Linking Increasing Returns to Industry-level Change

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Abstract

While the change literature is currently dominated by the punctuated equilibrium paradigm, anomalies have appeared to the paradigm in the form of high velocity change and hypercompetition. D'Aveni (1999) reconciles these anomalies with the punctuated equilibrium paradigm by suggesting that the frequency of change experienced affects the change experienced. This research considered whether the presence of increasing returns in an industry is correlated with the frequency of change experienced by the industry and the types of change that appear, thus providing an explanation for the differing forms of change.

A second observation in the literature is that an industry experiences a period of instability after a discontinuity. This research considered whether the temporal proximity or type of a preceding discontinuity influenced the likelihood or type of later discontinuities.

A longitudinal study identified discontinuities in nine industries throughout the industries' histories. The industries were categorised as: increasing returns, derived from external network effects (Airlines, Data Communications, Electricity and Shipping Lines), complementarity (Information Storage) or information content (Software), respectively; or as constant returns (Aircraft Manufacturing, Telecommunications Manufacturing and Shipbuilding). A comparison of discontinuities has been made between pairs of industries with a common end-user of the industry outputs, where one industry exhibits increasing returns and the companion industry has constant returns, using Binomial Distribution, Fisher's Exact Test and Generalised Linear Modelling techniques. Further Generalised Linear Models tested the interactions of discontinuities.

Industries with increasing returns were found to have greater frequency of change. The types of change experienced were found to affect subsequent change, with both types of discontinuities being correlated with increased proportions of competency-enhancing change for ten years, while competency-destroying and competency-

enhancing discontinuities were associated with increased frequency of change for twenty and ten years, respectively. The evidence associating increasing returns with competency type was unreliable.

Consequently, increasing returns industries may experience a greater variation of frequency of change, with industries entering and leaving periods of enhanced frequencies of change. Thus, industries with increasing returns are more likely to experience change consistent with hypercompetition and high velocity conditions, compared with the punctuated equilibrium style change experienced by constant returns industries.

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1. Introduction

The nature of change is a core question in the strategy literature. The transformation school in particular views change as an essential part of strategy, as firms and industries transform themselves to match changing environments. This research looks at industry-level change and considers the implications of increasing returns upon the change process: an issue of importance to practitioners and academics alike, with practitioners needing guidance upon the selection of strategic models and methods to maximise organisational performance, while the academic community needs to ground its research appropriately to ensure sensible outcomes to research questions and gain enhanced understanding of future strategic developments.

The dominant change model has been progressively developed over the past century. Marx (1906) introduced the concept of revolutionary change, from which Schumpeter (1934) developed the ideas of creative destruction. The current version of the revolutionary change model is the punctuated equilibrium paradigm, which defines change in the form of periods of equilibrium and revolutionary change (Gersick, 1991). Originally proposed to describe macroevolutionary change by Eldredge and Gould (1972), Gersick (1991) integrated individual, group, firm, science history and self-organising systems into a single theoretical framework, while recognising a similarity with industry-level change. Meyer, Brooks and Goes (1990) found evidence that change at the firm and industry level can be highly inter-related, supporting the contention that the punctuated equilibrium paradigm has relevance for understanding change at the industry-level.

However, the punctuated equilibrium model is not without criticism. It has been claimed that in some industries the punctuated equilibrium model does not adequately describe the change observed. Brown and Eisenhardt (1997) describe change in the computer industry as continuous and high-velocity. D'Aveni (1994) describes hypercompetition, where industry incumbents destroy their competencies in order to continually reinvent themselves and to establish new competencies. These two authorities reported findings that contradict the punctuated equilibrium paradigm, thus representing anomalies in the Kuhnian sense (Kuhn, 1970/1996).

D'Aveni (1999, 2001) provides a framework that helps to consolidate these apparent anomalies with the punctuated equilibrium model. The model distinguishes between industries with high and low frequency of change. Change in low frequency industries is described according to the punctuated equilibrium model, while change in high frequency environments results in change similar to the high-velocity and hypercompetition conditions reported by the anomalies.

This research considers whether frequency of change and/or the distribution of discontinuities experienced are associated with the presence of increasing returns in the industry output. The realisation that the industry that Brown and Eisenhardt (1997,1998) researched exhibits increasing returns, and thus provide an explanation regarding the differing change experienced by different industries, was the foundation of this research.

The construct of increasing returns is a well established principle in economics, where some industries have output with an ever-reducing marginal cost, often leading to one company dominating the market. These so-called natural monopolies have historically been associated with network industries, such as railways, shipping and banking.

A second source of increasing returns is complementary products, where the output of one industry derives increasing returns from the output of another industry. Computers are an example of complementary products, with the hardware deriving increased value from increasing amounts of software.

A third source of increasing returns is the presence of information as a significant proportion of the value of an industry's output. This issue is of increasing importance as a consequence of increasing computerisation across all industries and the trend towards separating information output of an industry from physical production. The computer industry was the first such industry, when perfection of the stored program computer in 1949 enabled the separation of the information product from the physical medium storing the information. Since that time there has been a growing diffusion of computerised technology into all other industries, allowing the instructions to operate products to be separated from the products themselves. Arrow (1996, 1999) noted that this separation of information provides for increasing returns in a previously constant returns industry.

This research used a longitudinal study of nine industries comparing increasing returns and constant returns industries with common end-users of their output to test the hypotheses that: (1) increasing returns are associated with the different rates of frequency of change; (2) increasing returns influence the type of change experienced; and (3) change can affect the types and/or distribution of further change being experienced. The addition of the last hypothesis enables consideration whether change may affect further change, and would provide further insight into any finding of the first two hypotheses.

Six industries were selected on the basis of having increasing returns by the nature of being network industries or having an information-intensive output or by being complementary products to an increasing returns industry: Airlines (1919-2003), Data Communications (1791-2003), Electricity (1870-2003) and Shipping Lines (1807-2005) are industries with network effects, the Software (1890-2003) industry has a significant information component in its output and the Information Storage (1890-2003) is complementary to the Software industry. The research spans the period from the creation of the industry until the latest reliable data available. A corresponding industry with constant returns and the same end-consumer for the industry output pair was determined for the first four industries: Aircraft Manufacturing (1919-2003) for Airlines; Telecommunications Manufacturing (1791-2003) for Data Communications; and Ship Building (1807-2003) for both Electricity and Shipping Lines. The Software and Information Storage industries have been included in the research as an extended dataset to improve the reliability of the Generalised Linear Model used as part of the data analysis.

The data were sourced from secondary sources. Published industry histories and Internet hosted information were used to build the dataset for each industry. Competencies were identified as competence-enhancing through an increase in the economics of the industry so significant that the earlier technologies were displaced over time, or as competence-destroying when the basic knowledge of the industry was devalued and new entrants were able to successfully enter the market (Tushman & Anderson, 1986).

The research first tested the data for a significant difference in frequency of change between the increasing returns and constant returns industry for each industry pair. First, tests were conducted using Binomial Distribution, Fisher's Exact test and Generalised Linear Model techniques. Second, a Generalised Linear Model (GLM) was used to test: (1) whether the occurrence of a competence-enhancing or competence-destroying discontinuity 0-10 or 11-20 years earlier affected the likelihood or type of a discontinuity; and (2) whether the returns in the industry influenced the proportions of competence-destroying versus competence-enhancing discontinuities that were experienced. Third, sensitivity tests were conducted to determine whether the selection of ten year periods for the GLM analysis affected the results, with the GLM tests repeated with eight year and eleven year periods.

Finally, a conclusion was drawn from the analysis of the data. The significance of findings of the research is discussed and some ideas for further research noted.

2. Literature Review

2.1 Introduction

The literature that defines change theory has been examined for a potential relationship between increasing returns and change. The development of the punctuated equilibrium paradigm has been traced and its components defined. Two anomalies to the paradigm have been observed and D'Aveni's (1999) framework reviewed as an extension to the paradigm. The D'Aveni framework defines environmental change in terms of two constructs: type of change and frequency of change. These constructs, as well as the literature's definition of turbulence, uncertainty and discontinuities (change events), have been drawn upon to provide the foundation for the D'Aveni framework.

Having reviewed the strategy literature on change, this research has examined the economics literature on increasing returns. A distinction has been drawn between: direct network effects, where consumers gain benefits from additional consumers using a product; indirect network effects or complementarity, where an industry's product derives increasing returns from a complementary product; and the commodity nature of information, where the costs of creating a product diminish with each additional unit.

Finally, the research has identified the gaps in the literature. A conclusion has been drawn regarding the value of examining the potential linkage between returns to scale and industry-level change and the impact upon practice.

2.2 The Development of the early Change Literature

The gradual change model of slow, stately, essentially uniform rates of change was first proposed by Hutton in 1785 (1911 Encyclopedia, 2003a) and further developed by Lyell in 1829 (Gould, 1991) as an explanation of geological formation. Darwin (1859) incorporated gradual change into his theory of evolution but rejected the prevalent notion of determinism, whereby change is a goal directed process (Kuhn, 1970/1996). Darwin instead claimed that evolution moves from low levels to high levels (Gould, 1997).

Gradualism became the dominant change paradigm in the nineteenth century and had significant influence beyond macroevolution. The economist Marshall incorporated Darwin's slogan *natura non facit saltum* (nature does not proceed in leaps) as the subtitle for *Principles of Economics* (Marshall, 1907), a seminal work that was significant in establishing modern economics as a major academic discipline. As a consequence, gradualism formed part of the foundation of modern business theory through its economics ancestry. Today the concept of the moving general equilibrium, in the language of economics, is the dominant change paradigm in economics (Nelson, 1995). Evolutionary economics has emerged as a relatively new sub-discipline, with Nelson and Winter (1974) being important early contributors examining firm-level change where firms adapt through learning and experimentation to an exogenously determined environment (Nelson, 1995).

The emergence of a competing change model can be traced to Marx's (1906) revolutionary theories that advocated radical discontinuous change. Marx's theories incorporated determinism, as he claimed that it is inevitable that progress moves from one environmental state to another (Gould, 1992).

Schumpeter (1934) introduced non-gradual change into mainstream economics, noting that economic change occurs "discontinuously in groups or swarms" (p. 223), and used the observation for developing the theory of business cycles. Schumpeter did not accept determinism and adopted instead the evolutionist's position that change is path dependent, in that the options available for change are limited by the existing state. Schumpeter (1976) developed the model of endogenous growth where the firm invested in new technologies and products to compete against competitors.

Radical change was introduced into organisational theory by Greiner (1972), who defined change in terms of evolution and revolution. However, Greiner also exhibits vestiges of determinism is his firm-level model of radical change.

The emergence of the transformational school of strategic management with Khandwalla (1970) and its subsequent growth (Mintzberg, Ahlstrand & Lampel, 1998) has generated increasing interest in change. Early research, such as Miller and Friesen (1980, 1982) and Pettigrew (1987), adopted radical change models to explain organisations moving between different configurations to better match exogenously changing environmental conditions.

Further research added exogenously driven industry level analysis, with Tushman and Anderson (1986) and Anderson and Tushman (1990, 2001) demonstrating the causal linkages between environmental change, firm exit, abundance of resources (munificence), turbulence and competency characteristics (competence-enhancing and competence-destroying).

2.3 Change Paradigm

The development of radical change in strategic management coincided with similar theories in other communities, including macroevolution (Eldredge & Gould, 1972) and science history (Kuhn, 1970/1996). The most influential development was Eldredge and Gould's (1972) punctuated equilibrium model, which explained evolutionary trends as a series of steps, consisting of periods of punctuations and stasis, rather than rolling up an inclined plane as described by the gradual change model (Gould, 1983). Since its introduction, the punctuated equilibrium model has replaced Darwin's gradualism as the dominant explanator for the evolutionary record (Gould & Eldredge, 1993).

Gould (1985) also noted that the evolutionary pressure on species varied over time, resulting in varying rates of change. Further, as macroevolutionists also reject determinism, the pre-punctuation stasis does not predetermine the nature of the post-punctuation stasis (Gould, 1985). The macroevolutionary discipline recognises change as varying over both time and magnitude dimensions.

Tushman and Romanelli (1985) introduced punctuated equilibrium to strategic management, with convergent periods punctuated by short periods of reorientation of strategy, structure, power and controls, created by industry discontinuities, product-life-cycle shifts and internal company dynamics. Meyer, Brooks and Goes (1990) applied the punctuated equilibrium model to industry-level change, finding that "although the firm, network and industry were distinct units of analysis, ... changes occurring at different levels can be highly interrelated" (p. 107).

Gersick (1991) consolidated the punctuated equilibrium theory across six disciplines, incorporating Eldredge and Gould (1972), Kuhn (1970/1996) and Tushman and Romanelli (1985), to produce a single coherent change model. Gersick (1991) defined three main components to punctuated equilibrium: deep structure, equilibrium periods and revolutionary periods. Deep structures are formed of differentiated parts that interact and exchange resources with the environment in a manner defined by the differentiation, underlying their established competitive positions (Wollin, 1999). Equilibrium periods are times when an organisation makes incremental adjustments that do not change their deep structure to meet internal and environmental fluctuations. Revolutionary periods are created by internal change that misaligns the differentiated parts or by environmental change that threatens the ability to obtain resources, resulting in a dismantling of the deep structure and the forming of a new differentiation.

Wollin (1999) extended Gersick's (1991) deep structure by adding multiple layers and nested branching. Deeper levels are more resistant to change than shallower levels, creating inertia. The effect of internal or environmental change upon deep structure depends on the level affected, from little to transformational system-wide change.

The punctuated equilibrium model has been well supported by empirical research over the years. Evidence supporting the paradigm can be found in organisational transformation (Romanelli & Tushman, 1994), in public policy (Meijerink, 2005; Jones & Baumgartner, 2005), the mutual funds industry (Siggelkow, 2002), in aligning information systems with organisations (Sabherwal, Hirscheim & Goles, 2001), in education (Gold, 1999), in explaining technology diffusion (Loch & Huberman, 1999), in understanding the pace, sequence and linearity of radical change (Amis, Slack & Hinings, 2004) and the development of law (Devereaux *et al.*, 2005), amongst others.

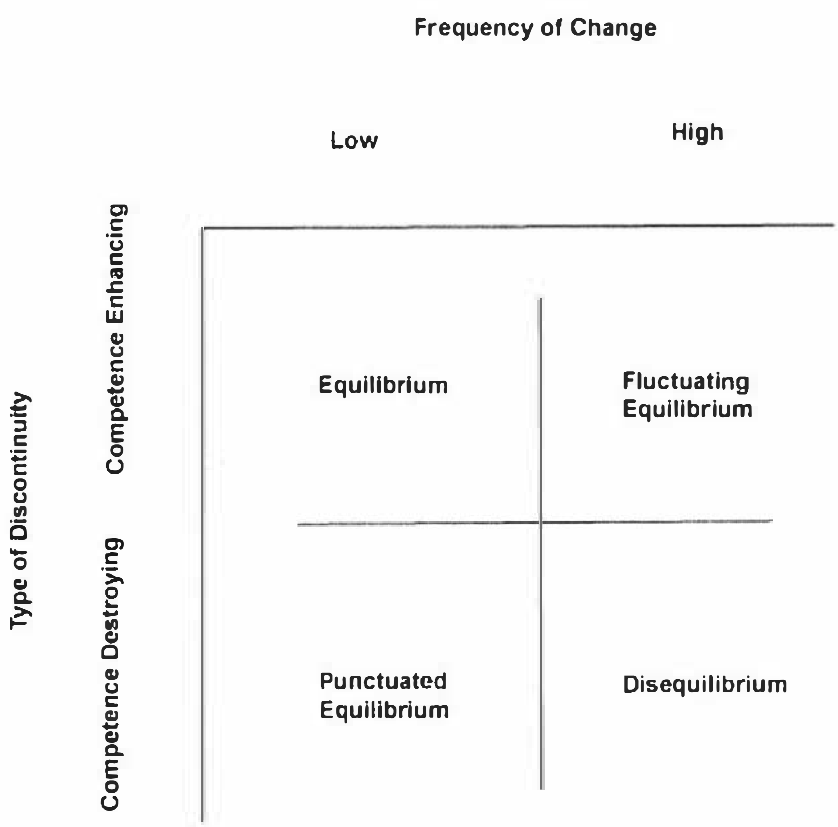
However, the validity of the punctuated equilibrium paradigm has been challenged by Brown and Eisenhardt's (1997, 1998) finding that the computer industry experiences 'high-velocity' continuous change, rather than equilibrium periods with punctuated change periods. A second anomaly is D'Aveni's (1994) hypercompetition model of high-velocity, continuous and radical change, with emphasis on inventing new competencies to replace old competences as the basis for ongoing competitive advantage. Two empirical studies supporting the hypercompetition model are McNamara, Vaaler and Devers (2003), who found evidence supporting varying hypercompetitive conditions, and Wiggins and Ruefli (2005), who claimed that hypercompetitive conditions are increasing across a broad range of industries and not just high technology and manufacturing industries.

These apparent anomalies have created the need for reviewing the dominant change model. However, the literature is silent regarding an explanation as to why these anomalies experience different patterns of change.

2.4 D'Aveni Framework

D'Aveni (1999, 2001) responded to the need for an enhanced change model to incorporate the anomalies. D'Aveni's (1999, 2001) change framework relies on two constructs: frequency of change and the type of change, defined as competence-enhancing or competence-destroying. The D'Aveni framework is illustrated in figure 1.

Figure 1: The D'Aveni Framework



In conditions of low frequency, a competence-enhancing change reinforces an organisation's access to resources and its deep structure, hence creating equilibrium conditions, while a competence-destroying change threatens access to resources and results in a punctuation, or a revolutionary period in Gersick's (1991) terminology. Hence, the low frequency condition is consistent with the punctuated equilibrium model.

However, both the computer industry researched by Brown and Eisenhardt (1997) and D'Aveni's (1994) hypercompetitive industries experienced high frequency of change. D'Aveni (1999) defines a fluctuating equilibrium as consisting of rapid and continuing series of competence-enhancing change, which is consistent with the continuous product cycles reported by Brown and Eisenhardt (1997). A rapid and continuous series of competence-destructive changes is defined as a disequilibrium, as portrayed in hypercompetitive conditions (D'Aveni, 1999).

Thus, the D'Aveni framework is both consistent with earlier research and reconciles the anomalies to the punctuated equilibrium by incorporating frequency of change as an additional construct in the change model. The framework provides a useful method for understanding change in both the high-velocity high-technology industries and in more traditional industries with slower rates of change, and thus is a useful extension to the punctuated equilibrium paradigm.

2.5 Constructs

This research is based upon the industry level of analysis, and thus the constructs used need to be valid at this level. Gersick (1991) developed the punctuated equilibrium paradigm in terms of organisational and sub-organisational level theory, and therefore there does not provide justification for applying the theory to a different unit of analysis, such as the industry level. D'Aveni (1999) described change theory primarily in terms of organisational level theory, but made occasional references to industry level, albeit without theoretical justification for shifting units of analysis. However, Meyer, Brooks and Goes (1990) did demonstrate that change was inter-related between the firm and industry-level, and thus there is support in the literature for applying change theory developed at the organisational theoretical level, such as Gersick's (1991) punctuated equilibrium paradigm and the D'Aveni (1999) framework, to the industry level.

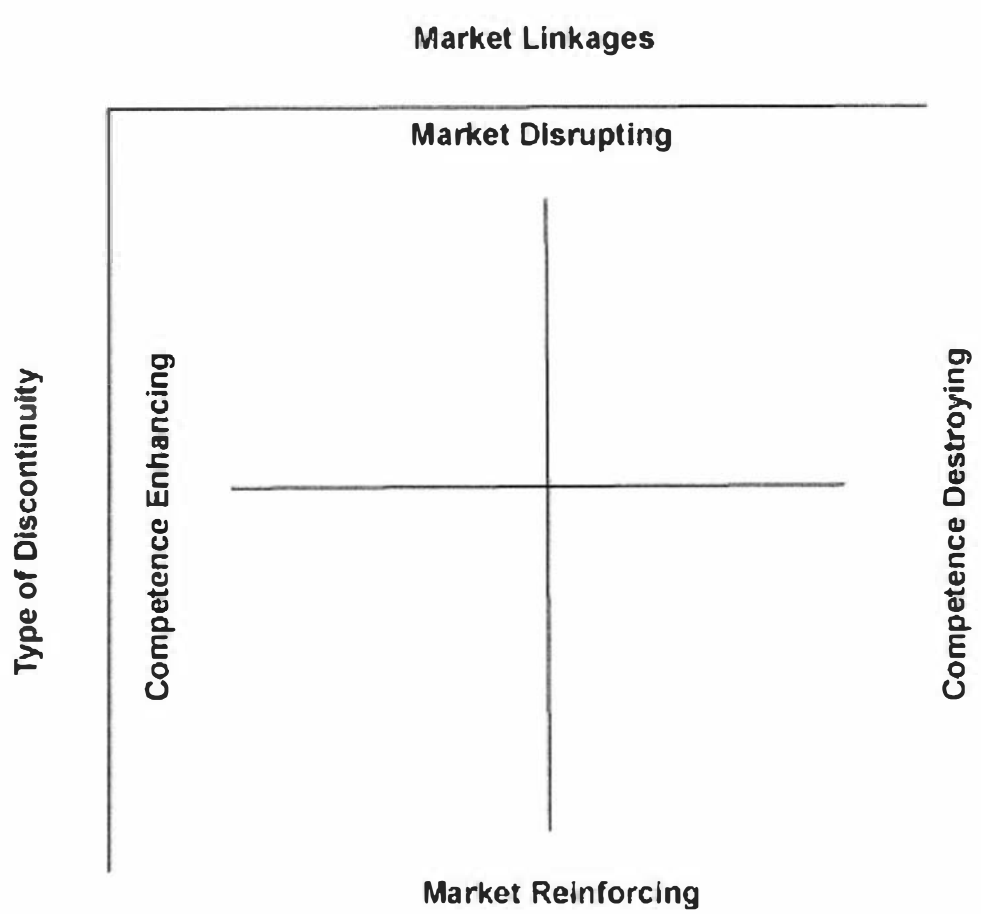
The D'Aveni (1999) framework relies on two constructs, discontinuities and frequency, which are defined and discussed in terms of the change literature. Further, turbulence is explored to differentiate this construct from frequency of change and to demonstrate the conceptual confusion of this construct in the literature, while uncertainty is considered in its impact on the theory relating to the other constructs.

