total
Self-reinforcing	*Total self-reinforcing*	*304*	*101*	*405*
	C1 (BM)	58	12	70
	C2 (CWE)	111	39	150
	C3 (RFX)	135	50	185
Reactive	*Total reactive*	*115*	*101*	*216*
	C1 (BM)	41	15	56
	C2 (CWE)	40	68	108
	C3 (RFX)	34	18	52
Grand Total		419	202	621

The estimation of the MFA model is similar to (M)ANOVA, where the likelihood ratio statistic G^2 is decomposed in terms corresponding to the main effects, as well as interactions. For two independent variables A and B, $G_T^2 = G_A^2 + G_B^2 + G_{AB}^2$ (1)

where G_i^2 corresponds to effect i and G_{ij}^2 to the interaction between i and j, whereas G_T^2 is the total effect that is decomposed.

The fit measures (K-Way and Higher-Order Effects output, not shown here for brevity) indicate that both main effects and interactions are significant, which means that the effect of the number of events on the path outcome depends on both the case and type of innovation path. This was also confirmed by significant partial associations.

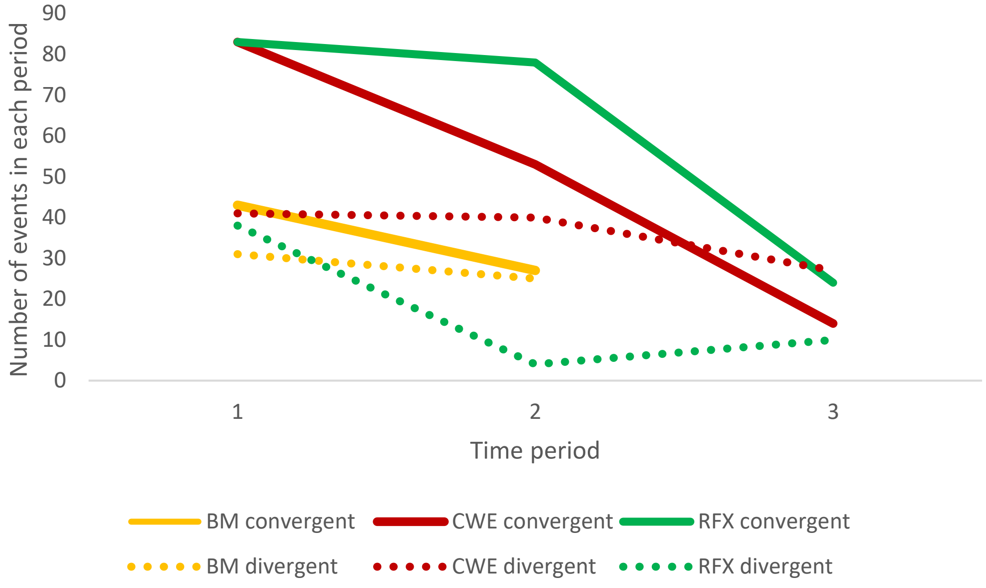
The parameter estimates (Table 3) provide insights in the path cycle outcomes. Compared to case 3, case 2 required more events for self-reinforcing periods (+ve signs) than case 1 (-ve sign) of commercialisation paths and in general it is 'harder' to reduce uncertainty for commercialisation than technology issues, as more decisions/events are needed (+ve sign, 0.205). Case 1 also required the lowest number of events for self-reinforcing periods of both commercialisation and technology development paths. Overall, fewer events are required for self-reinforcing of technological paths (+ve, 0.390) and commercialisation paths are richer in events. As shown by the data and the results, the timing of the events is not explicitly included in this model. Therefore, conclusions on when interventions may be fitting and effective cannot be extracted from this analysis.

Table 3. Parameter estimates

Effect	Par.	Estimate	Std. Error	Z	Sig.
Case*Convergent* Commercialisation	C1 vs C3	-0.071	0.080	-0.892	0.372
	C2 vs C3	0.186	0.064	2.902	0.004
Case*Convergent	C1 vs C3	0.219	0.080	2.731	0.006
	C2 vs C3	0.129	0.064	2.021	0.043
Case*Commercialisation	C1 vs C3	-0.248	0.080	-3.101	0.002
	C2 vs C3	0.261	0.064	4.086	<0.001
Convergent*Commercialisation	1	0.205	0.051	4.053	<0.001
Case	C1	-0.453	0.080	-5.656	<0.001
	C2	-0.355	0.064	-5.550	<0.001
Convergent	1	0.245	0.051	4.838	<0.001
Commercialisation	1	0.390	0.051	7.696	<0.001

Although a formal analysis was not possible considering the time period, Figure 1 presents the frequency of events by case and time period. Consistent with previous findings, self-reinforcing paths are characterised by a higher number of events than reactive paths and C1 recorded fewer events. The diagram also highlights a decreasing trend of the number of events and some non-linearities, which may be reflective of the Van de Ven (2016)'s observation that a 'gestating' period and number of events occur before launching an innovative venture. Also, the charts show that stages of divergent and convergent activities alternate and their pattern may be unpredictable. For example, the 'intersection' of the pathways for C2, between cycles 2 and 3, is illustrative of the simultaneous effect of events directing the commercialisation and technology paths towards convergence or divergence. As described by Van de Ven (2016), these cannot be 'controlled', but understood, and diagnosed, such as innovation leaders/managers can learn to 'manoeuvre' and intervene on divergent and convergent paths with their decisions.

Figure 1: Number events by type of path and time period



Conclusions

This paper presented a combination of case analysis and multiway frequency analysis to investigate the role of events in shaping commercialisation and technology development paths towards convergence and divergence, within the green energy sector in Australia.

The main findings align with previous research by Araujo & Harrison (2002) and Van de Ven (2017) and show that innovation paths are non-linear, but their oscillation between self-reinforcing and reactive event sequences depends on the decision making processes. Commercialisation paths require in general 'more effort' to stabilise, but the speed of processes depends on the case. This means that even within the same industry, 'standardisation' of the evolution and pathways cannot/should not be attempted nor expected. Although there is no chronological time included in the analysis, the number and frequency of events substantiate that commercialisation takes longer and requires a higher level of resources. Companies/managers and decision makers could use monitoring of the innovation pathways to find 'clues' regarding their innovation progression, benchmark new ventures against each other, and perhaps intervene if the outcome is inconsistent with their target.

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