Discontinuity

The first construct has been termed a discontinuity (Tushman & Anderson, 1986), a frame-breaking change (Tushman & Romanelli, 1985), a disruption (D'Aveni, 1994, 1999; Wollin, 1999) and a transition (Brown & Eisenhardt, 1997). These terms all describe the event that creates a change, and thus the terms are essentially synonymous. Gatignon *et al.* (2002) admits that there is confusion and ambiguity regarding this and other constructs in the literature, and so this research has standardised on 'discontinuity' as the term to describe the change.

The definition of discontinuity has evolved over time. Schumpeter (1976) defined such changes as those that "command a decisive cost or quality advantage and that strike not at the margins of the profits and the outputs of existing firms, but at their foundations and their very lives" (p. 84). Abernathy and Clark (1985) made the distinction of discontinuities as competence-enhancing or competence-destroying, with competence defined as the skills, knowledge and material used to produce products for the market. Abernathy and Clark (1985) introduced their transilience map to classify discontinuities as (1) competence-enhancing, (2) competence-destroying, (3) market disrupting or (4) market reinforcing, as illustrated in figure 2.

Figure 2: Transilience Map



Tushman and Anderson (1986) reduced their classification to: competence-enhancing, defined as improving the price/performance of an industry's output by an order of magnitude; and competence-destroying, defined as those technologies that devalued the industry knowledge; and used a narrower definition of competence as skills and knowledge only. Tushman and Anderson's (1986) use of competence-enhancing and competence-destroying change is consistent with Gersick's (1991) punctuated equilibrium paradigm. Gersick (1991) defined punctuated equilibrium in terms of equilibrium periods that do not destabilise existing deep structure configurations, and thus exercise and reinforce existing competencies, and revolutionary periods that destabilise deep structure and create new configurations, thus destroying old competencies and creating new competencies.

However, Abernathy and Clark (1985) also incorporated the disruption and reinforcement of market linkages in their change model. Abernathy and Clark's (1985) recognition of market-disrupting changes is consistent with the observations of Bower and Christensen (1995) of market disrupting change in the hard disk drive industry, and hence there is justification for considering market induced change in a change model. Further, Bower and Christensen's (1995) demonstration that disruption of customer linkages can induce radical change in an industry is also consistent with Gersick (1991), who noted that a radical form of change will occur when either a firm's access to key resources is threatened or when its competencies are eroded.

In the long-run, the results of market disrupting changes are to either lower barriers of entry into the industry or to eliminate a class of customers from the industry's market. The long-run is used in this paper in the economics sense as sufficient time for labour and capital to move freely between firms and industries (Wikipedia, 2005; Milgrom & Roberts, 1992), for an industry to realise all supply-side increasing returns and for the new technology introduced by a discontinuity to dominate an industry.

Anderson and Tushman (1990) measured the time required for a technology or method to dominate an industry, terming this period the era of ferment. A period of an average of eleven years following a competence-destroying discontinuity and eight years following a competence-enhancing discontinuity exists during which it was uncertain which platform technology would come to dominate an industry. This era of ferment varied between a maximum period of twenty years and a minimum period of seven years identified in their research.

Nair and Ahlstrom (2003) found that the length of the era of ferment can be influenced by innovations in subsystems, partitioning of markets, regulatory regimes and uncertainty, which can all lead to lengthened competition between rival technologies and methods, thereby delaying the dominance by the new technology or enabling coexistence. Thus, a discontinuity requires a period of time to displace the earlier technology or method, and this period can vary.

Hence, both competence-destroying discontinuities and market disruptions have the capability to generate revolutionary change. In the long-run market-disrupting change has a similar effect on the post-discontinuity industry as competence-destroying discontinuities, as defined by Tushman and Anderson (1986), in that there is an influx of new entrants into the industry and a devaluation of skill associated in dealing with a class of customer.

Similarly, market-enhancing changes tend to increase barriers to entry and reduce the number of industry incumbents over the long-term, though individual firms may continue to prosper (Hill & Rothaermel, 2003). Market-enhancing changes are thus consistent with the long-run effects of competence-enhancing changes reported by Tushman and Anderson (1986). Therefore, competence-destroying and market disrupting discontinuities can be considered equivalent in the change they induce, and similarly competence-enhancing and market-enhancing discontinuities, for the purposes of applying the D'Aveni framework.

Frequency

Frequency is the number of discontinuities over a period of time. Frequency is used in the D'Aveni (1999) framework to differentiate between fluctuating equilibrium and equilibrium, and between punctuated equilibrium and disequilibrium.

Earlier authorities such as Miles, Snow and Pfeffer (1974) and Cameron, Kim and Whetten (1987) have referred to rate of change, but have not explicitly looked at the temporal dimension. Indeed, the recognition that turbulence exists when change is rapid is the closest the authorities come to recognising that the rate of change can vary both on a temporal dimension as well as a magnitude level. Hence, this research is explicitly using frequency as a distinct construct separate from turbulence, and has used frequency to maintain consistency with D'Aveni (1999).

Further, Schumpeter (1976) first proposed that the environment varied over time, while Nelson (1995) linked Gould's (1985, 1980) contention that evolutionary pressures are not constant into the economics literature upon evolutionary change. Hence, there is a basis for considering that frequency of change is not a constant.

Turbulence

Unlike frequency, turbulence is a construct that has existed in the literature for some time. Turbulence exists when changes faced by an organisation are nontrivial, rapid and discontinuous (Cameron *et al.*, 1987). However, the definition of turbulence in the literature is less than satisfactory.

Siggelkow and Rivkin (2005) equate the constructs of turbulence, dynamism, velocity and uncertainty, where changes are frequent, profound and difficult to predict (p.103). Bourgeois and Eisenhardt (1988) defined high velocity environments as "those where there is rapid and discontinuous change" (p. 816), and in a state of continuous dynamism in the Dess and Beard (1984) sense.

However, Dess and Beard (1984) use dynamism as a combination of turbulence and stability-instability, noting that "turnover, absence of pattern and unpredictability are the best measures of environmental stability-instability" (p. 56). Dess and Beard (1984) then recognise Miles *et al.* 's (1974) separation of uncertainty and rate of change, and conclude that "dynamism should be restricted to change that is hard to predict and that heightens uncertainty" (p. 56).

The situation is confused by early authorities not distinguishing between uncertainty and rate of change. However, Cameron *et al.* (1987) has observed that uncertainty and rate of change have been considered separate constructs since Miles *et al.* (1974) noted that some authors "have not distinguished between rate of environmental change and degree of uncertainty (unpredictable change) and have, therefore, implicitly equated the two" (p. 248). Miles *et al.* (1974) discuss rate of change and turbulence separately, equating a perception of substantial change and uncertainty with turbulence (p. 258).

Hence, there is support for D'Aveni's (1999) differentiation between turbulence and frequency of change, with turbulence being the rate of change in the magnitude of the measured property that varies over a time period. High velocity change can be seen in terms of time between change rather than turbulence, while dynamism can be seen as turbulence plus uncertainty and uncertainty as a separate construct. This interpretation is at odds with Siggelkow and Rivkin (2005) equating turbulence, dynamism, velocity and uncertainty, and demonstrates confusion regarding the construct's definition.

To add to the confusion, another authority Chakravarthy (1997) uses complexity and dynamism as the determinants of turbulence, by citing an early authority (Emery & Trist, 1965), and then equated dynamism with rate of change. Chakravarthy (1997) measures complexity by the number of factors required to determine a firm strategy. Thus, there is an inconsistency with Dess and Beard (1984), as Chakravarthy (1997) implies that dynamism is a causal factor of turbulence, while Dess and Beard (1984) state that turbulence is a causal factor of dynamism. Further, Chakravarthy (1997) also sees uncertainty as a cause of turbulence, while Dess and Beard (1984) link uncertainty with dynamism. Therefore, it would appear that Chakravarthy (1997) may not be consistent with other modern literature.

Cameron *et al.* (1987) also note "a great deal of obscurity and diversity also exists in the literature regarding the appropriate measure of turbulence" (p. 230). They linked turbulence and volatility at one point, when they noted that "measuring relative variation from the mean or summative change, as has been done in almost all studies that have tried to assess turbulence and volatility objectively ... confounds turbulence with decline and growth" (p. 230-1). They adopted a measure of revenues that was "uncorrelated with either the mean revenues or the trend to increase or decrease revenues year by year [to] separate conditions of decline from conditions of turbulence" (p. 230-1).

Cameron *et al.* (1987) and Dess and Beard (1984) both measured the magnitude of a measure at fixed time periods to determine turbulence. Similarly, Miles *et al.* (1974) implicitly looked at the magnitude of the change occurring in their reference to turbulence. Siggelkow and Rivkin (2005) also looked at peaks and troughs at fixed time intervals, using a fixed frequency of change and the magnitude of change to create turbulence.

The common element is that all these authorities look at the variable magnitude of the change experienced over a given time period. None of the authorities look at the variable time period between a given magnitude of change to generate turbulence.

Therefore, turbulence can be defined as the change in the change of the magnitude over time. A measure that varies at a constant rate has no turbulence (Cameron *et al.*, 1987), but the change of that rate of change is the turbulence of the measure. This use of the construct is consistent with Tushman and Anderson's (1986) use of turbulence. This definition is explicitly different from frequency of change, which is the number of changes over time, and thus supports D'Aveni (1999)'s separation of the two constructs.

Further, as greater frequency of change of the same magnitude would generate greater turbulence, as there is more change to be measured within a given period of time, but greater magnitude has no impact on the number of changes, then turbulence can be perceived as an outcome of frequency of change. Thus, D'Aveni's (1999) reference to rapid turbulence being associated with high frequency of change environments is an implicit acknowledgement of the relationship between frequency of change and turbulence.

Finally, Tushman and Anderson (1986) found that turbulence is affected by the nature of discontinuities experienced. Competence-enhancing discontinuities reduce turbulence while competence-destroying discontinuities increase turbulence. They conjectured that competence-enhancing discontinuities progressively consolidate an industry and that a competence-destroying discontinuity would reset an industry's evolutionary clock.

Uncertainty

Duncan (1972) found that the rate of change and uncertainty are not independent variables, while Miles *et al.* (1974) equated uncertainty with unpredictable change. Lawrence and Lorsch (1967, p. 28) defined environmental uncertainty in terms of three components: (1) the lack of clarity of information, (2) the length of the time span to receive definitive feedback and (3) the general uncertainty of causal relationships. Uncertainty can be perceived as affecting deep structure (Gersick, 1991; Wollin, 1999) through: (1) the introduction of time lags into the feedback mechanisms; and (2) by reduction of inertia through less effective linking of deep structure layers.

Tushman and Anderson (1986) found evidence that both competence-enhancing and competence-destroying discontinuities generate uncertainty. Anderson and Tushman's (1990) era of ferment would, as a consequence of delaying the emergence of a new dominant technology or method, generate uncertainty within the industry, which could destabilise the industry's deep structure and thereby increase the likelihood of a competence-destroying change instead of competence-enhancing change.

Further, successive competence-enhancing discontinuities generate decreasing levels of uncertainty (Tushman & Anderson, 1986). Therefore, the likelihood of a competence-destroying discontinuity being triggered instead of a competence-enhancing change will decline over time through decreasing pressure on deep structure.

In addition, increased turbulence may influence the type of change experienced though inducing greater uncertainty and thus an increased effect on deep structure, resulting in more radical forms of change and heightened turbulence, as a competence-destroying discontinuity resets the industry clock and increases turbulence (Tushman & Anderson, 1986). Therefore, uncertainty plays a role both as an outcome of turbulence and as a factor inducing increasing turbulence. The literature does not consider this point.

Finally, as uncertainty destabilises deep structure and thereby induces change, it is likely that change can be triggered more rapidly with uncertainty than without uncertainty. It is possible that high turbulence may induce uncertainty and hence greater frequency of change. As a competence-destroying discontinuity creates greater turbulence (Tushman & Anderson, 1986), this type of discontinuity may induce greater frequency of change. Hence, there is a potential link between turbulence, uncertainty and frequency of change that has not been explored in the literature.

However, this research focuses on frequency of change, and turbulence and uncertainty are beyond the design of this research. Instead the understanding of turbulence and uncertainty is used to provide further understanding of the literature foundation upon which this research is based, insights into patterns of change and a base upon which to progress further research into change.

2.6 Increasing Returns

The economics literature provides an insight that this research has used to test as a possible explanator for change. Increasing returns can be traced back to Adam Smith and his pin factory model (Arrow, 2000), where specialisation provides increasing internal returns to the firm. Smith's firm increased its volume of production for given inputs of labour and capital through changing the method it organised its inputs, and hence the gains were sourced internally.

Marshall (1907) refined the theory, defining increasing returns as "an extra return larger in proportion than it gives to his present expenditure" (p. 151) and diminishing returns as "an extra return smaller in proportion than he gets for the last applications of capital and labour" (p. 151). Marshall based his definition upon Senior's 1836 postulates (Schumpeter, 1994), which included the necessary condition of a "given and constant technological horizon" (p. 584-5). Hence, a firm producing a product with increasing returns experiences an improved benefit/cost ratio for each unit produced for a given state of technology.

However, if all firms could realise increasing returns in the nature of Smith's pin factory, then the natural consequence would be for one firm to develop a price advantage in the market and drive all other firms out of the market. As this was not the case, Marshall (1907) repositioned increasing returns as externally sourced to allow organisations to compete within a market by allowing growth at the expense of other industries (Marchionatti, 2003), thus reconciling competition and industry-level increasing returns (Buchanan & Yoon, 2000).

Two major sources of increasing returns are: (1) the economic nature of information; and (2) network effects, also known as positive feedback, demand-side increasing returns and network externalities (McGee & Bonnici, 2002). Products with network effects derive increasing returns from users gaining an additional benefit or a reduction in cost from each additional node in the network (Saloner & Shepard, 1992).

Katz and Shapiro (1985) use the terminology of direct and indirect to describe the two forms of network effects. Katz and Shapiro (1985) use the examples of telephone and telex networks for direct network effects, where the greater the number of users of a product such as a telephone, the greater the utility the phone has for the individual user. As this product, in this example, would then displace communications products from other industries, the direct network effects are consistent with Marshall (1907).

The indirect network effect is derived from a complementary product with increasing returns (Katz & Shapiro, 1985; Ohashi, 2003). In this case, the more that the complementary product is available, the greater the utility of the first product to the consumer. Ohashi (2003) found that video cassette recorders derived indirect network effects from video productions, while Katz and Shapiro (1985) described computers as deriving indirect network effects from software. In these examples, the increasing returns for VCRs and computers would come at the expense of other forms of entertainment and information technology, such as books, and thus indirect network effects are also consistent with Marshall (1907).

Shapiro and Varian (1999) divide increasing returns into demand-side and supply-side, similar to Marshall's (1907) external and internal sources of increasing returns, respectively, as demand-side increasing returns are sourced externally from the market while the supply-side increasing returns are sourced internally from the firm. Learning by using, scale economies in production and information search costs and risk reduction are supply-side increasing returns (Arthur, 1988; Shapiro & Varian, 1999), and have natural limits to their increasing returns that are realised by a firm at a competitive level below industry dominance. Hence, supply-side increasing returns have more effect on a firm-level analysis than on an industry-level analysis.

However, supply-side increasing returns may provide an explanation for the era of ferment reported by Anderson and Tushman (1990, 2001), as an industry requires time to fully learn the use of a new technology, to realise the optimal economies of scale and to overcome search costs relating to the new technology, and hence for a new deep structure to come into alignment. These sources of increasing returns become incorporated into the new equilibrium established after a discontinuity, as any increasing returns from these sources are fully realised by an industry over time, in line with Marshall (1907), and thus these sources of increasing returns do not have a long-run effect upon the frequency or nature of further change experienced by the industry.

Shapiro and Varian (1999) explicitly refer to network effects as demand-side increasing returns. Demand-side increasing returns have little effect within a market for compatible technologies, and hence have little influence at the firm-level. However, incompatible products in the same market, such as different railroad gauges or VCR standards (Shapiro & Varian, 1999; Ohashi, 2003), lead to competition between two standards and usually the eventual emergence of one as the dominant standard for the industry. Further, demand-side increasing returns are not exhausted below the level of industry dominance, as demonstrated by the example of Microsoft Windows operating system standard, where additional benefit was created for software firms for each user adopting the standard and additional benefit was created for each user for each software firm that provided software operating upon that standard at all competitive levels up to one hundred per cent of the desktop operating system industry output. Thus, demand-side increasing returns are of interest for industry-level analysis.

However, there is a further source of increasing returns noted by McGee and Bonnici (2002) that is surprisingly absent from Shapiro and Varian (1999). Information also derives increasing returns internally. It is now recognised that information can be a product in its own right, with the software industry creating value almost entirely from an information product. Arrow (1996, 1999) demonstrated that information meets the definition of a commodity, in that it is costly to create and valuable. However, once created, information can be reused repeatedly, in contrast to the physical resources that are used to create products can only be used once. Hence, information intrinsically has increasing returns (Arrow, 1996) and it is reasonable to expect that those products where information forms a significant component of their value to also exhibit increasing returns.

Further, an information product can also have network effects. In the case of a software application, each user gains additional advantage from their software from each new user that adopts the same software, as they are able to transfer and share their databases for additional mutual benefit. Indeed, Shapiro and Varian (1999) note that industries can experience both supply-side and demand-side increasing returns, and use the software industry as an example. Thus, an industry with information-intensive output can experience increasing returns from more than one source.

The limited research linking increasing returns to discontinuous change was recognised by Gould (1992), who noted that "economics scholars are only now bringing discontinuities into a central place in their field, mainly through the study of increasing returns to scale" (p. 14). When one considers that the founder of modern information economics Kenneth Arrow (Arrow, 1962) declared in Arrow (1996) that economics had, by its focus on information as a risk reduction tool, missed the main economic effect of information in its role as a product and its intrinsic increasing returns; and that one can readily observe the increasing use of electronic products, online information, and general computerisation of society is leading to an increasing information component in practically all industries; then there is obvious value in examining the effect of increasing returns upon industry.

Increasing returns has only had limited exposure in the strategy literature. Arthur (1996, 1999) proposed increasing returns as an explanator for industries such as the computer operating systems and knowledge-based industries in general, casting increasing returns as the source of positive feedbacks that lead to dominance by one player in an industry. The strategy analysis examining increasing returns to date has largely concentrated on network effects, with research on the video gaming (Shankar & Bayus, 2003), VCR (Ohashi, 2003), telecommunications (Majumdar & Venkataraman, 1998), computer (Chakravarthy, 1997) and consulting (Sarvary, 1999) industries. Only recently has a fuller range of increasing returns been considered, with van den Ende and Wijnberg (2003) looking at bandwagon effects and network effects at the sub-firm level.

2.7 Gaps in Literature

The lack of research into the effects of increasing returns upon change is a significant gap in the literature. Increasing returns are a long-established principle in economics, yet it appears that measurement difficulties have discouraged researchers from considering the impacts of differing returns on business theory (Arrow, 1999). This gap is particularly puzzling when one considers the rapid rise of the economic importance of information products fueled by the diffusion of computerisation, and may reflect more the difficulty of collecting data on increasing returns than the importance of the concept.

Further, while network effects in industries such as banking, airlines and software have been studied (Katz & Shapiro, 1985; Ohashi, 2003; Saloner & Shepard, 1992), the research has not been linked back into the change literature. The differing nature of products provides a possible but hitherto unexplored explanation for the observations that some industries operate at higher frequency of change (Bourgeois & Eisenhardt, 1988; Brown & Eisenhardt, 1997) or are more prone to more radical forms of change (Gould, 1992; D'Aveni, 1994).

Arrow's (1996) recognition that information is important has yet to become widely cited. The most significant contribution citing Arrow (1996) to date is Boisot and Canals (2004), who argue that we need to review the difference between data, information and knowledge in the light of Arrow (1996) and propose a new economics of information for a future information-intensive economy. Quah (2003), while not citing Arrow (1996), has also recognised the economic nature of information as an industry output in a review of digital goods and the New Economy. It would appear that the message that information has important economic properties as a commodity is only starting to register upon the research community.

Second, the literature since Abernathy and Clark (1985) has largely ignored transilience as a construct – with a few exceptions such as Rothaermel (2000) - and thus, has not fully explored the effects of combinations of competence and customer linkages inducing industry-level change. Instead, research has tended to focus upon competencies (Tushman & Anderson, 1986; Anderson & Tushman, 1990) and customer linkages (Bower & Christensen, 1995; Christensen, 1997) independently.

Third, while the D'Aveni (1999) framework overcomes the anomalies reported in the literature, no empirical studies testing the framework have yet been reported. The framework's relatively recent publication in a practitioner-orientated journal is possibly a factor in the limited referencing of the framework and its influence on the strategic management community. However, the D'Aveni (1999) framework only describes the different change environments and does not suggest why industries face differing frequency of change.

It is interesting to note that the industry researched by Brown and Eisenhardt (1997) has high information content in the value of the industry's output. Brown and Eisenhardt (1997) and D'Aveni (1999) both suggest that high rates of change are becoming more common, while Arrow (1999) notes the increasing importance of information across industries. This is consistent with growing diffusion of computerisation in society.

Fourth, frequency of change has not been explored in the literature. Change has been generally measured using specified time periods, and a gap exists in the literature in considering variation in the time periods between change events. This gap in the literature may be explained by Ancona's *et al.* (2001) recognition that time is a lens rarely used to explore strategy. The link between uncertainty and frequency of change is also undeveloped.

Fifth, the definition of turbulence is unsatisfactory, with a variety of definitions in use in the literature. There is also no explicit separation of turbulence from frequency of change. D'Aveni (1999, 2001) implicitly separates turbulence from frequency of change, but does not define the relationship between the constructs.

Sixth, there is the possibility that the returns intrinsic in the products created by an industry, whether derived from either network effects or information, have the potential to influence the change experienced by an industry. The management literature has only limited research incorporating increasing returns and no research that considered the economic characteristics of information, and thus has not yet considered this question. The focus of research into the consequences of information outputs by industry has to date been primarily linked to examining information's role in risk reduction, rather than as an economic output in its own right (Arrow, 1996).

Hence, there are significant gaps in the literature for research to make a contribution.

2.8 Conclusion

The literature on increasing returns suggests that network effects and information output can have an effect upon industries. It would be quite reasonable to suggest that the economic properties of information are at least partially responsible for the high frequency of change reported by Brown and Eisenhardt (1997, 1998), as the dominance of information in the industry output is a key difference between the computer industry and the other industries researched by other authorities that have supported the punctuated equilibrium model. However, there is a lack of research examining the effect of these increasing returns upon change at the industry-level, possibly as a result of the difficulty of measuring increasing returns.

Second, the punctuated equilibrium paradigm is the dominant change model in management literature. However, anomalies have appeared in industries with continuous change or hypercompetition. The D'Aveni (1999) framework provides a theoretical model to extend the punctuated equilibrium paradigm and thus resolve these anomalies. Further, the D'Aveni framework provides a basis to explore the relationship between increasing returns and change through the influence of increasing returns upon frequency of change and on the forms of discontinuities experienced.

Third, Tushman and Anderson's (1986) findings suggest a path dependency in industry-level change may exist, with the type of discontinuity influencing the likelihood of the next discontinuity being competence-enhancing or competence-destroying. Increasing returns may influence this path dependency and influence the distribution of types of change experienced in different industries over time.

Fourth, the relationship between turbulence, uncertainty and frequency of change may provide an explanation for changing frequencies of change as a result of different types of discontinuities. However, the confusion in the literature regarding the relationships between these three constructs restricts the value of turbulence and uncertainty in the context of this research. Frequency of change, conversely, is operationally simple to measure and relatively new to the literature, and thus provides an uncontroversial construct to measure change over time.

These issues have both practical and academic importance. The majority of business models, whether from strategic management or other disciplines such as economics, focus on a static perspective of an organisation's environment. These static models may have relevance in industries where the pace of change is slow, but there is no clear guidance in the literature regarding the selection of these models and instead the models' authors typically assume that their models are universally applicable.

However, there are also some dynamic models introduced in more recent years that focus on industries where change is more rapid, in particular the computer industry. These dynamic models tend to promote issues such as using pacing of change as a method of influencing a market (Brown & Eisenhardt, 1998), continually inventing new competencies to replace old competencies or even actively destroying existing competencies in order to create future competitive advantage (D'Aveni, 1994).

Practitioners need guidance to decide when models are relevant to their circumstances and to more effectively understand the nature of change in their industry. The use of a dynamic model in a constant returns industry may prove just as disastrous as the use of a static model in an increasing returns industry.

If increasing returns were found to be associated with the frequency of change and/or the types of change experienced, then such a finding would be highly useful to practice. The ongoing diffusion of computerisation and increasing separation of information into products is already introducing increasing returns into previously constant returns industry and presumably influencing the scales of returns experienced in already increasing returns industries. The role of information as a commodity in its own right opens new areas for competition and can enhance the strategist's ability to achieve superior organisational performance, through new strategies and the development of different product options. Traditionally successful strategies may not work in the future, as the nature of change in industries change as a result of changing industry outputs. In any case, the need to consider the output of one's industry would provide a new lens for practice to consider strategic options, and to move to a more sophisticated understanding of strategy than trying to fit to an environment, or differentiating from competition, or developing internal resources, as a strategic choice for competing in one's market.

Further, a greater understanding of industry level change and an ongoing close scrutiny of markets may reveal previously unrecognised strategic opportunities, such as taking advantage of competency-destroying change as an opportunity to move into a new market previously dominated by incumbents and fostering competence-enhancing change as a method to consolidate a hold on an existing market.

Similarly, academia has an important stake in understanding the impact of increasing returns on change. The enhancement of the change models will allow future research to be designed to more effectively capture the nature of the object of research. The use of time as a research lens, as advocated by Ancona *et al.* (2001), has the potential to open news areas of understanding about the nature of strategy.

Thus, this research seeks to make a useful contribution, through its focus on the relationships between increasing returns and the constructs in the D'Aveni framework, namely frequency of change and discontinuity type.

3. Methodology

This section describes the research strategy, data collection and analysis. First, the research strategy is outlined, including the logic behind the choice of a longitudinal study, the use of paired industries and the triangulation of data through the use of multiple data sources to improve data reliability.

Second, the data collection process is described by the selection and sourcing techniques, the methods used to identify the data from those sources, the classification techniques to discern the types of data and finally how the data were formatted into a form suitable for analysis.

Third, the data analysis section describes how the data have been checked and analysed for differences between constant returns and increasing returns industries, by testing for: (1) a significant difference in frequency of change; (2) the ratios of competence-enhancing and competence-destroying discontinuities; and (3) the effect that a relationship between the type of change and the interval since the previous discontinuity may have on the likelihood or type of the next discontinuity.

3.1 Research Strategy

The research design is based on finding differences between increasing returns and constant returns industries that may be used to explain frequency of change and discontinuity types experienced by those industries. The long-term nature of the data lends itself to a longitudinal research design.

Longitudinal Research

The research depends upon the identification of both competence-enhancing and competence-destroying discontinuities to provide a comparison between industries with increasing returns and industries without increasing returns. Tushman and Anderson (1986) identified only six competence-enhancing and two competence-destroying discontinuities over three industries with a combined 138 years of annual data.

Therefore, a longitudinal study based on secondary source information has been adopted to provide a sufficient dataset to measure multiple discontinuities. The use of multiple industries provides a fuller dataset and hence can improve the reliability of results.

Paired Industries

One complication in comparing different industries is that the data may reflect differing economic conditions confronting these industries. The potential for data contamination by this effect is resolved by using pairs of industries with a common end consumer of the outputs of the industries. In each case one industry in an industry pair is an input into the second industry. Further, as an increasing returns industry would induce increasing returns through complementarity in any industry using its output, the constant returns industry was required to provide an essential input into the increasing returns industry. The aircraft manufacturing industry, as an example, provides an essential input (aircraft) for the airlines industry. This requirement excluded industry pair comparison of some otherwise obvious industries, such as the software and information storage industries, as insufficient data were available to create a dataset for an industry that provides a constant returns input for these increasing returns industries.

This technique ensured that, while a time lag may exist in economic conditions, the industry pair member industries would each experience change induced by the same economic patterns in the long-run. An example of this effect is a downturn in airline passengers leading to the postponement or cancellation of new orders for aircraft, thereby inducing a downturn in aircraft manufacturing once existing orders have been delivered.

Data Reliability

The use of secondary data creates the possibility of bias by the source's author or incompleteness. Indeed, bias has been of considerable concern with some earlier research being parochial in nature by examining an industry in one economy only and ignoring earlier discoveries, technologies or practices in other countries.

Two examples of parochialism are contained in the data used by Tushman and Anderson (1986): (1) the niche opening was dated at the introduction of competitive airlines in the United States in 1924 rather than the London-Paris route in 1919 (EAA Aviation Center, 2003); and (2) the introduction of jet commercial travel was given as the Boeing 707 in 1959 rather than the De Havilland Comet 1 in 1951, though admittedly the Comet 1 was withdrawn from service prematurely but in any case was replaced by the De Havilland Comet 4 three weeks before the Boeing 707 commenced services, in addition to the Soviet Tupolev Tu-40 and French Sud Est Caravelle airliners that also preceded the American airliner into service (Ward, 2003). In Tushman and Anderson's (1986) defence, they were examining data before and after particular discontinuities and were using detailed data on US airlines for their analysis, rather than attempting to create an international industry timeline, but these examples highlight the weaknesses in secondary data sources.

The research is based upon the selection of exemplar secondary sources as available, where the source was either written by a qualified academic as an economic history of an industry or by a professional with extensive industry knowledge. Other available source material including Internet-based timelines, economic histories and corporate histories were used as available to check dates, and in some cases exposed a failure in the exemplar work to consider a competing claim for earliest practice or technology.

Thus triangulation of secondary data was a requirement for confidence in including the industry dataset into the research. The method of triangulation was the identification of multiple data sources for an industry to check dates for errors, expose inaccuracies due to missing data or a perspective of a particular source, and to reveal data that might have been omitted from the exemplar source for any reason. The triangulation process was continued until new sources merely repeated already collected data.

Any industry dataset that did not have an exemplar source or could not be triangulated with available data was excluded. Excluded datasets included the Banking and Railway industries due to triangulation issues and the Robotics industry due to a lack of an exemplar.

3.2 Data Collection

The data collection process began with identifying the data sources. The historical nature of the data allowed the data to be collected sequentially by industry. Each industry was searched for relevant material until new additional searches failed to provide new data.

Selection

The industries were selected in pairs where the output of one industry has increasing returns and the other industry has constant returns, and where both industries share a common end-consumer of their product. The nature of each industry was considered, and industries which had an ever decreasing cost for each unit of production or ever increasing utility value to their customer for each unit produced (Katz & Shapiro, 1985; Saloner & Shepard, 1992) or had a complementary product that exhibits increasing returns (Katz & Shapiro, 1985; Ohashi, 1993) or had a significant information component in its output (Arrow, 1996, 1999) were deemed to be increasing returns industries. This selection of increasing returns industries through the use of the definition of increasing returns negated the need for this research to attempt to measure the increasing returns within each industry, which would have been beyond the available data. The corresponding industry paired to the increasing returns industry was categorised as constant returns if it failed to meet the criteria for increasing returns.

The purpose for using industry pairs with a common end consumer was to eliminate varying macro economic influences over time that could distort the results when comparing the two types of industry, and hence improve the reliability of the results. The industry pairs would thus provide a reliable comparison between industries with increasing and constant returns.

The dataset available was largely specified in years, and hence to remove a potential suggestion of data inadequacy, each industry selected was required to have at least 50 years of history. Tushman and Anderson (1986) found only eight discontinuities in a combined 138 year dataset, averaging one discontinuity every 17 years. A fifty-year dataset would provide sufficient time for at least one discontinuity to appear after the formation of the industry. Further, Yaffee and McGee (2000) suggest that fifty items of data are sufficient for a times series analysis and using this minimum dataset size has improved the reliability of the results, and thus fifty years was deemed consistent with other research and provides sufficient data for other researchers to test the data with time-series techniques.

The industries selected were also required to have available reliable source material detailing technological change and manufacturing techniques in that industry. This information forms the basis for each industry's dataset. In some cases industries were rejected due to the available data being incomplete or insufficiently accurate.

A total of nine industries were selected that met these criteria: Airlines, Aircraft Manufacturing, Data Communications, Telecommunications Manufacturing, Electricity, Shipping Lines and Shipbuilding. One industry (Shipbuilding) was paired to two increasing returns industries (Electricity and Shipping Lines) that shared manufacturing inputs with similar technology and techniques, and hence provided a reasonable basis for comparison.

The increasing returns industries used for the case comparisons all derived their increasing returns from direct network effects. The Airlines industry was deemed to have network effects from the additional utility enjoyed by each passenger from each addition destination flown by the airline, through increased flexibility of passenger travel, and for each additional aircraft flown within each route, through increased choice of time to travel. The Data Communications industry was deemed to have network effects derived from the additional utility enjoyed by each customer from each new customer connecting to the Data Communications network, as noted by Katz and Shapiro (1985). The Electricity industry costs of distribution decrease with each additional customer who joins the network, while the costs of providing sufficient base load power reduce with each additional customer decreasing the variation of load and thus increasing the efficiency of generation. The Shipping Lines industry provided additional utility for each route destination as it increased the customer's travel options, and from each additional ship as it increased customer choice over the timing of travel.

Two other industries were deemed to have increasing returns derived from information (Software) and complementarity (Information Storage). The output of the Software industry is predominately information, as the physical media used to store software has relatively insignificant value. Arrow (1999) expressly mentioned the Software industry as an example of an industry where the commodity nature of information created increasing returns. The Information Storage industry is analogous to Ohashi's (2003) study of the VCR industry, in that each customer of an information storage device gains benefit from each additional software product available, and thus Information Storage is complementary to Software. Thus, the Information Storage industry is deemed an increasing returns industry due to its compelmentarity to another increasing returns industry. The Software and Information Storage industry datasets were included as additional data for testing the hypotheses.

Source

The industry data have been sourced from industry histories and Internet sources. The histories have been exemplars selected on the basis of: (1) being a comprehensive history on the technologies and organisation of an industry; (2) availability; and (3) being authored by either academically qualified historians or industry leaders. Where exemplars were incomplete, then the data were sourced from multiple sources of academic and professional literature.

The availability issue did restrict the dataset to an extent, as some sources, such as nation state archives, were not available. However, it is not expected that this restriction induced any significant risk of unreliable results, but may have led to rejection of some datasets that otherwise may have contributed useful additional data. The exclusion of the Railroad and Banking industries from the research dataset are examples of increasing returns datasets, where increasing returns are derived from additional utility for each route and branch, respectively, which might otherwise have formed part of the research.

Second, over the long length of time measured, industry leadership in a number of industries changed from one nation to another. The nation with the industry leadership is termed the frontier nation in economics (Milgrom & Roberts, 1992). Sources from the frontier nation were preferred when available, to improve the reliability of the dating of individual technologies, which would generally diffuse into non-frontier nations after a time lag.

A record was maintained of the source and page number of each data element to provide a method for later researchers to cross-check the results. All Internet web pages were electronically copied to ensure that no data could be lost due to web site changes.

The search for new source material iterated with the identification stage, in that new sources were sought until it became apparent that no new data were being identified by the process.

Identification

Having identified the sources, the first step was to discern the industry's 'key performance parameter' (Tushman & Anderson, 1986). This measure defines the long-term source of competitiveness within the industry from the data. In some industries the key performance parameter has been constant since the industry's beginnings, e.g. speed of communications for the telecommunications industry, while in others the key performance parameter has changed over time, e.g. from speed to passenger capacity for the airline industry. A single measure has been used in line with other longitudinal studies rather than a multiple measure approach recommended for in-depth limited time horizon studies (Bonaccorsi, Giuri & Pierotti, 2005).

Discontinuities are generated by a change of the inputs to an industry. A change in an industry's output can form a discontinuity for its customers but not for the industry that created it. An example is the introduction of the duplex telegraph circuit, which was a discontinuity for the Data Telecommunications industry in that it used existing circuits to provide a service to customers with half the capacity previously required, but did not affect the techniques and technology used by the Telecommunications Manufacturing industry to supply telecommunications circuits. In the long-run the industry adjusts its economics to the new technology, realises any supply-side increasing returns and establishes a new equilibrium.

The individual discontinuities were identified from the sources by a significant improvement in their key performance parameter or by their displacement of earlier technologies or techniques, which in turn indicates either a significant improvement in the key performance parameter in the case of competence-enhancing discontinuities or a devaluation of industry knowledge in the case of a competence-destroying discontinuity, respectively. Firms that failed to adopt the new technology were eliminated from the industry. In rare cases, the discontinuity might change the industry's key performance parameter, e.g. the introduction of passenger reservation systems redefined the airlines industry's key performance parameter away from aircraft characteristics to yield management.

There are many cases in the source material where a new and promising technology or practice is introduced into an industry, and yet fails to displace the earlier dominant technology or practice. Some examples include: the Bain printing machine of 1840, that failed to displace the manual Morse key despite being 70% faster; composite wood and iron hulled ships existed at the same time as iron hulled ships despite the composite ships being lighter and thus more efficient; and the PRML encoding introduced by IBM with its Redwing drive in 1990 failed to displace earlier drives from the market despite being 55% more cost effective. If two technologies or practices co-existed, then the new technology or technique has been deemed to have failed to become the dominant technology in the industry and has been eliminated from the dataset.

However, in a few industries there is insufficient data to allow a key performance parameter to be calculated. The discontinuities in these industries were identified in the literature by those changes in the industry where a technology or practice displaced the earlier technology or practice, as these changes must be discontinuities by definition in that they succeeded in displacing the previous technology or practice.

The discontinuities were then classified according to their characteristics, using the criteria identified in the literature.

Classification of Discontinuity Characteristics

The literature review demonstrated the long-run equivalence of market-disrupting and competence-destroying change at the industry level. Hence, the dataset has equated competence-destroying and market-disrupting discontinuities, and competence-enhancing and market-enhancing discontinuities, for the purposes of the data analysis.

Competence-destroying technologies are those technologies that devalued the industry knowledge. Each new technology or technique that forced an industry to adopt new skills to operate or manufacture the technology or technique has been deemed competence-destroying, along with technologies or techniques that enabled new firms to enter the marketplace and displaced the incumbents, in accordance with the findings of Tushman and Anderson (1986). Discontinuities that eliminated a major class of customers for an industry or created a whole new class of customers which were supplied by new entrants rather than incumbents, such as 5.25inch hard drives reported by Bower and Christensen (1995), were classified as market-disrupting. The niche opening for each industry was categorised as market-disruptive, as a new class of customers were created.

Competence-enhancing discontinuities were defined by Tushman and Anderson (1986) as improving the price/performance of an industry's output by an order of magnitude. However, the nature of the researched industries is such that the percentage improvement of the key performance characteristic required to displace an earlier technology varies from industry to industry. Instead, competence-enhancing discontinuities were identified as those discontinuities that were not competence-destroying or market-disruptive, and instead displaced the earlier performance or practice through improvement in the key performance parameter. All market-enhancing changes, such as the introduction of reservation systems by airlines, not only strengthened customer linkages, but also increased the value of knowledge within the industry, and thus were equated with competence-enhancing discontinuities for the purposes of this research.

Further, as a quality assurance test, the key performance characteristic data have been used to identify the threshold level beyond which all change events improved the key performance parameter sufficiently to displace the earlier technology or practice. All other identified technologies or practices with a greater improvement in the key performance parameter that had not been classified as a discontinuity in the identification stage were reviewed to ensure that their exclusion from the discontinuity dataset was justified and to eliminate a potential source of selection bias by the researcher.

Formatting

Following classification the industry data were collated by the year and the type of discontinuity. In those instances where data were available, the state of the art of the key performance parameter was measured. The data were formatted by industry datasets and by a total of all industry datasets for total discontinuities, competence-enhancing discontinuities and competence-destroying discontinuities. Market disruptive discontinuities were treated as competence-destroying. Niche openings for each industry were also considered competence-destroying, as they enabled an influx of new entrants to enter the new industry with little knowledge.

The datasets were prepared in Microsoft Excel as a time series, with time being segmented into years. Whenever one or more than one discontinuity was observed in an industry in a single year, then the number of discontinuities "*n*" was entered. Otherwise a "0" was entered.

The datasets were then used as inputs into binomial distributions, Fisher's Exact tests and generalised linear models. The Fisher's Exact test datasets were converted to dichotomous form for testing, where *n* was replaced by "1", in accordance with the data requirements of the test.

Case Studies

The industry datasets have been compiled into industry case studies for further reference. The key performance parameter is identified, each discontinuity is described and the nature of the discontinuities considered. The development of each industry case study was used to confirm the classification of the industry as an increasing returns or constant returns industry. Each case study includes a separate bibliography to allow it to be used in the future as a stand alone document.

The case studies are included in the Appendices. The Shipping Lines and Shipbuilding case studies have also been included in the Summary of the Data section as an example of the data for an industry pair.

3.3 Data Analysis

The data were analysed using three techniques: Binomial Distribution, Fisher's Exact Test and Generalised Linear Model.

First, the data were analysed using a binomial distribution to determine if we can reject the hypothesis that the increasing returns and constant returns industries are drawn from the same population.

Second, a Fisher's Exact Test has been conducted on each industry pair to determine if a statistically significant difference in the ratios of competence-enhancing to competence-destroying discontinuities between the two industries can be discerned.

Third, a Generalised Linear Model (GLM) has been calculated for each industry pair and for the total of all industries to determine if: (1) a significant difference in frequency of change can be determined between increasing returns and constant returns industries; (2) a significant difference exists between the discontinuity types of increasing returns and constant returns industries; (3) the type of discontinuity is influenced by the period of time since the previous discontinuity; (4) whether the previous discontinuity was of the competence-enhancing or competence-destroying type influences the type of a discontinuity; and (5) whether there is evidence that a discontinuity influences the likelihood of another discontinuity.

The statistical tests were conducted using version 2.0.1 of the Windows version of R, an open source statistical package available from www.r-project.com, SPSS version 11 and Microsoft Excel 2002.

Binomial Distribution

A Binomial Distribution is "the discrete probability distribution of the number of successes in a sequence of N independent yes/no experiments, each of which yields success with probability p" (Wikipedia, 2005a). The classical example of this distribution is coin tossing, with the dichotomous variable of heads and tails. Hence this test is suitable for testing the dichotomous form of the dataset.

First, a requirement is that the data are normally distributed. Data that are skewed towards one or other result, whether the data elements are heads and tails as in the coin tossing test or 0s and 1s, will violate the ability to use a Normal Distribution to approximate the Binomial Distribution, and a continuity correction would have to be applied in order to achieve valid results. A heuristic used to determine whether a continuity correction is required is to calculate Np and $N(1-p)$. If the sample is large enough and the skewness not sufficiently large, then the results will show $N(1-p) \geq 5$ and $N(p) \geq 5$ (Wikipedia, 2005a).

Second, we need to ensure that we have a sufficiently large sample size to generate a Normal Distribution in any case. A distribution does tend towards a Normal Distribution as the number of observations increase – an observation first made by Bernoulli in 1713 (Stigler, 1986). A commonly used heuristic assumes that when the number of observations exceeds fifty, then a distribution can be assumed to be normally distributed.

Thus, if the industry dataset has more than fifty observations in each case and the distribution is not heavily skewed, then we can assume that a Normal Distribution can be used to approximate a Binomial Distribution and generate valid results.

The third step is to calculate the confidence interval for each dataset, to determine whether there is a significant difference in the number of discontinuities in increasing returns and constant returns industry in each industry pair or whether they belong to the same population. The confidence interval is calculated as the mean plus or minus

1.96 times the standard error, to give a 95% level of confidence in the results. If the confidence intervals do not overlap, then the two industries are significantly different.

The standard error for the each industry has been calculated using the formula:

Figure 3: Standard Error

$$S.E. = \sqrt{\frac{p(1-p)}{N}}$$

where S.E. is the standard error, p is the observed proportions of the event and N is the number of observations.

The calculations have been performed using Microsoft Excel 2002.

Fisher's Exact Test

Fisher's Exact Test is a statistical significance test for use with small sample sizes (Wikipedia, 2005b). The test compares the ratios of a 2x2 table, where one axis represents the two industries in each industry pair and the other axis represents the presence or absence of a discontinuity.

The Fisher's Exact Test uses the hypothesis that both sets of data can be drawn from the same population. A finding of 0.05 or less would reject this hypothesis and support the null hypothesis that the data for the two industries was selected from the same populations with a 95% level of confidence.

However, Fisher's Exact Test has the limitation that it should not be used when the expected values of any cell are less than 10 and there should be more than one degree of freedom (Wikipedia, 2005b).

The cross tabulations function of SPSS version 11 has been used to calculate the Fisher's Exact Test.

Generalised Linear Model

A Generalised Linear Model (GLM) allows the modelling of independent observations (McCullagh & Nelder, 1983) that follow probability distributions other than the Normal distribution, such as the Poisson distribution (Connor, 2002). GLM thus provides a more powerful test than the Binomial Distribution testing. In addition, GLM relaxes the requirement of equality or constancy of variances that is required for hypothesis tests in traditional linear models (Connor, 2002).

A Generalised Linear Model has been calculated for each industry pair separately. A further GLM (Total Industry Pairs) was calculated as the sum of these four industry pairs to provide more data for a significant GLM result and ensuring that the same amount of data did not bias the tests for increasing returns testing. A sixth GLM (Paired Industries) was prepared summing the seven industries using in the industry pair analysis for testing interactivity with the competency type, as the duplication of one industry in the Total Industry Pairs GLM may bias the competency type results. A seventh GLM (Total Industries) was calculated summing all nine industries to determine if the additional data surfaced further information.

The model counts the number of discontinuities coded for: (1) industry with increasing or constant returns; (2) by discontinuity type; (3) whether the preceding discontinuity was competence-enhancing or competence-destroying; (4) whether the preceding discontinuity was 0-10 years earlier; and (5) whether the preceding discontinuity was 11-20 years earlier. The twenty year span for modelling previous discontinuities is based upon the maximum length of time required for a new technology or method to dominate an industry (Anderson & Tushman, 1990).

The industry data were formatted in .csv file format as the vector input for the GLM. A decision matrix in .csv file format was created to reflect the layout of the data. Two extended matrices in .csv file format were also prepared to test the interactivity of the codes for the effect of increasing returns and for competency type, respectively.

Further GLM tests were then conducted to determine the sensitivity of the results to the selection of the 0-10 year and 11-20 year periods. GLMs were conducted using 0-8 year and 9-16 year periods to correspond with Anderson and Tushman's (1990) finding of an average of eight years for the era of ferment following a competence-enhancing discontinuity and for a 0-11 year and 11-22 year period to correspond with the average eleven year period following a competence-destroying discontinuity.

The GLM testing was calculated using the Windows version of R release 2.0.1 (R Development Core Team, 2004). R's glm.fit command was used to input each decision matrix and vector using a Poisson distribution. The summary.glm command was used to display the significance of the GLM for each of the model codes.

3.4 Summary

The methodology has been followed to create longitudinal industry datasets to test for significant differences between pairs of increasing return versus constant return industries for frequency of change and discontinuity characteristics.

Data from the Binomial Distribution were tested to determine if there was any difference in frequency of change and if any differences detected are significant. The Fisher's Exact Test compared ratios of types of discontinuities in industry pairs to determine if the hypothesis could be rejected that there was no statistical difference between the industry pairs.

A Generalised Linear Model was created for each industry pair, for the Total of Industry Pairs, for the Paired Industries and Total of Industries. The GLMs were used to test for increasing returns influencing frequency of change and whether the type and period since the preceding discontinuity affected the discontinuity in a significant manner.

The evidence from these tests allowed conclusions to be drawn.

4. Results

4.1 Summary of the Data

Introduction

The industry data have been compiled into individual case studies. Two case studies representing one industry pair are reported as examples of the case study analysis, while the complete set of case studies are contained in the Appendices for further reference. The case studies give background information for each industry to provide a context for the analysis; the industry's key performance parameter has been identified and justified based on the source data; the discontinuities are identified and described; the nature of each discontinuity is described along with its characteristic; and a conclusion is drawn regarding the industry's frequency of change.

The datasets have been derived from the case studies. The discontinuities of each industry have been incorporated into a time series with annual periods. The data have been presented in the format where a number *n* represents the presence of *n* discontinuities and "0" represents that no discontinuity occurred in the industry in that year.

These datasets have been compiled into total discontinuities, competence-destroying discontinuities and competence-enhancing discontinuities.

Sample Case Study – Shipping Lines

Introduction

This case study first outlines the background to the shipbuilding industry. Second, the industry's key performance parameter is defined as cargo carrying productivity. Third, the discontinuities in the industry are described in chronological order. Fourth the competence-enhancing or destroying nature of the discontinuities is determined. Finally, a conclusion is drawn regarding the nature of change in the industry.

Industry Background

Shipping lines initially grew from the need for timetabled services for transporting messages and high value cargo. In the early nineteenth century Britain's maritime empire was linked by the Royal Mail, which was initially carried by sailing naval vessels. In the 1820s the Post Office developed a network of small steamers (Harcourt, 1997) for mail services around coastal Britain, including the first all the year round steamer service from the end of May 1821 (Bagwell, 1988, p. 54). Naval steamers carried the mail on longer routes, such as the Mediterranean.

However, from 1834 political pressure aimed at reducing the Post Office's costs encouraged the outsourcing of mail routes (Harcourt, 1997, p. 33). By 1840 three major long distance contracts had been let for the North Atlantic, West Indies and South America and the Mediterranean (to connect to India via Egypt) routes. The mail subsidy reduced the risk and created a sound economic base for entrepreneurs to invest in establishing coaling stations and building a fleet of large and fast ships for the service (p. 34). The initial subsidy rate averaged around 25 per cent of total capital required to establish and maintain the route (p. 35). The result was "steam ships have been constructed of a size and power that, without Government aid, could hardly at least for many years, have been produced" (p. 38).

The mail contract system was later adopted by other countries to promote new liner routes, including the United States (1847-1850), Canada and France. Shipping was regarded as an extension of national power and hence the contract mail system spread throughout the world (p. 41). The resulting liners provided a regular and punctual service between designated ports, with linking services adding value to the established liner network.

Consequently, the diffusion of the steam ship led to a division of shipping in two categories: liners supported by mail, passengers and high value freight; and tramps for other cargoes (Broeze, 1997). Tramp steamers gradually displaced sail for carrying bulk cargoes and low value passengers, until in turn containerisation and air travel displaced tramps from these markets. Today's liners still carry freight in the form of container ship services.

The liner business enjoyed some network externalities derived from the structure of its network built upon the subsidised mail route. The subsidies gradually declined over time, with the subsidy for the shipping line that serviced the Mediterranean and India routes (P&O) falling from 37% of gross receipts in 1845-50 to 9% in 1910-1914 (Harcourt, 1997, p. 38).

Industry's Key Performance Parameter

The industry's key performance parameter was the vessel's cargo carrying capacity as a fraction of its size. This cargo carrying efficiency is primarily influenced by machinery, fuel and ship weights. In addition, from 1961 crew costs became a significant cost and assumed a position of a secondary basis for competition within the industry.

Discontinuities

Sailing vessels built from wood have provided an important and inexpensive method to transport bulky goods and people from early times. However, the vagaries of weather and tide ensured that sail could provide only an unreliable service, and high value freight and passengers preferred to travel by land rather than using coastal sail (Bagwell, 1988).

The introduction of steam propulsion in the shipping industry enabled the creation of reliable shipping schedules for the carriage of valuable cargos. The first commercial steamer service was a river service in the USA from 1807 using a paddle steamer with a wooden hull, simple boilers and engines (Bellis, 2004). By 1821 steamers on the Edinburgh to Aberdeen route in Scotland each maintained a reliable weekly return service, compared with an average three week return voyage with sailing vessels (Bagwell, 1988). Thus, steamers represented a 200% service improvement over sail.

The first discontinuity was the replacement by wood with all iron ships. Iron fittings had been used to strengthen wooden hulls since 1670 (Goodwin, 1997), allowing the building of stronger and larger hulls. In 1823 the SS *Aaron Manby* was the first iron-hulled steamship, and she was used on a cross-English Channel service (Steamertrunkmerchants, 2004). All wooden hulls larger than 40m length and heavier than 500 tons tend to suffer from structural problems (Tri-Coastal Marine, 2002). Iron hulls removed the construction limits on hull size. As "a ship's capacity increases as the cube of the hull's dimensions, the power required to drive it increases only as the square of the dimensions" (Houghton Milfflin, 2003), larger iron hulls enable a greater cargo carrying capacity for the same performance, and thus represent a substantial improvement over a similar capacity of smaller wooden hulls.

The side lever engine was first introduced in 1835 and used in Royal Mail packets (Thurston, 1878). These engines were the dominant form of engines used in the large paddle steamers and they surpassed other seagoing steamships in speed and comfort until being replaced in turn by propeller-driven steamships. The 1340 gross registered ton 2300 net tonnage (Houghton Mufflin, 2003) wooden-hulled *Great Western* carried two side lever engines (Griffiths, 2004) in her maiden trans-Atlantic voyage in 1838, and used 460 tons (VRCurassow, 2004) of her 660 tons of coal to propel her 450 horsepower (Thurston, 1878) for fifteen days, equating to 6.4 pounds of coal per hour per horsepower.

The first commercially significant railway was the Liverpool & Manchester, opening in 1830 (Pollins, 1971). The line's success unleashed a wave of railway investment to link major centres previously serviced primarily by coastal shipping. Railways were built that linked the most important British port London (Bagwell, 1987) to the important ports of Liverpool via Birmingham in 1837, Newcastle in 1839, Southampton in 1840 and Bristol in 1841 (Freeman & Aldcroft, 1985; Pollins, 1971). British coastal passenger steamship traffic peaked in the early 1840's, and was subsequently displaced by rail (Bagwell, 1987). By 1885 only the wealthiest steam packet companies were still providing significant coastal passenger services in Britain (p. 65). Subsequent liner services principally serviced overseas routes.

Long distance liner services depended upon ships being able to navigate across oceans. However iron disrupts the ship's magnetic field, and hence rendered unusable the magnetic compass then used for navigation. In 1838 a correction for magnetic deviation was found and ocean navigation for iron ships became practical (University of Michigan, 1997). The first steamers that steamed continuously across the Atlantic used wooden construction (Griffiths, 2004), but iron ships followed from 1845 with the first ocean-going iron ship *Great Britain*'s maiden trans-Atlantic voyage (Houghton Mufflin, 2003a). Thus, the magnetic deviation enabled trans-oceanic liner services by iron hulled ships and was a competence-enhancing discontinuity for steamship operators, by increasing the practical ship size in non-coastal routes. By 1873 British steam tonnage on overseas trade had exceeded sailing tonnage (Bagwell, 1988).

The first ocean-going propeller-driven steamer was the warship USS *Princeton* built in 1840 with a 950 displacement tonnage (Thurston, 1878). Propellers provided greater propulsive efficiency and an immense increase in economy, while also clearing up deck space and enabling improved cargo storage and handling (Thurston, 1878). Propellers rapidly diffused in new construction, and by 1850 had displaced paddlewheels almost completely (Thurston, 1878).

Further, the propeller prompted the shift from heavy, long stroked, low speed engines to light engines with small cylinders and high piston speed. The new geared engines used simple wooden cogs (Parsons, 1911), developed 5-15 pounds of steam pressure and consumed 7-10 pounds of coal per hour for each horsepower. The smaller and lighter engines enabled greater cargo carrying capacity while greater fuel efficiency reduced the ship capacity allocated to carrying fuel and improved economics through lower fuel costs (Thurston, 1878).

The direct acting engine with jet condensation followed, with steam at 20 pounds of pressure and consuming 5-6 pounds of coal per horsepower (Thurston, 1878). The engine operated at a higher speed to allow it to be directly connected to the propeller (Parson, 1911). The 2936 gross registered ton iron-hulled *Great Britain* was completed in 1844 with a direct acting engine driving one propeller via a drive chain (Houghton Mifflin, 2003a).

Forced draft boilers followed in 1851 (USGennet, 2003) and surface condensation allowed increased steam pressures to rise to 75 pounds or higher, while coal consumption dropped to 3-4 pounds of coal per horsepower (Thurston, 1878).

The compound engine uses two cylinders and passes steam from a high pressure cylinder to a low pressure cylinder. The engine was slowly perfected over many years and proved successful once surface condensation allowed higher steam pressures. In 1853 the small vessel *Brandon* required only 3.25 pounds of coal per horsepower per hour, and by 1858 larger compound engines were running on 2.25 to 2.5 pounds of coal per horsepower per hour. Later models of compound engines in 1881 ran at around 77 pounds of pressure and used a little under 2 pounds of coal per horsepower per hour (1911 Encyclopedia, 2003).

The water tube boiler was first introduced in the USA in 1867 and was initially considered to have only minor advantages over the fire tube boilers in use (Thurston, 1878). However, as steam pressures increased, water tube boilers became the dominant boiler technology as it enabled higher steam pressure, which improves fuel efficiency.

The triple expansion engine is a redesigned compound engine with a third cylinder. Kirk introduced the engine, which was first fitted to the *Aberdeen* in 1869 (USGennet, 2003). Steam pressure rose to 150-200lbs of pressure and coal consumption dropped to circa 1.5 (1911 Encyclopedia, 2003) to 1.54 pounds of coal per horsepower per hour (Baker, cited in Locock, 2001).

Mild steel was introduced for hull construction in 1877, and quickly become the dominant material in Britain (University of Michigan, 1997). Steel diffused into other countries' industries and had replaced iron as the dominant material in the fledgling Japanese shipbuilding industry by 1890 (Chida & Davies, 1990). The first Cunard Line steel ship, *Servia* built in 1881, reduced 620 tons from its 3971 net tonnage, or 15%, from total ship weight, through the use of mild steel (Robbins & Innola, 2003).

Oil fuel was first used in 1886, with the launch of the *Himalaya* in Britain. Oil fuel replaced coal for heating water into steam to power the ship's engines. Fletcher (1997) claimed that oil fuel required one-eighth the space and one-third the weight of coal and hence significantly improved the cargo carrying capacity of the ship, while the Energy and Planning Office (2004) gives thermal conversion rates that equates 1 tonne of oil to 2.39 tonnes of coal. However, oil fuel was initially difficult to source and more costly than coal, and it required almost thirty years for distribution stations to become widely established and to diffuse in new shipbuildings. In 1914 only around three per cent of total world non-sailing gross tonnage used oil fuel, but war changed some national priorities and by 1919 eighty per cent of US ships burnt oil fuel (Fletcher, 1997), while globally almost 26 per cent of non-sailing gross tonnage used oil fuel in 1922 and 49 per cent in 1935. Oil's diffusion was aided by the wartime construction of oil storage facilities in many ports to support naval activities.

The turbine was first demonstrated on the 44.5 ton *Turbinia* in 1897, followed in 1901 by the 650 ton merchant ship *King Edward* and in 1904 by the 3000 ton cruiser HMS

Amethyst (Parsons, 1911). The early turbines typically used 200 pound steam pressure and were directly connected to the propeller. However, due to propeller cavitation problems, the direct turbine was suitable only for faster vessels (Parsons, 1911). Some installations solved this problem by using turbines in conjunction to triple expansion engines as a booster engine for higher speeds only. One such ship, the 20,000 ton line *Laurentic*, achieved a 14 per cent saving in fuel consumption compared with her reciprocating engine powered sistership *Megantic* (Parsons, 1911).

The 4350 ton *Vespian* was altered from triple expansion engine to a geared turbine in 1908. Extensive trials demonstrated a twenty-two per cent reduction in fuel consumption compared with the original machinery. Further, geared turbines enabled turbines to be applied to slow vessels unsuited to the directly driven turbine and replaced the need for triple expansion engines for slow speeds. Hence, the geared turbine was more economic than the direct turbine and the triple expansion engine, while it was also smaller in size than the triple expansion engine. In 1920 the efficiency of geared turbines using coal as a fuel was estimated at 2.4 pounds of coal per horsepower per hour at low speeds, reducing to 1.2 pounds of coal per horsepower per hour at high speeds, but with a 2 per cent loss in efficiency from the gearing (Baker, cited in Locock, 2001). Hence, the geared turbine operating at high revolutions was up to 29 per cent more efficient than the triple expansion engine.

The first sea-going diesel engine was the tanker 1179 ton *Vulcanus* in 1909 and by 1914 diesel engines powered approximately one-half of one per cent of the world's merchant gross tonnage (Fletcher, 1997). By 1927 over half of new construction was diesel powered and by 1950 25 per cent of all gross tonnage comprised of motorships (Fletcher, 1997). The two stroke diesel engine in the 1920s consumed fuel at the rate of 0.47 pounds of oil per horsepower per hour, while the four stroke engine consumed 0.44 pounds of oil per horsepower per hour (Baker, cited in Locock, 2001). Thus, using Locock's (2001) 1920 estimates and the Energy and Planning Office (2004) conversion factors between the weights of coal and oil sources, the two stroke diesel engine was 7 per cent more efficient than the oil fuel driven geared steam turbine at maximum efficiency, while the four stroke engine was up to 14 per cent more efficient in the same conditions.

Small tube boilers were available by 1912 and weighed two-thirds of the earlier water tube designs (Henneman, 2004). These boilers reduced machinery weight and thus allowed a greater cargo capacity for the same sized hull and speed.

The first turbo-charged diesel engined ship was completed in Germany in 1925, while the first turbocharged ocean-going vessel was built in Britain in 1928 (Virginia Tech, 2004). Turbo-charging technology was in widespread use in the Second World War. Modern turbocharged diesel engines commonly achieve fuel consumption levels lower than 200 g/kWhr (Gee, 2001), or 0.323 pounds per horsepower per hour. Thus, the geared turbocharged diesel provide at least a 56 per cent efficiency improvement over geared turbines when operating in their most efficient mode and a 46 per cent improvement over the non-turbocharged diesel engine.

The first trans-oceanic airline routes were created in 1927, with the US carrier Pan American Airways providing a service to South America, and later across the Pacific and Atlantic oceans (Afriqonline, 2003). Britain's Imperial Airways also established routes from Britain to South Africa and used mail contracts to establish the new routes, in a repetition of the founding of the steamship routes (Afriqonline, 2003a). However, trans-oceanic air travel was initially substantially more expensive than sea travel and hence was the domain of the high value passengers only.

Superheated steam turbines were introduced by the German Navy in 1934 in the Type 1934 Destroyer (Lienau, 2000; Blohm und Voss, 2002) to improve fuel efficiency and reduce machinery weights. Steam pressures were increased to 1028 pounds per square inch (psi) (Flixco, 2004), but the engines initially suffered from poor reliability. The engines developed 23.7 horsepower per ton, compared with 17.4 horsepower per ton achieved by the contemporary British J class with 300 psi boilers (Flixico, 2004a) and the earlier Type 24's 18.1 horsepower per ton with 268 psi boilers (Flixico, 2004b). Hence, the superheated steam pressures improved steam turbine machinery efficiency by over 31 per cent. By the 1950s the US Navy finally perfected superheated steam turbine technology using 1200psi steam pressures and earlier steam technologies were superseded (Gardiner, Chumbley & Budzbon, 1996).

The first trans-Atlantic jet air service was introduced by BOAC in October 1958 with a De Havilland Comet 4, followed by Pan American with the Boeing 707 jet airliner three weeks later (Afriqonline.con, 2003b). Long-haul jet services were rapidly introduced around the world, with passenger numbers crossing the Atlantic by plane surpassing liner passenger numbers by 1960 (National Air Traffic Services, 2004). By the late 1960s jet aircraft had largely displaced ocean liner passenger and high value freight services. The world's fastest liner SS *United States* was withdrawn from its trans-Atlantic service in 1969 (SS-United-States.com, 2003), while the largest British liner company, P&O, ended its services to East Africa in 1969, New Zealand in 1969 and India in 1970. The remaining passenger liners were redeployed into the cruise ship market from 1969, with purpose-built cruise ships being built from 1972 onwards (Howarth & Howarth, 1986).

In 1961 the world's first automated ship, the *Kinokasan Maru* of 9800 gross tons, was delivered in Japan. Crew numbers were reduced from 51 to 36 (Childa & Davies, 1990). Further automation allowed crews to be reduced further to 14 man crews from 1977.

Containerisation was introduced in Japan in 1968. By 1973 all cargo routes from Japan were containerised and non-containerised cargo traffic had been superceded by the more efficient container system (Childa & Davies, 1990). Containerisation diffused rapidly to other markets and soon dominated international freight. The first OCL containerships built from 1969 replaced 4-5 general cargo ships each, with substantial savings in crewing costs (Howarth & Howarth, 1986).

In 1990 ABB introduced the electric azimuthing pod drive system (Azipod). The Azipod quickly replaced propellers as the dominant drive in large passenger vessels, and has since increased penetration in freight vessels (ABB, 2002). The Azipod has proven to be more fuel efficient in vessels where transit time represents no more than 65 per cent of total operating time. The Azipod system is eight percent less efficient than a mechanical drive when operating at maximum power (ABB, 2003). However, electric propulsion does not require long shafting, enabling engines to be placed in novel locations leading to more efficient hull designs and allowing a power station concept in ships, where engines can used at their most efficient levels.

The first large trimaran *Triton*, of 1200 tons displacement, was launched in 2000. The stabilised narrow hull form is 25% more efficient than the non-stabilised monohull form, and is beginning to become adopted in commercial traffic (Vosper Thornycroft, 2003).

The first high temperature superconductor motor was built in 2003. The first naval vessel with these drives is intended to be ordered in 2005 for delivery in 2012 and it is expected that these motors will rapidly diffuse into the larger passenger vessel market (American Superconductor, 2003). Super conductors have lower resistance than standard electric motors, with a 25MW motor suited for larger ships rated at 97 per cent efficiency at full power and 99 per cent efficiency at one third power, while the 25MW generator is rated at 98.6% efficiency (Kalsi, 2002). Hence, the superconductor motor and generator combination operates at 95.6 per cent efficiency compared with 97 per cent efficiency for a geared diesel installation - 1.4% less efficient at full speed. However, superconductors are a similar weight to geared engines, and hence provide the opportunity for Azipods and other electric propulsors to replace geared diesels over time.

Nature of the Discontinuities

The shipping industry has experienced a series of discontinuous changes over time, that have changed the economics of ship operation and often obsoleted much of the existing shipping stock. In practice, any change that provided a performance advantage has diffused over time, while those changes that could be retrofitted to existing stock, such as magnetic deviation and oil fuel boilers, have progressed rapidly.

The industry's key performance parameter has traditionally focused on cargo efficiency, which is influenced by the weight and space allocated to the hull, machinery and fuel. The increase of personnel costs from the 1960s has led to labour costs becoming an important secondary issue.

The discontinuities have been described as competence enhancing (CE) or market disrupting (MD) depending upon their impact on existing shipping organisations.

Table 1: Shipping Technologies Discontinuities 1807-2005.

Date	Discontinuity	Improvement over preceding technology	Type
1807	Wooden Paddle steamer	N/A	Niche opening
1823	Iron Hull	Variable	CE
1835	Side lever engine	Significant	CE
1837	Railway network begins linking ports	Replaced coastal steamship passenger traffic	MD
1838	Magnetic Deviation	Significant	CE
1840	Propeller	Significant	CE
1841	Geared Engines	Significant	CE
1844	Direct Acting Engines	+55% fuel economy	CE
1851	Surface Condensation	+57% fuel economy	CE
1854	Compound Engine	+50% fuel economy	CE
1867	Water tube boiler	Became significant	CE
1869	Triple Expansion Engine	+25% fuel economy	CE
1877	Mild Steel Hull	+18.5% cargo capacity	CE
1886	Oil Fuel	+138% energy from same fuel weight	CE
1897	Steam Turbine	+16% fuel economy	CE
1908	Geared Steam Turbine	+12% fuel economy	CE
1908	Diesel Engine	+ 7% economy	CE
1927	Long range trans-oceanic aircraft	Replaced mail and high value passengers	MD
1928	Turbocharged Diesel Engine	+46% fuel economy over non-turbocharged diesel	CE
1934	Superheated High Pressure Steam Turbine	+30% power from steam turbine weight	CE
1958	Long-range jet passenger aircraft	Replaced long distance passenger traffic	MD
1961	Automated Ship	Reduce crew by 72%	CE
1968	Containerisation	Replace general cargo vessels	CE
1990	Azimuthing electric pod	More efficient when transit times no more than 65 % total operating time; -8% at full power; efficient hull design	CE
2000	Trimaran hull form	+25% fuel economy	CE
2005	High temperature superconductor motor	-1.4% at full power	CE

Conclusion

There have been a total of 22 competence-enhancing and 3 market-disrupting discontinuities during the 199 year 1807-2005 period, excluding the niche opening. The market-disrupting changes were all created by new industries depriving the shipping industry of one of its original sources of customers: railways displaced coastal passenger services; flying boats long range mail; and jet aircraft trans-oceanic passengers and high value freight.

The rate of change in the shipping industry since niche opening has been 1 discontinuity per 8.0 years and 88 per cent of discontinuous changes were competence-enhancing. The industry can be divided into four eras split by the market-disrupting discontinuities, as displayed in the following table:

Table 2: Frequency of change of Shipping Industry

Era	Industry Era	Competence-enhancing Discontinuity Quantity	Frequency of change
1807-1837	Coastal Passenger	3	0.067 p.a.
1838-1927	Oceangoing Passenger, Mail, High Value Cargo	14	0.156 p.a.
1928-1959	Oceangoing low value passengers, mail, cargo	1	0.031 p.a.
1960-2005	Low value Cargo	4	0.087 p.a.

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Sample Case Study – Shipbuilding

Introduction

The shipbuilding industry has one of the longest of industrial histories. Wooden shipbuilding was originally centred in areas with access to supplies of raw materials and nearby markets for completed vessels. The industry was, and is, a major input to the shipping industry, and the two industries share common end-users for their respective products.

This case study first outlines the background to the industry. Second, the industry's key performance parameter is defined as material and labour productivity. Third, the discontinuities in the industry are described in chronological order. Fourth, the competence-enhancing or destroying nature of the discontinuities is determined. Finally, a conclusion is drawn regarding the nature of change in the industry.

Industry Background

The eighteenth and early nineteenth shipbuilding industry had been established to supply predominately sailing vessels for coastal and ocean-going trade. In Britain, the leading maritime nation of the period, the coal trade had grown as wood become a more scarce and expensive fuel, and dominated Britain's coastal trade for 350 years, with over 40 million tons of coal being imported by London alone between 1670 and 1750 (Bagwell, 1988, p. 47).

Thus, coal provided both the foundation of the shipbuilding industry in the supply of hulls and the fuel later required for steamships to establish liner routes. The increased use of iron led to the focus of shipbuilding moving from sources of supply of wood to supply of iron, and later steel, following access to competitively priced material. The shift from wood to iron partially explains the loss of a competitive position for the American merchant marine around the US civil war period.

Further, the shipbuilding industry established modern factory methods and has been a leader in many aspects of heavy manufacturing.

The frontier nation for shipbuilding from 1800 to 1955 was Britain, based in part upon its competitive position with plentiful and cheap coal supplies. However, Japan replaced Britain as the largest shipbuilder in 1956 (Chida & Davies, 1990) and since then Japan has operated at the frontier in shipbuilding, though under increasing challenge from other Asian nations in recent years.

Industry's Key Performance Parameter

The management of resources has been the key performance parameter since the fifteenth century. Semi-skilled labour has been the dominant labour type throughout the period, and the management of these costs are an input resource input for the shipbuilding firm.

Discontinuities

The Venetian Arsenal introduced factory techniques to shipbuilding in 1418, with products built using standardised parts on an assembly line (Wikipedia, 2003; Hoppenfeld, 2003). Earlier ships were built by small numbers of skilled craftsmen and with designs based upon experience. In 1800 ships were built from wood, though iron fastenings were first used in warships on the *Royal James* in 1670 to strengthen the hull (Goodwin, 1997) and iron rivets had been in use as early as the 7th century (Centre for Marine Archaeology, 1999).

Steam power for machinery was first used in mines in the late eighteenth century and by 1800 had been applied to iron works and ropemaking, but not the shipbuilding industry (Lord, 1923). The first smelting facility at a British naval dockyard was built in 1803 and a new metal mill with purpose built machinery was opened in 1806 (Goodwin, 1997). One of these events is most likely to have been the first application of steam power to shipbuilding. The completion of the first effective steamship in 1807 (Bellis, 2004) would have provided further practical experience with steam machinery to spur steam adoption in shipbuilding.

The first all-iron hull was completed in 1819 (University of Michigan, 1997), the first iron-hulled steamship in 1823 (Steamertrunkmerchants, 2004) and the first iron-hulled ocean-going steamship in 1844 (Houghton Mifflin, 2003). Iron eliminated the need for carpentry skills for essential hull components and allowed the construction of larger ships – though also requiring access to large quantities of iron for construction purposes.

Steam railways appeared in 1830, supplying coal and iron to shipyards. The simplified transport system significantly reduced the costs of raw materials, though as shipbuilding is, by necessity, a coastal activity, shipyards also had access to sea transport for raw materials from other coastal regions. By 1865 railways in Britain carried 50 million tons of coal plus 13 million tons of all other minerals, predominately iron, compared to 32 million tons of general merchandise, though rail only surpassed sea for coal imports into London during the period 1867-1897 (Bagwell, 1988). Hence, railways were an important transport system for moving raw materials at least from inland regions.

Composite iron-ribbed and wooden hulled vessels were popular during 1860-1880, as they proved lighter than iron-hulled vessels (Sunderland Marine Heritage, 2003). The *Sobraon* launched in 1866 was the largest composite ship built, measuring 2131 gross registered tons (Clipper Ship Museum, 1997). The use of iron ribs allowed larger vessels to be built than was feasible with wooden construction, which is limited to 500 tons displacement (Tri-Coastal Marine, 2002). The structural limit for wooden ships is generally considered as 61m in length, though a 1950s US minesweeper type was 69m long (University of Michigan, 1997).

Steel was introduced in hull construction in 1877 and quickly become the dominant material in Britain through its greater strength and easier working (University of Michigan, 1997). Steel diffused into other countries' industries and had replaced iron as the dominant material in the fledgling Japanese shipbuilding industry by 1890 (Chida & Davies, 1990). The first Cunard Line steel ship, *Servia* built in 1881, used mild steel to reduce hull weight by 620tons, or 15% of total ship weight (Robbins & Innola, 2003).

DC Electric Motors were available from the 1870s, but were never widely used (Hannah, 1979, p. 15). However, the invention of the AC polyphase motor in 1887 allowed electric power to replace steam as the power source for factory machinery (p. 15) and found increasing factory applications by the early 1890s (p. 18). In Britain electric motors represented one-ninth of motor capacity in the manufacturing and mining segments by 1907, growing to one-fourth by 1912 (p. 19). By 1908 all shipbuilders on the north bank of the Tyne received at least 95 per cent of their power requirements from an electrical utility (Hannah, 1979, p. 32-3). In the US electric motors supplied fifty per cent of all factory horse power by 1919 (Gordon, 2000).

The first diesel powered ship was built in 1909 and diesel propulsion achieved one-half of one per cent of gross tonnage by 1914 (Fletcher, 1997). By 1918 many Scandinavian shipyards had converted to diesel construction and gained an advantage over traditional steamship yards in the new technology (p. 163). However, diesel power only fully displaced steam for new construction in the 1970s when oil prices increased rapidly – with a few niche market exceptions.

The first welding was used during the First World War to assist the assembly of pre-constructed components. The first all-welded ship was finished in Britain in 1920 (University of Michigan, 1997) and reduced the hull weight by five per cent. However, welding required specialised and expensive labour, so riveting remained the dominant construction technique.

Production control was developed by Western Electric in the telecommunications manufacturing industry and introduced into shipbuilding during the Second World

War. The Kaiser yard in the USA built standardised merchantships during 1940-5 as part of the emergency shipbuilding programme. Post-war American engineers diffused these techniques into the Japanese shipbuilding industry and they became widely adopted by the 1960s.

Block (or section) building was also introduced in 1940, to facilitate the American emergency shipbuilding programme. Pre-manufactured blocks were built in covered halls and only shifted to the slipway for assembly into the finished vessel. Consequently, the slipway was occupied for a shorter period of time, increasing slipway efficiency and raising the shipbuilding capacity of the shipyard.

Killed steel was introduced in 1950, and, as this form of steel allowed easier and more precise welding than the earlier rimmed steel, it reduced the labour cost in welded ships (Chida & Davies, 1990, p. 110). Consequently, welding rapidly replaced riveting.

Pre-outfitting was introduced in the mid-1950s (University of Michigan, 1997), allowing more rapid fitting out of a vessel after launching.

The flowline system was developed at the NBC shipyard at Kure Japan during the 1951-61 period, and introduced aircraft manufacture techniques into ship building. The emphasis shifted from 'what to build' to 'how to build', with every process pre-planned and integrated into a production plan. The flowline system increased productivity, the quality of output and allowed more sophisticated vessels to be built (Chida & Davies, 1990, p. 112).

In 1959 drydocks were first introduced for building commercial ships. Since that time, all new major shipyard facilities have used drydocks, and this technology has replaced end-launching as the main method for launching new ships (University of Michigan, 1997).

Automation was introduced in the 1960s in the shipbuilding industry. Automatic cutting of steel plate and automatic welding significantly improved productivity (Chida & Davies, 1990, p. 92, p. 111)

Megablocks were introduced in the 1990s for greater efficiency. The *Triton* was built in 1998-2000 of five megablocks of 200 tons each (DERA, 2001), and new construction warships are being built of 500 ton blocks. The result is shorter construction periods and greater efficiency for the shipyard, with the *Triton* being delivered a year earlier than possible with traditional techniques.

Nature of the Discontinuities

The discontinuities described above all become industry norms within usually one decade of introduction. Hence, while the paucity of accurate data cannot substantiate the actual effect on the industry's basis for competition, it can be determined that these changes were significant enough to become common practice and drive the earlier practice out of the industry. By definition, the nine competence-enhancing discontinuities reflect order of magnitude improvements over the preceding situation, while the competence-destroying discontinuities represent devaluation of existing knowledge and skills (Tushman & Anderson, 1986).

Table 3: Shipbuilding Industry Discontinuities 1807-2003.

Date	Discontinuity	Effect on Basis for Competition	Type
1417	Venetian Arsenal		
1670	Iron fastenings		
1803	Steam power		
1807	Steam propulsion	Niche Opening	N/A
1819	All iron hull	Allowed bigger ships	CE
1830	Railroads	Cheaper access to inland resources	CE
1860	Composite Hull	Lighter than iron, stronger than wood	CE
1877	Steel	Easier to use, 15% lighter than iron	CE
1887	AC Electric Motor	Reduced machinery costs	CE
1908	Widespread electric utilities	Lower power cost	CE
1909	Diesel engine	Different engine design and construction	CD
1920	Welding	Reduced ship weight	CD
1940	Production Control	Improved productivity	CE
1940	Section Building	Double shipbuilding capacity of slipway	CE
1950	Killed Steel	Reduced construction times	CE
Mid-50s	Pre-outfitting	Reduced construction times	CE
1959	Drydocks	Replaced slipway	CE
1960s	Automation	Significant manpower reduction	CE
1990s	Megablocks	Reduced construction times	CE

Conclusion

The shipbuilding industry experienced 15 discontinuities from the beginning of the steamship era in 1807 to 2003. The diesel engine and welding both significantly devalued existing skills, and it is not surprising the then dominant shipbuilding nation was slow to adopt these innovations (Fletcher, 1997) and was superseded as both technologies became dominant in the 1950s.

The industry frequency of change was one discontinuity every 13 years and 87 per cent of discontinuities were competence enhancing.

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The Industry Datasets

The datasets cover the period 1791-2005. In most cases the industry did not exist for the full period of the dataset. Where industry data were not available for the last few years, the dataset has been terminated at the point of time when the last reliable datum was available. Hence, there are missing values in the dataset.

Total Discontinuities

A sample of the dataset for total discontinuities is listed in the following table. The full dataset is contained in the Appendices. The period 1919-1930 has also been selected for its inclusion of niche opening of the Airlines and Aircraft Manufacturing Industries and the presence of data across all industries.

Table 4: Sample Period of Total Discontinuities

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1919	2	1	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	1	0	0
1921	0	0	0	0	0	0	0	0	0
1922	0	0	0	0	0	0	0	0	0
1923	0	0	0	0	0	0	0	0	0
1924	0	1	0	1	0	0	0	0	0
1925	1	0	1	0	0	0	0	0	0
1926	0	0	0	0	2	0	0	0	0
1927	0	0	0	0	0	1	0	0	0
1928	0	0	0	0	0	1	0	1	1
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0

Competence-Destroying Discontinuities

A sample of the dataset for competence-destroying discontinuities is listed in table 5. The full dataset is contained in the Appendices. The period 1919-1930 has been selected for comparison with table 4.

Table 5: Sample Period of Competence-Destroying Discontinuities

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1919	1	1	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	1	0	0
1921	0	0	0	0	0	0	0	0	0
1922	0	0	0	0	0	0	0	0	0
1923	0	0	0	0	0	0	0	0	0
1924	0	0	0	0	0	0	0	0	0
1925	0	0	0	0	0	0	0	0	0
1926	0	0	0	0	0	0	0	0	0
1927	0	0	0	0	0	1	0	0	0
1928	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0

Competence-Enhancing Discontinuities

A sample of the dataset for competence-enhancing discontinuities is listed in table 6. The full dataset is contained in the Appendices. The period 1919-1930 has been selected for comparison with tables 4 and 5.

Table 6: Sample Period of Competence-Enhancing Discontinuities

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1919	1	0	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	0	0	0
1921	0	0	0	0	0	0	0	0	0
1922	0	0	0	0	0	0	0	0	0
1923	0	0	0	0	0	0	0	0	0
1924	0	1	0	1	0	0	0	0	0
1925	1	0	1	0	0	0	0	0	0
1926	0	0	0	0	2	0	0	0	0
1927	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	1	0	1	1
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0

Dichotomous Datasets

The Binomial Distribution and Fisher's Exact Test both require dichotomous forms of the datasets. A number of the observations in the industry datasets are greater than one, with more than one discontinuity experienced in each year. The dichotomous dataset treats each year with at least one discontinuity as a single successful outcome, while any year with no discontinuity is an unsuccessful outcome.

The dichotomous forms of the datasets are listed in the Appendices.

Summary

The datasets have been prepared as time series listing total, competence-enhancing and competence-destroying discontinuities within each industry. The datasets were prepared using Microsoft Excel 2002 for the basis of calculating confidence intervals, for importing into the SPSS statistical package for the Fisher's Exact Test and to generate the vectors and matrices for the GLM tests in R.

A summary of the datasets contained in the Appendices is included in table 7. The number of competence-destroying discontinuities, competence-enhancing discontinuities and total discontinuities listed in the dataset for each industry is listed below. The table also lists the number of years contained in the time series for each industry.

Table 7: Summary of Discontinuity Datasets

Year	**Airlines**	**Aircraft Manufacturing**	**Data Telecommunications**	**Telecommunications Manufacturing**	**Electricity**	**Shipping Lines**	**Ship Building**	**Software**	**Information Storage**
Competence-Destroying Discontinuities 1791-2005	1	2	4	4	2	4	3	5	7
Competence-Enhancing Discontinuities 1791-2005	10	3	17	9	17	22	13	13	13
Total Discontinuities 1791-2005	11	5	21	13	19	26	16	18	20
Years in Series	85	85	213	210	134	199	197	114	114

Table 8 below lists a summary of the dichotomous values from the datasets. The Total Discontinuities data does not equate the sum of the competence-enhancing and competence-destroying data, due to the presence of both types of discontinuity during the same year in four industries (Airlines, Telecommunications Manufacturing, Software and Information Storage).

Table 8: Summary of Dichotomous Datasets

Year	**Airlines**	**Aircraft Manufacturing**	**Data Telecommunications**	**Telecommunications Manufacturing**	**Electricity**	**Shipping Lines**	**Ship Building**	**Software**	**Information Storage**
Competence-Destroying Discontinuities 1791-2005	1	2	4	4	2	4	3	5	7
Competence-Enhancing Discontinuities 1791-2005	10	3	16	8	15	21	12	12	13
Total Discontinuities 1791-2005	10	5	20	11	17	25	15	16	19
Years in Series	85	85	213	210	134	199	197	114	114

Further, Tushman and Anderson (1986) found that successive competence-enhancing discontinuities reduced the amount of change experienced in an industry, while competence-destroying discontinuities increased the amount of change. The data compiled into a table below lists the number of years between each discontinuity and the preceding competence-destroying discontinuity for each industry and for the total of all industries (Total Industries).

Table 9: Industry discontinuity distribution

Years since last preceding competence-destroying discontinuity	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage	Total Industries
0-10	2	1	8	4	2	8	0	7	12	44
11-20	2	1	1	2	5	3	4	6	5	29
21-30	0	1	0	0	1	3	2	0	0	7
31-40	2	0	2	2	2	4	2	1	1	16
41-50	1	0	2	0	2	3	2	0	0	10
51-60	2	0	0	0	0	1	1	1	0	5
61-70	1	0	0	0	2	0	1	0	1	5
71-80	1	1	1	0	3	2	2	0	0	10
81-90	0	0	0	0	1	0	1	0	0	2
91-100	0	0	2	1	0	0	0	0	0	3
101-110	0	0	2	1	1	0	2	0	0	6
111-120	0	0	1	0	1	0	0	0	0	2
121 +	0	0	2	1	0	0	0	0	0	3

4.2 Testing using Binomial Distribution

Introduction

The dataset is required to be sufficiently large for the sample to approximate the Normal Distribution. A heuristic often used is that the sample should have at last 50 observations (*N*). Further, the data are required to not be skewed heavily towards one end of the distribution. The second heuristic for *Np* and *N(1-p)* to equal to or to exceed five ensures that small proportion (*p*) values need to be matched with large population (*N*) sizes.

First, the data are tested to check if it meets the observation and *Np* and *N(1-p)* heuristics to ensure that the use of the Normal Distribution for the Binomial Distribution is valid. Second, a confidence interval is calculated for a 95% level of confidence for each industry forming part of an industry pair. Third, the industries in each industry pair are compared to determine if there is a significant result. Finally, the results of the test are summarised.

Test Validity

Number of Observations

The Binomial Distribution requires the use of the dichotomous dataset. There is one observation in each industry for each year. Thus, the number of observations for each industry is determined by the number of years covered by the industry dataset. The number of observations for each industry is listed in the following table:

Table 10: Number of Observations

Industry	N
Airlines	85
Aircraft Manufacturing	85
Data Communications	213
Telecommunications Manufacturing	210
Electricity	134
Shipping Lines	199
Shipbuilding	197
Information Storage	114
Software	114

The number of observations exceeds fifty in each industry. Therefore, the number of observations is sufficient for a binomial distribution to be valid.

Assumptions of the Test

The values of p have been calculated from the dichotomous form of each industry's total discontinuities dataset. Each year with at least one observed discontinuity is counted as "1", while observations with no discontinuities are coded as "0". The values have been summed and divided by the number of observations to find the value of *p* for each industry.

The value of *Np* is identical to the total discontinuities listed in table 8 for each industry, while *N(1-p)* is the number of years when no discontinuity was present. The following table lists the values for *N*, *p*, *Np* and *N(1-p)* for each industry, where *p* is rounded to two decimal places.

Table 11: Values of *Np*, *N(1-p)* and *p*

Industry	*N*	*p*	*Np*	*N(1-p)*
Airlines	85	0.12	10	75
Aircraft Manufacturing	85	0.06	5	80
Data Communications	213	0.09	20	193
Telecommunications Manufacturing	210	0.05	11	202
Electricity	134	0.13	17	117
Shipping Lines	199	0.13	25	174
Shipbuilding	197	0.08	15	182
Information Storage	114	0.14	16	98
Software	114	0.17	19	95

The values for *Np* and *N(1-p)* are at least 5 for each industry. Therefore, the values of *Np* and *N(1-p)* are sufficient to expect that the data are not overly skewed and that valid results can be generated for each industry.

Further, comparing each increasing returns industry with the constant returns industry in each industry pair (Airlines/Aircraft Manufacturing, Data Communications/Telecommunications Manufacturing, Electricity/Shipbuilding, Shipping Lines/Shipbuilding) demonstrates that the increasing returns industry had the greater *p* value in each case.

Confidence Intervals

The 95% confidence interval for each industry is $p \pm 1.96$ times the standard error, where p is the observed proportions of the event. The p value and 95% confidence interval for each industry is listed in the following table, along with a confidence interval rounded off to two decimal places, and a column denoting whether a significant result was found for each industry with the result listed under the increasing returns industry for that industry pair:

Table 12: Confidence Intervals

Industry	p	**95% confidence interval**	**Confidence Interval**	**Significant result**
Airlines	0.12	0.07	0.12+/-0.07	NS
Aircraft Manufacturing	0.06	0.05	0.06+/-0.05	
Data Communications	0.09	0.04	0.09+/-0.04	NS
Telecommunications Manufacturing	0.05	0.03	0.05+/-0.03	
Electricity	0.13	0.06	0.13+/-0.06	NS
Shipping Lines	0.13	0.05	0.13+/-0.05	NS
Shipbuilding	0.08	0.04	0.08+/-0.04	
Information Storage	0.14	0.06	0.14+/-0.06	
Software	0.17	0.07	0.17+/-0.07	

where S denotes that the two industries are significantly different with a 95% level of confidence; and NS denotes no significant difference between the industries to a 95% level of confidence.

The confidence intervals listed are sufficiently large that in every case the lower end of the confidence interval for the industry with the greater p value is less than the upper end of the confidence interval for its corresponding industry pair.

Hence, while in each industry pair case the increasing returns industry had higher p values than the corresponding constant returns industry, the results do not show the difference between the industry pairs to be significant.

Summary

Testing the data using a Normal Distribution approximation for the Binomial Distribution did not find that the difference between increasing returns and constant returns industries was significant. However, the values for p were consistently greater for increasing return industries than constant returns industries.

4.3 *Testing using Fisher's Exact Test*

Introduction

The Fisher's Exact Test creates a 2x2 matrix from the data and compares the two cases to determine whether the data could be drawn from the same population.

The hypothesis being tested is that the frequency of change of increasing returns and constant returns industries are not significantly different. If this hypothesis is rejected, then one would have found a statistically significant difference in industry means between the increasing returns and constant returns industry of each industry pair.

Cross Tabulations

A Fisher's Exact Test was conducted for total discontinuities on each industry pair comparing an increasing returns industry with a constant returns industry (Airlines/Aircraft Manufacturing, Data Communications/Telecommunications Manufacturing, Electricity/Shipbuilding, Shipping Lines/Shipbuilding). The dichotomised form of the total discontinuity datasets has been used to fit the 2x2 matrix requirements of the Fisher's Exact Test. SPSS's crosstabs command was used to select the columns of data from the dataset relating to the two industries in each industry pair in turn, with the number of years tested limited by the common range of years between the two industries.

The test uses cross tabulations of the industry pairs. The following four tables provide the cross tabulations for each industry pair in turn, as outputted by SPSS. In each case the increasing returns industry is represented on the left axis and the constant returns industry along the top. For each industry, 0 represents an absence of a discontinuity and 1 represents the presence of a discontinuity. Thus, each (1,1) case represents a year when the industries each experienced a discontinuity in the same year, each (0,0) case represents a year when neither industry had a discontinuity and the (1,0) and (0,1) cases are the years when one industry experienced a discontinuity while the other did not.

Table 13: Airlines/Aircraft Manufacturing Cross tabulation

		Aircraft Manufacturing		**Total**
		0	1	
Airlines	0	72	3	75
	1	8	2	10
Total		80	5	85

Table 14: Data Communications/Telecommunications Manufacturing Cross tabulation

		Telecommunications Manufacturing		**Total**
		0	1	
Data Communications	0	183	10	193
	1	19	1	20
Total		202	10	213

Table 15: Electricity/Shipbuilding Cross tabulation

		Shipbuilding		**Total**
		0	1	
Electricity	0	107	10	117
	1	16	1	17
Total		123	11	134

Table 16: Shipping Lines /Shipbuilding Cross tabulation

		Shipbuilding		**Total**
		0	1	
Shipping Lines	0	162	11	173
	1	20	4	24
Total		182	15	197

Results

SPSS uses the cross tabulations to calculate one-sided and two-sided significance results for the Fisher's Exact Test. The results relate to the probability of the hypothesis that the two industries have the same frequency of discontinuities.

The one-sided significance results for the Fisher's Exact Test are listed in the following table:

Table 17: Fisher's Exact Test

Industry pair	**Exact Significance (1-sided)**
Airlines/Aircraft Manufacturing	0.103
Data Communications/Telecommunications Manufacturing	0.724
Electricity/Shipbuilding	0.580
Shipping Lines/Shipbuilding	0.092

The Fisher's Exact Test statistic exceeded 0.05 in all circumstances. Hence, the test fails to reject the hypothesis that industry pair data represents the same population to a level of significance of 95%.

Validity of Results

The Fisher's Exact Test has a limitation that the expected value for each cell should be at least 10 (Wikipedia, 2005b). SPSS' cross tabulations function reports this value as the minimum expected count. SPSS calculates the minimum expected count for each cell and displays a warning where any cell has an expected count less than 5.

The SPSS cross tabulations reported that the minimum expected count for each cross tabulation as:

Table 18: Fisher's Exact Test Expected Counts

Industry pair	**Number of cells with expected count less than 5**	**Minimum expected count**
Airlines/Aircraft Manufacturing	2	0.59
Data Communications/Telecommunications Manufacturing	1	1.03
Electricity/Shipbuilding	1	1.40
Shipping Lines/Shipbuilding	1	1.83

The table above demonstrates that each industry cross tabulation has at least one cell with an expected count less than 5. Therefore, the Fisher's Exact Test results are unreliable.

Summary

The Fisher's Exact Test has been calculated for each pair of increasing returns and constant returns industries. The null hypothesis would reject that the ratio of "0"s and "1"s for each industry are representative of the same population, and hence have different frequency of change.

However, the Fisher's Exact Test failed to find a significant difference between the frequency of change of increasing returns and constant returns industries. Furthermore, the cross tabulation test of SPSS reported expected counts less than 5 for each industry pair cross tabulation, and thus the Fisher's Exact Test results cannot be relied upon.

4.4 Generalised Linear Model

Introduction

The Generalised Linear Model (GLM) technique can model multi-dimensional data and has the distinct advantages over other techniques that it is not constrained by stationarity. Thus the GLM technique can analyse data with varying means and variances, which can be expected in the dataset as a result of Tushman and Anderson's (1986) observation of varying change after different types of discontinuities.

R version 2.0.1 can use GLM to calculate significance levels for each data code, and hence determine significance between the two states for each code. R can also test relationships between separate codes.

GLM was used to test the hypotheses that there is a significant difference:

(1) in the distribution of discontinuities of increasing returns and constant returns industries;

(2) between the proportions of competence-enhancing and competence-destroying discontinuities experienced in an increasing returns industry compared with a constant returns industry;

(3) in the distribution of discontinuities following a competence-destroying discontinuity in the preceding 0-10 year period;

(4) in the distribution of discontinuities following a competence-destroying discontinuity in the preceding 11-20 year period;

(5) in the distribution of discontinuities following a competence-enhancing discontinuity in the preceding 0-10 year period; and

(6) in the distribution of discontinuities following a competence-enhancing discontinuity in the preceding 11-20 year period.

Hypothesis One has been designed to test whether increasing returns are correlated with increased frequency of change. Such a finding would imply that the high information content in the industry researched by Brown and Eisenhardt (1997, 1998) would be responsible for their finding of a high frequency of change.

Hypothesis Two has been designed to test whether increasing returns are correlated with a change in the types of discontinuities experienced. A positive finding could provide support that industries that tend to experience hypercompetitive conditions, such as described by D'Aveni (1994), would be correlated with increasing returns derived from network effects and information content

Hypotheses Three, Four, Five and Six test whether Tushman and Anderson's (1986) finding that industry-level change increases after a competence-destroying discontinuity and decreases after a competence-enhancing discontinuity. A finding of support for these hypotheses would provide further insights into the nature of industry level change and the path dependency of change implied by Tushman and Anderson (1986).

The GLM has been prepared for each of the four industry pairs of one increasing returns and one constant returns industry (Airlines/Aircraft Manufacturing, Data Communications/Telecommunications Manufacturing, Electricity/Shipbuilding, Shipping Lines/Shipbuilding). In addition, the GLM has been prepared for the total of all the paired industries (Total Industry Pairs), to analyse the data together to improve the significance in the GLM findings. The Shipbuilding industry has been counted twice to allow for its pairing with both the Electricity and Shipping Lines industries, and to eliminate any distortion regarding the frequency of discontinuities.

A further GLM was prepared including the data from the seven industries included in the industry pair analysis (Paired Industries). The exclusion of the duplicated industry is to eliminate possible distortion in analysing effects on competency-type by preceding competency type and temporal proximity. A final GLM (Total Industries) included the software and information storage industries to the seven industries analysed in the industry pairs to examine whether these two industries with high levels of information in their output have any further influence that can be detected with the GLM results.

Finally, the GLM tests were repeated using 0-8 years in lieu of 0-10 years and 9-16 years in lieu of 11-20 years, and again with 0-11 years in lieu of 0-10 years and 12-22 years in lieu of 11-20 years to test the sensitivity of the results to the selection of the period lengths.

Decision Matrices

R's GLM module loads a decision matrix to control the analysis of each model. The GLM analyses corresponding to the datasets are controlled by identical decision matrices.

Hypotheses Two to Six required an analysis of the interaction of pairs of codes to determine whether a significant relationship exists. Two extended decision matrices were created to test these relationships between pairs of codes by increasing returns and discontinuity type.

The decision matrices are listed in the Appendices to enable the reproduction of the results.

Data Vectors

The data vectors for each GLM analysis have been prepared from the case study data. The niche opening discontinuity has been deleted from the dataset in each case as it is impossible to calculate the length of time since a non-existent preceding discontinuity. The first discontinuity following the niche opening has treated the niche opening as a competence-destroying discontinuity (as it has destroyed prior industry knowledge and opened the niche for a large number of new entrants).

Whenever a competence-destroying discontinuity and a competence-enhancing discontinuity occurred in the same year, then each discontinuity was treated as being equal in time and as having the other discontinuity within its preceding 0-10 preceding period as it is unclear from the data which discontinuity occurred first, unless it was clear from the data that one discontinuity was a pre-requisite for the other (for example, the stored program computer is a pre-requisite technology to enable software routines to be developed), in which case they were treated as sequential. If more than one competence-enhancing discontinuity occurred in the same year, then they were treated as sequential.

The data vectors for each industry pair, the Total Industry Pairs, the Paired Industries and for the Total Industry datasets are listed in the Appendices. A sample of the coding for the Airlines/Aircraft Manufacturing Vector is listed in the following table:

Table 19: Sample Vector

Code	Vector
IR11010	1
IR11000	1
IR10111	2
IR10011	2
IR10010	1
IR10001	3
CR11001	1
CR11000	1
CR10000	1
CR00110	1

Each case has been labelled IR or CR (for Increasing Returns or Constant Returns, respectively), and then 1 or 0 for each of the last five columns in the matrix, corresponding with yes or no in the respective coding, respectively, for: (1) whether the discontinuity is competence-enhancing; (2) a competence-destroying discontinuity in the past 0-10 years; (3) a competence-destroying discontinuity in the past 11-20 years; (4) a competence-enhancing discontinuity in the past 0-10 years; and (5) a competence-enhancing discontinuity in the past 11-20 years. Thus, for example, IR11010 is the code for a competence-enhancing discontinuity in an increasing returns industry, with both a competence-destroying and a competence-enhancing discontinuity within the previous 0-10 year period.

The data vectors for the 0-8 and 9-16 year and 0-11 and 12-22 year periods used for sensitivity testing are also listed in the Appendices, with the first and second period of each data vector being substituted for 0-10 and 11-20 years, respectively.

R

The seven vectors and the decision matrix have been loaded in R's GLM module. The glm.fit command has been used with a Poisson distribution. The results produced by R's summary.glm command are listed in the Appendix under GLM results.

Hypothesis One

Hypothesis One considers whether there is a significant difference between increasing returns and constant returns industries. The GLM results for each industry pair for the Industry code are listed in the following table, with the full GLM results listed in the Appendices:

Table 20: GLM results – Hypothesis One

Industry	Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	-0.02729	0.40184	-0.068	0.94585	NS
Data Communications v Telecommunications Manufacturing	0.05657	0.29370	0.193	0.8473	NS
Electricity v Shipbuilding	-0.1204	0.3038	-0.396	0.69188	NS
Shipping Lines v Shipbuilding	0.16175	0.27083	0.597	0.550	NS
Total Industry Pairs	0.4000	0.1718	2.328	0.0199	S
Paired Industries	0.64436	0.17962	3.587	0.000334	S
Total Increasing Returns/Constant Returns	0.91640	0.15542	5.896	3.72e-09	S

where S denotes a significant result and NS denotes a non-significant result.

The Total Industry Pairs (Total Pairs) is the sum of all four industry pairs, with the Shipbuilding industry being counted twice as it is paired with both the Electricity and Shipping Lines industries and not including its data twice may bias the results for testing Hypothesis One: whether there is a significant difference between the frequency of change for increasing and constant returns industries. The Total Pairs GLM shows a 95% probability of increasing returns industries having a greater frequency of change than constant returns industries. The z value for this finding is 2.328, which is a little high and does suggest that there is a degree of risk of a false positive in this finding.

The Paired Industries and Total Increasing Returns/Total Constant Returns Industries (Total Industries) GLMs also showed a significant result. However, these industries contain differing numbers of increasing returns and constant returns industries, and hence the results could possibly be attributable to a different number of discontinuities from different number of industries. Hence, the evidence from these GLMs has been discounted for this purpose. In any case, the z values of these GLMs were too high to be considered reliable.

However, the individual industry pair GLMs are all inconclusive. The GLM matrix can be truncated to the Industry code only, to increase the power of the GLM to distinguish the difference between industry types. The purpose is to focus the GLM on the hypothesised relationship in question. The reduced matrix enables the GLM to isolate patterns more effectively - essentially the test has greater statistical power.

The following table list the results from this truncated test applied to the four industry pairs.

Table 21: Truncated GLM - Hypothesis One

Industry	Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	-1.1632	0.3162	-3.678	0.000235	S
Data Communications v Telecommunications Manufacturing	-0.4700	0.2236	-2.102	0.0356	S
Electricity v Shipbuilding	-0.5754	0.2357	-2.441	0.0146	S
Shipping Lines v Shipbuilding	-0.2469	0.2000	-1.234	0.217	NS

where S denotes a significant result and NS denotes a non-significant result.

The truncated GLM found a significant difference between the industry codes in three out of four industry pairs (Airline/Aircraft Manufacturing, Data Communications/Telecommunications Manufacturing and Electricity/Shipbuilding) with z values that ranged from -2.102 to -3.678. The fourth industry pair (Shipping

Lines/Shipbuilding) did not have a significant result, but did have a reliable z value of -1.234. Therefore, there is a significant difference in the frequency of change between increasing returns and constant returns industries in three out of four industry pairs.

The nature of this significant difference can be deduced from the dataset, where the increasing returns industries exhibit a greater number of discontinuities than constant returns industries. These findings are listed in table 11, where the number of discontinuities, represented by the *Np* score, of the increasing returns industries was consistently greater than the corresponding *Np* score of its constant returns pair.

Therefore, Hypothesis One is supported by the Total Pairs GLM and three out of four industry pairs truncated industry code GLMs. However, the z values for these GLMs suggest a degree of trepidation that the GLM results may not be robust and there is some risk of a false positive result, which is constrained to some extent by the consistency of the results across four different GLMs.

Hypothesis Two

Hypothesis Two requires analysis of the interaction of GLM terms to detect correlations between constructs. The first extended decision matrix was used, as it tests for correlation between the industry code and other codes. The following tables provide the results for each industry pair and the Total Pairs GLMs for each paired code.

The following table reports the GLM tests of the interaction between the Industry construct and the type of discontinuity, coded as Industry.CE in the GLMs. The Total Industry Pairs GLM incorporating the Shipbuilding industry twice, as the pair for each of the Electricity and Shipping Lines industry, was used to eliminate any possible influence by differing industry numbers between increasing returns and constant returns industries on the Industry GLM code, which is central to this analysis. The full GLM results are listed in the Appendices.

Table 22: GLM results – Hypothesis Two

Industry	Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	19.47982	3414.04935	0.006	0.9954	NS
Data Communications v Telecommunications Manufacturing	1.0924	0.7677	1.423	0.1548	NS
Electricity v Shipbuilding	1.5425	1.0991	1.403	0.160497	NS
Shipping Lines v Shipbuilding	0.7017	0.7266	0.966	0.334199	NS
Total Industry Pairs	0.2516	0.4732	0.532	0.59497	NS

where S denotes a significant result and NS denotes a non-significant result.

No significant interaction was found between increasing returns in an industry and the type of discontinuity experienced in any GLM. Thus, Hypothesis Two, that there is a significant difference between the proportions of competence-enhancing and competence-destroying discontinuities experienced in an increasing returns industry compared with a constant returns industry, is not supported by these GLM tests. The z values for these findings are all robust, with values ranging from 0.006 to 1.423.

Therefore, Hypothesis Two has been tested further by truncating the decision matrix to the Industry.CE code only, in order to enhance the power of the test. The results are contained in the following table:

Table 23: Truncated GLM – Hypothesis Two

<table>
<tr><th>Industry</th><th>Estimate</th><th>Std Error</th><th>z value</th><th>Pr(>|z|)</th><th>Significant</th></tr>
<tr><td>Airlines v Aircraft Manufacturing</td><td>-0.4700</td><td>0.3162</td><td>-1.486</td><td>0.137</td><td>NS</td></tr>
<tr><td>Data Communications v Telecommunications Manufacturing</td><td>0.06062</td><td>0.24252</td><td>0.25</td><td>0.803</td><td>NS</td></tr>
<tr><td>Electricity v Shipbuilding</td><td>0.06062</td><td>0.24253</td><td>0.25</td><td>0.803</td><td>NS</td></tr>
<tr><td>Shipping Lines v Shipbuilding</td><td>0.3185</td><td>0.2132</td><td>1.494</td><td>0.135</td><td>NS</td></tr>
<tr><td>Total Industry Pairs</td><td>1.4171</td><td>0.1231</td><td>11.51</td><td><2e-16</td><td>S</td></tr>
</table>

where S denotes a significant result and NS denotes a non-significant result.

The four industry pairs were not significant. The Total Industry Pairs has a highly significant correlation between increasing returns and the type of discontinuities experienced. However, as the z value for the Total Industry Pairs is rather high at 11.51, the evidence supporting Hypothesis Two is not sufficiently robust to be relied upon.

Hypotheses Three-Six

Hypotheses Three, Four, Five and Six consider whether a type of discontinuity up to twenty years prior to a discontinuity influences the type of discontinuity experienced. Hypothesis Three considers whether there is a significant difference in discontinuity distribution and type following a competence-destroying discontinuity in the preceding 0-10 year period. Hypothesis Four is the same as Hypothesis Three, but for an 11-20 year period. Hypothesis Five is the same as Hypothesis Three, but testing for competence-enhancing discontinuities, and likewise for Hypotheses Six and Four, respectively.

These hypotheses test require testing of interactive terms against the CE code, and hence the second extended matrix was used for these tests. The Paired Industries and Total Industries GLMs were tested instead of the Total Industry Pairs GLM as the Industry code is not the element being examined, and hence there was no justification for counting the Shipbuilding industry twice. Further, the addition of the software and information storage industries in the Total Industries GLM provided the possibility of extracting further information from the results. The extended GLMs for these tests are listed in the Appendices.

Hypothesis Three

For Hypothesis Three, the CD0.10 code denoting changes in distribution and CE.CD0.10 code denoting changes in discontinuity type, respectively, for 0-10 years following a competence-destroying discontinuity are listed in the following table:

Table 24: GLM results – Hypothesis Three

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CD0.10	-18.3656	2894.1846	-0.006	0.995	NS
	CE.CD0.10	17.5547	2894.1846	0.006	0.995	NS
Data Communications v Telecommunications Manufacturing	CD0.10	-1.8960	1.0430	-1.818	0.0691	S
	CE.CD0.10	1.8960	1.1143	1.702	0.0888	S
Electricity v Shipbuilding	CD0.10	-18.0891	2144.3197	-0.008	0.9933	NS
	CE.CD0.10	15.4500	2144.3198	0.007	0.9943	NS
Shipping Lines v Shipbuilding	CD0.10	-18.2712	2123.7260	-0.009	0.9931	NS
	CE.CD0.10	17.0548	2123.7260	0.008	0.9936	NS
Paired Industries	CD0.10	-2.60266	1.02441	-2.541	0.0111	S
	CE.CD0.10	1.68637	1.05037	1.606	0.1084	NS
Total Industries	CD0.10	-1.57265	0.47955	-3.279	0.00104	S
	CE.CD0.10	0.99283	0.51683	1.921	0.05473	S

where S denotes a significant result and NS denotes a non-significant result.

The Total Industries GLM and one industry pair (Data Communications / Telecommunications Manufacturing) reported a significant interaction between competency type and the presence of a competency-destroying discontinuity 0-10 years prior to the discontinuity within a 90% level of confidence. The z value of -1.702 for the industry pair and 1.921 for Total Industries suggest that this finding is robust.

Second, a correlation was found between the distribution of discontinuities and the presence of a competence-destroying discontinuity 0-10 years prior to the discontinuity with a 90%, 95% and 99% levels of confidence for the Data Communications/Telecommunications Manufacturing industry pair, the Paired

Industries and the Total Industries, respectively. The z value for the industry pair was -1.818 and therefore is reliable. The z values for the Paired Industries and Total Industries were -2.541 and -3.279, and therefore carry a significant risk of a false positive result.

Hypothesis Four

Hypothesis Four uses the CD11.20 code to denote the distribution of competences 11-20 years following a competence-destroying discontinuity, and the CE.CD11.20 code to denote competency type for 11-20 years following a competence-destroying discontinuity. These results are listed in the following table:

Table 25: GLM results – Hypothesis Four

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CD11.20	-1.1495	1.0513	-1.093	0.274	NS
	CE.CD11.20	-0.5552	1.3024	-0.426	0.670	NS
Data Communications v Telecommunications Manufacturing	CD11.20	-18.3116	2075.2566	-0.009	0.9930	NS
	CE.CD11.20	16.8765	2075.2566	0.008	0.9935	NS
Electricity v Shipbuilding	CD11.20	-0.6267	0.7742	-0.809	0.4182	NS
	CE.CD11.20	-0.2206	0.8707	-0.253	0.8000	NS
Shipping Lines v Shipbuilding	CD11.20	-1.7958	1.0441	-1.720	0.0855	S
	CE.CD11.20	0.2202	1.1364	0.194	0.8463	NS
Paired Industries	CD11.20	-1.34370	0.62196	-2.160	0.0307	S
	CE.CD11.20	0.07675	0.67150	0.114	0.9090	NS
Total Industries	CD11.20	-0.64695	0.36607	-1.767	0.07718	S
	CE.CD11.20	-0.08491	0.41591	-0.204	0.83822	NS

where S denotes a significant result and NS denotes a non-significant result.

The Shipping Lines/Shipbuilding industry pair, Paired Industries and Total Industries demonstrated a significant result for the distribution of discontinuities for 11-20 years following a discontinuity, with levels of confidence of 90%, 95% and 90%, respectively, and z values of -1.720, -2.160 and -1.767, respectively, suggesting that two out of three of these results can be relied upon. No significant relationship was found between competency type and a competence-destroying discontinuity 11-20 prior to a discontinuity.

Hypothesis Five

Hypothesis Five uses the CE0.10 code to denote the distribution of competences 0-10 years following a competence-enhancing discontinuity, and the CE.CE0.10 code to denote competency type for 0-10 years following a competence-enhancing discontinuity. These results are listed in the following table:

Table 26: GLM results – Hypothesis Five

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE0.10	-1.1495	1.0513	-1.093	0.274	NS
	CE.CE0.10	0.9954	1.1894	0.837	0.403	NS
Data Communications v Telecommunications Manufacturing	CE0.10	-0.4402	0.6486	-0.679	0.4973	NS
	CE.CE0.10	0.9954	1.1894	0.837	0.403	NS
Electricity v Shipbuilding	CE0.10	-0.6267	0.7742	-0.809	0.4182	NS
	CE.CE0.10	0.7602	0.8563	0.888	0.3747	NS
Shipping Lines v Shipbuilding	CE0.10	-0.9211	0.7682	-1.199	0.2305	NS
	CE.CE0.10	1.2088	0.8407	1.438	0.1505	NS
Paired Industries	CE0.10	-0.06894	0.44459	-0.155	0.8768	NS
	CE.CE0.10	0.35662	0.49248	0.724	0.4690	NS
Total Industries	CE0.10	0.20020	0.31594	0.634	0.52629	NS
	CE.CE0.10	0.23384	0.36830	0.635	0.52549	NS

where S denotes a significant result and NS denotes a non-significant result.

No significant results were found to support Hypothesis Five. The z values ranging from -1.199 to 1.438 showed that these results are robust.

Hypothesis Six

The final hypothesis, Hypothesis Six, uses the CE11.20 code to consider the distribution of, and the CE.CE11.20 code to test discontinuity type of, discontinuities in the 11-20 year period following a competence-enhancing discontinuity. These results are listed in the following table:

Table 27: GLM results – Hypothesis Six

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE11.20	-18.3656	2894.1846	-0.006	0.995	NS
	CE.CE11.20	18.8356	2894.1846	0.007	0.995	NS
Data Communications v Telecommunications Manufacturing	CE11.20	-0.4402	0.6486	-0.679	0.4973	NS
	CE.CE11.20	0.4402	0.7579	0.581	0.5614	NS
Electricity v Shipbuilding	CE11.20	-0.2937	0.6419	-0.458	0.6473	NS
	CE.CE11.20	1.2884	1.1145	1.156	0.2477	NS
Shipping Lines v Shipbuilding	CE11.20	-0.2937	0.6419	-0.458	0.6473	NS
	CE.CE11.20	0.50241	0.51710	0.972	0.3312	NS
Paired Industries	CE11.20	-0.34826	0.47241	-0.737	0.4610	NS
	CE.CE11.20	0.50241	0.51710	0.972	0.3312	NS
Total Industries	CE11.20	0.23384	0.36830	0.635	0.52549	NS
	CE.CE11.20	0.47151	0.38466	1.226	0.22028	NS

where S denotes a significant result and NS denotes a non-significant result.

There were no significant results found to support Hypothesis Six. The z values range from -0. 737 to 1.226 and therefore demonstrate that the results are reliable.

4.5 *Sensitivity Tests*

Sensitivity tests were conducted only for the GLM tests, as the Binomial Distribution and Fisher's Exact Tests were inconclusive. Each hypothesis was tested in turn, to determine whether the results were particularly sensitive to the time periods originally selected. The GLM tests were repeated using the data vectors for 0-8 and 9-16 years (8/16 years) and 0-11 and 12-22 years (11/22 years) listed in the Appendices.

Hypothesis One Sensitivity Test

The sensitivity test results for Hypothesis One are listed in the Appendices. A summary table is listed below for each sensitivity test:

Table 28: GLM results – Hypothesis One (8/16 years)

Industry	Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	0.01439	0.40482	0.036	0.97165	NS
Data Communications v Telecommunications Manufacturing	0.08642	0.29517	0.293	0.769684	NS
Electricity v Shipbuilding	-0.0833	0.3064	-0.272	0.785685	NS
Shipping Lines v Shipbuilding	0.22981	0.27507	0.835	0.403	NS
Total Industry Pairs	1.0135	0.1593	6.363	1.98e-10	S

where S denotes a significant result and NS denotes a non-significant result.

Table 29: GLM results – Hypothesis One (11/22 years)

Industry	Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	-0.04905	0.40041	-0.122	0.90250	NS
Data Communications v Telecommunications Manufacturing	0.05588	0.29373	0.190	0.849108	NS
Electricity v Shipbuilding	-0.1653	0.3011	-0.549	0.5829	NS
Shipping Lines v Shipbuilding	0.08812	0.26698	0.330	0.741350	NS
Total Industry Pairs	0.35622	0.16973	2.099	0.0358	S

where S denotes a significant result and NS denotes a non-significant result.

The findings are consistent with the standard 0-10 year and 11-20 year (10/20 years) findings. The four industry pairs are inconclusive, with convincing z values. The Total Industry Pairs findings are significant – to a significance level of 99% for the 8/16 case and 95% for the 11/22 case. However, the z values for the Total Industry Pairs differ, with the 8/16 case having a high z score of 6.363 suggesting that the result is unreliable, while the 11/22 case had a z value of 2.099 suggesting that the result may be reliable, but there is still some likelihood of a false positive result.

Hypothesis Two Sensitivity Test

The sensitivity tests for Hypothesis Two are also summarised in two tables. The GLM results are listed in the Appendices for reference.

Table 30: GLM results – Hypothesis Two 8/16 years

Industry	Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	20.33067	5150.65509	0.004	0.997	NS
Data Communications v Telecommunications Manufacturing	1.0764	0.7674	1.403	0.1607	NS
Electricity v Shipbuilding	1.3549	1.0975	1.235	0.217006	NS
Shipping Lines v Shipbuilding	0.51414	0.72424	0.710	0.477764	NS
Total Industry Pairs	-0.03918	0.40081	-0.098	0.92213	NS

where S denotes a significant result and NS denotes a non-significant result.

Table 31: GLM results – Hypothesis Two 11/2 years

Industry	Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	19.62193	3418.60968	0.006	0.9954	NS
Data Communications v Telecommunications Manufacturing	1.0924	0.7677	1.423	0.1548	NS
Electricity v Shipbuilding	1.67892	1.10029	1.526	0.12704	NS
Shipping Lines v Shipbuilding	0.8381	0.7284	1.151	0.24989	NS
Total Industry Pairs	0.40671	0.47516	0.856	0.392027	NS

where S denotes a significant result and NS denotes a non-significant result.

The correlation between the Industry and competency type code (Industry.CE) was insignificant for all industry pairs and for Total Industry Pairs for both the 8/16 years and 11/22 years cases. The z values ranged from -0.098 to 1.526, providing confidence in these results. This finding is consistent with the original 10/20 years case.

The GLM for the truncated matrix is insensitive to the selection of time period length.

Hypotheses Three-Six Sensitivity Tests

The Hypothesis Three, Four, Five and Six tests were run for the 8/16 years and 11/22 years cases. The results are listed in the two tables for each hypothesis below, with the full results listed in the Appendices.

Hypothesis Three Sensitivity Tests

Table 32: GLM results – Hypothesis Three 8/16 years

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CD0.8	-18.3607	2887.0327	-0.006	0.995	NS
	CE.CD0.8	17.5498	2887.0327	0.006	0.995	NS
Data Communications v Telecommunications Manufacturing	CD0.8	-18.3355	2100.2216	-0.009	0.9930	NS
	CE.CD0.8	18.0253	2100.2216	0.009	0.9932	NS
Electricity v Shipbuilding	CD0.8	-18.0886	2143.8056	-0.008	0.99327	NS
	CE.CD0.8	15.4496	2143.8057	0.007	0.99425	NS
Shipping Lines v Shipbuilding	CD0.8	-18.1411	2089.6785	-0.009	0.9931	NS
	CE.CD0.8	16.7548	2089.6786	0.008	0.9936	NS
Paired Industries	CD0.8	-18.9636	2125.0034	-0.009	0.993	NS
	CE.CD0.8	17.8796	2125.0034	0.008	0.993	NS
Total Industries	CD0.8	-2.10235	0.60264	-3.489	0.000486	S
	CE.CD0.8	1.37049	0.63416	2.161	0.030686	S

where S denotes a significant result and NS denotes a non-significant result.

Table 33: GLM results – Hypothesis Three 11/22 years

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CD0.11	-18.38534	2922.83469	-0.006	0.995	NS
	CE.CD0.11	17.57441	2922.83475	0.006	0.995	NS
Data Communications v Telecommunications Manufacturing	CD0.11	-1.8960	1.0430	-1.818	0.0691	S
	CE.CD0.11	1.7418	1.1147	1.563	0.1181	NS
Electricity v Shipbuilding	CD0.11	-1.64571	1.04940	-1.568	0.1168	NS
	CE.CD0.11	-0.55151	1.21310	-0.455	0.6494	NS
Shipping Lines v Shipbuilding	CD0.11	-1.90705	1.04313	-1.828	0.0675	S
	CE.CD0.11	0.69065	1.11810	0.618	0.5368	NS
Paired Industries	CD0.11	-1.8726	0.7419	-2.524	0.011600	S
	CE.CD0.11	1.0095	0.7766	1.300	0.193597	NS
Total Industries	CD0.11	-1.39625	0.44307	-3.151	0.00163	S
	CE.CD0.11	0.85339	0.48279	1.768	0.07712	S

where S denotes a significant result and NS denotes a non-significant result.

The tests for cases 8/16 years and 11/22 years were consistent with the 10/20 years case, except that neither the 8/16 or 11/22 years case found support for a significant interaction between competency type and the presence of a competency-destroying discontinuity in the Data Communications/Telecommunications Manufacturing industry pair. The z value for the Total Industries GLM for the 11/22 years case for this test was compelling at 1.768, but the 8/16 years case at 2.161 was less certain of the result not being a false positive.

The findings of competency distribution being correlated with a preceding competency-destroying discontinuity were significant for the Paired Industries in the 11/22 years case and the Total Industries in both the 8/16 and 11/22 years cases, but the z values were not compelling at -3.489, -2.524 and -3.151, respectively, leading to the likelihood that the results represent false positives. The 11/22 years case found a significant result for the Data Communications/Telecommunications Manufacturing and Shipping Lines/Shipbuilding industry pairs, with a 90% level of significance in each case and acceptable z values of -1.818 and -1.828, respectively.

Hypothesis Four Sensitivity Tests

Table 34: GLM results – Hypothesis Four 8/16 years

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CD9.16	-1.1495	1.0513	-1.093	0.274	NS
	CE.CD9.16	-1.3354	1.4794	-0.903	0.367	NS
Data Communications v Telecommunications Manufacturing	CD9.16	-1.8960	1.0430	-1.818	0.0691	S
	CE.CD9.16	0.4609	1.1556	0.399	0.6900	NS
Electricity v Shipbuilding	CD9.16	-0.6267	0.7742	-0.809	0.41825	NS
	CE.CD9.16	-0.9828	0.9162	-1.073	0.28340	NS
Shipping Lines v Shipbuilding	CD9.16	-0.3669	1.1722	-0.313	0.7543	NS
	CE.CD9.16	-0.3669	1.1722	-0.313	0.7543	NS
Paired Industries	CD9.16	-0.9184	0.5533	-1.660	0.097	S
	CE.CD9.16	-0.7043	0.6213	-1.134	0.257	NS
Total Industries	CD9.16	-0.56282	0.36835	-1.528	0.126525	NS
	CE.CD9.16	-0.64115	0.42876	-1.495	0.134817	NS

where S denotes a significant result and NS denotes a non-significant result.

Table 35: GLM results – Hypothesis Four 11/22 years

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CD12.22	-1.14953	1.05132	-1.093	0.274	NS
	CE.CD12.22	-0.05444	1.24040	-0.044	0.965	NS
Data Communications v Telecommunications Manufacturing	CD12.22	-18.2966	2059.7775	-0.009	0.9929	NS
	CE.CD12.22	17.0926	2059.7775	0.008	0.9934	NS
Electricity v Shipbuilding	CD12.22	-1.64571	1.04940	-1.568	0.1168	NS
	CE.CD12.22	0.79841	1.12248	0.711	0.4769	NS
Shipping Lines v Shipbuilding	CD12.22	16.70807	2036.61188	0.008	0.9935	NS
	CE.CD12.22	16.70807	2036.61188	0.008	0.9935	NS
Paired Industries	CD12.22	-1.8726	0.7419	-2.524	0.011603	S
	CE.CD12.22	-0.7043	0.6213	-1.134	0.257	NS
Total Industries	CD12.22	-0.70509	0.36436	-1.935	0.05298	S
	CE.CD12.22	0.05016	0.41322	0.121	0.90338	NS

where S denotes a significant result and NS denotes a non-significant result.

The 8/16 years case only found a significant relationship between competency distribution and the presence of a preceding competence-destroying discontinuity for the Data Communications/Telecommunications Manufacturing industry pair, with a level of significance of 90% and an acceptable z value of -1.818. Neither case found a significant relationship for the Shipping Lines/Shipbuilding industry pair, which had been found in the 10/20 years case. Thus these industry pair findings seem sensitive to the selection of the time period tested.

Further, both cases found a significant relationship between competency distribution and the presence of a preceding competence-destroying discontinuity for the Paired Industries with 90% and 95% levels of significance for the 8/16 years and 11/22 years case, respectively, and with an acceptable z value of -1.660 for the 8/16 years case and a less acceptable -2.524 for the 11/22 years case.

In addition, the analysis of the Total Industries only found a significant relationship between competency distribution and the presence of a preceding competence-destroying discontinuity for the 11/22 years case, with a level of significance of 90% and an acceptable z value of -1.935.

Hypothesis Five Sensitivity Tests

Table 36: GLM results – Hypothesis Five – 8/16 years

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE0.8	-18.3607	2887.0327	-0.006	0.995	NS
	CE.CE0.8	17.8907	2887.0327	0.006	0.995	NS
Data Communications v Telecommunications Manufacturing	CE0.8	-0.4402	0.6486	-0.679	0.4973	NS
	CE.CE0.8	0.7504	0.7604	0.987	0.3237	NS
Electricity v Shipbuilding	CE0.8	-0.6267	0.7742	-0.809	0.41825	NS
	CE.CE0.8	0.4931	0.8563	0.576	0.56470	NS
Shipping Lines v Shipbuilding	CE0.8	-0.7816	0.7656	-1.021	0.3073	NS
	CE.CE0.8	0.6097	0.8374	0.728	0.4665	NS
Paired Industries	CE0.8	-0.2903	0.4725	-0.615	0.539	NS
	CE.CE0.8	0.2684	0.5169	0.519	0.604	NS
Total Industries	CE0.8	0.03221	0.33092	0.097	0.922458	NS
	CE.CE0.8	0.08759	0.37924	0.231	0.817344	NS

where S denotes a significant result and NS denotes a non-significant result.

Table 37: GLM results – Hypothesis Five – 11/22 years

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE0.11	-1.14953	1.05132	-1.093	0.274	NS
	CE.CE0.11	1.30368	1.18945	1.096	0.273	NS
Data Communications v Telecommunications Manufacturing	CE0.11	-0.4402	0.6486	-0.679	0.4973	NS
	CE.CE0.11	1.2512	0.7754	1.614	0.1066	NS
Electricity v Shipbuilding	CE0.11	-0.73829	0.77350	-0.954	0.3398	NS
	CE.CE0.11	1.28483	0.86130	1.492	0.1358	NS
Shipping Lines v Shipbuilding	CE0.11	-1.05312	0.76884	-1.370	0.1708	NS
	CE.CE0.11	1.70371	0.84730	2.011	0.0444	S
Paired Industries	CE0.11	-0.1348	0.4452	-0.303	0.762053	NS
	CE.CE0.11	0.7952	0.4972	1.599	0.109721	NS
Total Industries	CE0.11	0.11652	0.31480	0.370	0.71128	NS
	CE.CE0.11	-0.01589	0.32082	-0.050	0.96050	NS

where S denotes a significant result and NS denotes a non-significant result.

With a single exception, the sensitivity tests for Hypothesis Five replicated the 10/20 case by providing no significant results.

The exception was the finding of a significant correlation between the type of discontinuity type and the presence of a competence-enhancing discontinuity in the preceding 0-11 years, with a level of significance of 95%. However, the corresponding z value of 2.011 is sufficiently high that there is some likelihood that the result is a false positive. Therefore, there is value in testing Hypothesis Five further in order to determine if more robust results can be achieved.

Hypothesis Five Sensitivity Test – truncated

The 11/22 years case for Hypothesis Five found a significant correlation between the competency type and a preceding competence-enhancing discontinuity 0-11 years prior to the discontinuity. A truncated version second extended matrix with the interactions used for Hypotheses Three, Four and Six removed was retested for the 10/20, 8/16 and 11/22 years cases to determine whether significant support for Hypothesis Five could be found using a more focused test.

The results are summarised in the following three tables, corresponding to the three periods tested. The full results are listed in the Appendices.

Table 38: GLM results – Hypothesis Five – 8/16 years, truncated

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE0.8	-17.78669	1831.97814	-0.010	0.99225	NS
	CE.CE0.8	17.31668	1831.97823	0.009	0.99246	NS
Data Communications v Telecommunications Manufacturing	CE0.8	-0.91427	0.61826	-1.479	0.139201	NS
	CE.CE0.8	1.22442	0.73473	1.667	0.095614	S
Electricity v Shipbuilding	CE0.8	-0.82818	0.73786	-1.122	0.261693	NS
	CE.CE0.8	0.69464	0.82363	0.843	0.399010	NS
Shipping Lines v Shipbuilding	CE0.8	-1.16827	0.73786	-1.583	0.11335	NS
	CE.CE0.8	0.99642	0.81214	1.227	0.21986	NS
Paired Industries	CE0.8	-0.5566	0.4386	-1.269	0.204	NS
	CE.CE0.8	0.5346	0.4861	1.100	0.271	NS
Total Industries	CE0.8	-0.1422	0.3048	-0.466	0.641	NS
	CE.CE0.8	0.2620	0.3567	0.735	0.463	NS

where S denotes a significant result and NS denotes a non-significant result.

Table 39: GLM results – Hypothesis Five – 10/20 years, truncated

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE0.10	-1.66701	1.03521	-1.610	0.1073	NS
	CE.CE0.10	1.51286	1.17524	1.287	0.1980	NS
Data Communications v Telecommunications Manufacturing	CE0.10	-0.9080	0.6181	-1.469	0.141802	NS
	CE.CE0.10	1.5440	0.7429	2.078	0.037686	S
Electricity v Shipbuilding	CE0.10	-0.86976	0.73768	-1.179	0.23838	NS
	CE.CE0.10	1.00329	0.82347	1.218	0.22308	NS
Shipping Lines v Shipbuilding	CE0.10	-1.225457	0.737539	-1.662	0.096603	S
	CE.CE0.10	1.513139	0.812790	1.862	0.062651	S
Paired Industries	CE0.10	-0.40347	0.40978	-0.985	0.324817	NS
	CE.CE0.10	0.69115	0.46129	1.498	0.134055	NS
Total Industries	CE0.10	-0.04322	0.28838	-0.150	0.881	NS
	CE.CE0.10	0.47726	0.34494	1.384	0.166	NS

where S denotes a significant result and NS denotes a non-significant result.

Table 40: GLM results – Hypothesis Five – 11/22 years, truncated

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE0.11	-1.65353	1.03501	-1.598	0.1101	NS
	CE.CE0.11	1.80768	1.17506	1.538	0.1240	NS
Data Communications v Telecommunications Manufacturing	CE0.11	-0.8697	0.6181	-1.407	0.159422	NS
	CE.CE0.11	1.6806	0.7501	2.241	0.025053	S
Electricity v Shipbuilding	CE0.11	-0.8864	0.7376	-1.202	0.22942	NS
	CE.CE0.11	1.4330	0.8292	1.728	0.08395	S
Shipping Lines v Shipbuilding	CE0.11	-1.3258	0.7378	-1.797	0.072354	S
	CE.CE0.11	1.9764	0.8193	2.412	0.015849	S
Paired Industries	CE0.11	-0.408133	0.409678	-0.996	0.319139	NS
	CE.CE0.11	1.068490	0.465575	2.295	0.021734	S
Total Industries	CE0.11	-0.08731	0.28796	-0.303	0.761748	NS
	CE.CE0.11	0.81917	0.34913	2.346	0.018962	NS

where S denotes a significant result and NS denotes a non-significant result.

All three cases found no significant relationship in one of the industry pairs (Airlines/Aircraft Manufacturing). One industry pair (Data Communications/Telecommunications Manufacturing) was found to have a significant correlation between competency type and a preceding competence-enhancing discontinuity 8, 10 or 11years earlier, with levels of confidence of 90% for the 8/16 case and 95% for the 10/20 and 11/22 years cases and z values of 1.667, 2.078 and 2.241, respectively. A second industry pair (Shipping Lines/Shipbuilding) was significant for the same relationship for the 10/20 and 11/22 years cases only, to 90% and 95% levels of confidence and z values of 1.862 and 2.412, respectively. The remaining industry pair (Electricity/Shipbuilding) was significant only in the 11/22 years case, with a level of confidence of 90% and a z value of 1.728, while the Paired Industries and Total Industries were likewise significant for the same relationship only for the 11/22 years case, to levels of confidence of 95% each and z values of 2.295 and 2.346.

The 10/20 and 11/22 years cases also found a significant relationship between discontinuity distribution and a preceding competence-enhancing discontinuity 10 or 11 years earlier in the Shipping Lines/Shipbuilding industry pair, with a level of confidence of 90% in each case and z values of -1.662 and -1.797, respectively.

Thus, there is some reliable evidence supporting Hypothesis Five. Further, the consistent pattern was for the longer period tests to be more significant than the shorter tests, suggesting that this hypothesis is more time sensitive than earlier results.

Hypothesis Six Sensitivity Tests

Table 41: GLM results – Hypothesis Six 8/16 years

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE9.16	-1.1495	1.0513	-1.093	0.274	NS
	CE.CE9.16	1.6195	1.1959	1.354	0.176	NS
Data Communications v Telecommunications Manufacturing	CE9.16	-0.4402	0.6486	-0.679	0.4973	NS
	CE.CE9.16	0.7504	0.7604	0.987	0.3237	NS
Electricity v Shipbuilding	CE9.16	-1.5566	1.0518	-1.480	0.13889	NS
	CE.CE9.16	1.5566	1.1134	1.398	0.16209	NS
Shipping Lines v Shipbuilding	CE9.16	-0.7816	0.7656	-1.021	0.3073	NS
	CE.CE9.16	1.0693	0.8383	1.276	0.2021	NS
Paired Industries	CE9.16	-0.2903	0.4725	-0.615	0.539	NS
	CE.CE9.16	0.5780	0.5178	1.116	0.264	NS
Total Industries	CE9.16	-0.11307	0.33863	-0.334	0.738455	NS
	CE.CE9.16	0.47597	0.38730	1.229	0.219082	NS

where S denotes a significant result and NS denotes a non-significant result.

Table 42: GLM results – Hypothesis Six 11/22 years

Industry		Estimate	Std Error	z value	Pr(>|z|)	Significant
Airlines v Aircraft Manufacturing	CE12.22	-18.38534	2922.83469	-0.006	0.995	NS
	CE.CE12.22	18.53949	2922.83474	0.006	0.995	NS
Data Communications v Telecommunications Manufacturing	CE12.22	-0.4402	0.6486	-0.679	0.4973	NS
	CE.CE12.22	0.2861	0.7586	0.377	0.7061	NS
Electricity v Shipbuilding	CE12.22	-0.73829	0.77350	-0.954	0.3398	NS
	CE.CE12.22	0.33282	0.85860	0.388	0.6983	NS
Shipping Lines v Shipbuilding	CE12.22	0.06903	0.56690	0.122	0.9031	NS
	CE.CE12.22	0.33643	0.66365	0.507	0.6122	NS
Paired Industries	CE12.22	-0.1348	0.4452	-0.303	0.762054	NS
	CE.CE12.22	0.2008	0.4922	0.408	0.683334	NS
Total Industries	CE12.22	-0.01589	0.32082	-0.050	0.96050	NS
	CE.CE12.22	0.27372	0.37106	0.738	0.46071	NS

where S denotes a significant result and NS denotes a non-significant result.

The Hypothesis Six sensitivity tests found no significant results, and thus were consistent with the original 10/20 years case.

Summary

A sensitivity analysis has been conducted for each of the hypotheses to determine their sensitivity to the selection of time periods. The GLMs were rerun using 8/16 and 11/22 year periods to compare with the original 10/20 year periods.

Hypothesis One

Hypothesis One considered whether there was a significant difference between the distribution of discontinuities in increasing returns and constant returns industries. A summary of the findings for Hypothesis One for the three periods tested for sensitivity purposes is listed in the following table:

Table 43: Summary Hypothesis One sensitivity tests, Pr(>|z|)

Industry	10/20 years	8/16 years	11/22 years	Significant
Airlines v Aircraft Manufacturing	0.94585	0.97165	0.90250	NS
Data Communications v Telecommunications Manufacturing	0.8473	0.769684	0.849108	NS
Electricity v Shipbuilding	0.69188	0.785685	0.5829	NS
Shipping Lines v Shipbuilding	0.550	0.403	0.741350	NS
Total Industry Pairs	0.0199	1.98e-10	0.0358	S

where S denotes a significant result in at least one case and NS denotes no significant result in any case.

The findings for all three cases for Hypothesis One were consistent. Increasing returns were found to result in significant differences in the Total Industry pairs, with at least a 95% level of confidence in all cases. However, all of the z values were above 2.0, with z values of 2.328, 6.363, 2.099 for 10/20, 8/16 and 11/22 years cases, respectively, thus this finding must be considered less than reliable and there is the possibility of a false positive result.

The sensitivity testing for Hypothesis One did show an improved z value and reduced level of confidence for the longer periods, and thus it appears that the GLM has some sensitivity to the selection of time period for this hypothesis.

Hypothesis Two

Hypothesis Two considered whether there was a significant difference between the proportions of competence-enhancing and competence-destroying discontinuities in an increasing returns industry compared with a constant returns industry. A summary of the findings for Hypothesis Two is listed in the following table:

Table 44: Summary Hypothesis Two sensitivity tests, Pr(>|z|)

Industry	10/20 years	8/16 years	11/22 years	Significant
Airlines v Aircraft Manufacturing	0.9954	0.997	0.9954	NS
Data Communications v Telecommunications Manufacturing	0.1548	0.1607	0.1548	NS
Electricity v Shipbuilding	0.160497	0.217006	0.12704	NS
Shipping Lines v Shipbuilding	0.334199	0.477764	0.24989	NS
Total Industry Pairs	0.59497	0.92213	0.392027	NS

where S denotes a significant result in at least one case and NS denotes no significant result in any case.

Thus, the results for Hypothesis Two are consistent for all cases and were insensitive to time period selection. The GLM failed to find any significant correlation between increasing returns and discontinuity type. The truncated GLM test, which is insensitive to case type, did find that increasing returns are associated with a higher proportion of competence-enhancing discontinuities in the Total Pairs case, but the z value was sufficiently high at 11.51 that this finding can be dismissed as a probable false positive.

Hypothesis Three

Hypothesis Three examined whether a preceding competence-destroying discontinuity was correlated with the distribution of discontinuity experienced. The sensitivity tests tested this relationship for 0-10, 0-8 and 0-11 year periods. The results for Hypothesis Three are listed in the following table:

Table 45: Summary Hypothesis Three sensitivity tests, Pr(>|z|)

Industry	Interaction	0-10 years	0-8 years	0-11 years	Significant
Airlines v Aircraft Manufacturing	CD	0.995	0.995	0.995	NS
	CE.CD	0.995	0.995	0.995	NS
Data Communications v Telecommunications Manufacturing	CD	0.0691	0.9930	0.0691	S
	CE.CD	0.0888	0.9932	0.1181	S
Electricity v Shipbuilding	CD	0.9933	0.99327	0.1168	NS
	CE.CD	0.9943	0.99425	0.6494	NS
Shipping Lines v Shipbuilding	CD	0.9931	0.9931	0.0675	S
	CE.CD	0.9936	0.9936	0.5368	NS
Paired Industries	CD	0.0111	0.993	0.011600	S
	CE.CD	0.1084	0.993	0.193597	NS
Total Increasing Returns/Constant Returns Industries	CD	0.00104	0.000486	0.00163	S
	CE.CD	0.05473	0.030686	0.07712	S

where S denotes a significant result in at least one case and NS denotes no significant result in any case.

First, the findings for the relationship of discontinuity type and a preceding competence-destroying discontinuity in the three cases were consistent, with the exception of the Data Communications / Communications Manufacturing industry pair that was only found to be significant in the 10/20 years case with a level of confidence of 90% and a z value of 1.702 that suggests a reliable result. The Total Industries GLM found at least a 90% level confidence across the three cases, with z values of 1.921, 2.161 and 1.768 for the 10/20, 8/16 and 11/22 years cases, respectively.

Second, a significant relationship was found between discontinuity distribution and the presence of a preceding competence-destroying discontinuity in the Data Communications/Telecommunications Manufacturing industry pair for the 10/20 and 11/22 years cases only, with levels of confidence of 90% and z values of -1.818 in both cases, plus the Shipping Lines and Shipbuilding industry pair only in the 11/22 years case with a level of confidence of 90% and a z value of -1.828. Further, the 10/20 and 11/22 years cases had a significant finding for the Paired Industries and all three cases had a significant relationship for the Total Industries, but with the z values ranging from -2.524 to -3.489, these findings could represent false positive results and therefore not reliable.

Thus, the sensitivity tests confirmed the original findings, with the longer time period providing a greater number of significant results suggesting that the GLM is sensitive to the selection of time for this hypothesis.

Hypothesis Four

Hypothesis Four considered whether a competence-destroying discontinuity preceding a discontinuity by 11-20, 9-16 or 12-22 years was correlated with discontinuity type or distribution. The results for Hypothesis Four are listed in the following table:

Table 46: Summary Hypothesis Four sensitivity tests, Pr(>|z|)

Industry	Interaction	11-20 years	9-16 years	12-22 years	Significant
Airlines v Aircraft Manufacturing	CD	0.274	0.274	0.274	NS
	CE.CD	0.670	0.367	0.965	NS
Data Communications v Telecommunications Manufacturing	CD	0.9930	0.0691	0.9929	S
	CE.CD	0.9935	0.6900	0.9934	NS
Electricity v Shipbuilding	CD	0.4182	0.41825	0.1168	NS
	CE.CD	0.8000	0.28340	0.4769	NS
Shipping Lines v Shipbuilding	CD	0.0855	0.7543	0.9935	S
	CE.CD	0.8463	0.7543	0.9935	NS
Paired Industries	CD	0.0307	0.097	0.011603	S
	CE.CD	0.9090	0.257	0.392865	NS
Total Increasing Returns/Constant Returns Industries	CD	0.07718	0.126525	0.05298	S
	CE.CD	0.83822	0.134817	0.90338	NS

where S denotes a significant result in at least one case and NS denotes no significant result in any case.

No significant relationship was found between discontinuity type and a competence-destroying discontinuity 11-20, 8-16 or 12-22 years prior to a discontinuity. Thus, for this relationship, the GLM provided insensitive to time period selection.

However, a significant relationship was detected between discontinuity distribution and the preceding competence-destroying discontinuity in one industry pair in each of two different cases: Shipping Lines/Shipbuilding in the 10/20 years case with a level of confidence of 90% and a z value of -1.720; and Data Communications/Telecommunications Manufacturing in the 8/16 years case with a 90% level of confidence and a z value of -1.818. The finding of two robust results in different industries when different periods of time are selected suggests that the GLM is sensitive to the time period selection for this hypothesis.

All three cases also found a significant result for Paired Industries, with levels of confidence of 95%, 90% and 95% and z values of -2.160, -1.818 and -2.524 for the 10/20, 8/16 and 11/22 years periods, respectively. Further, the 10/20 and 11/22 years cases found a significant result for the Total Industries, with levels of confidence of

90% and z values of -1.767 and -1.935, respectively. These findings demonstrated increasing z scores and improving levels of confidence for longer time periods. Thus, these results reinforce that the GLM has some sensitivity to the time period selection for this hypothesis.

Hypothesis Five

Hypothesis Five examined whether a competence-enhancing discontinuity preceding a discontinuity by 0-10, 0-8 or 0-11 years was correlated with discontinuity type. The results are listed in the following table:

Table 47: Summary Hypothesis Five sensitivity tests, Pr(>|z|)

Industry	Interaction	0-10 years	0-8 years	0-11 years	Significant
Airlines v Aircraft Manufacturing	CE	0.274	0.995	0.274	NS
	CE.CE	0.403	0.995	0.273	NS
Data Communications v Telecommunications Manufacturing	CE	0.4973	0.4973	0.4973	NS
	CE.CE	0.1614	0.3237	0.1066	NS
Electricity v Shipbuilding	CE	0.4182	0.41825	0.3398	NS
	CE.CE	0.3747	0.56470	0.1358	NS
Shipping Lines v Shipbuilding	CE	0.2305	0.3073	0.1708	NS
	CE.CE	0.1505	0.4665	0.0444	S
Paired Industries	CE	0.8768	0.539	0.762053	NS
	CE.CE	0.4690	0.604	0.109721	NS
Total Increasing Returns/Constant Returns Industries	CE	0.52629	0.922458	0.71128	NS
	CE.CE	0.52549	0.817344	0.96050	NS

where S denotes a significant result in at least one case and NS denotes no significant result in any case.

The findings are consistent in finding no significant relationship for all cases but one, which had a z value of 2.011 and therefore is a possible false positive in any case.

Hypothesis Five was further tested using a truncated decision matrix to increase the power of the GLM. One industry pair (Data Communications / Telecommunications

Manufacturing) had a significant relationship between discontinuity type and a preceding competence-enhancing discontinuity for all three cases, with z values of 1.667, 2.078 and 2.241 for the 8/16, 10/20 and 11/22 years cases, respectively; one industry pair (Shipping Lines / Shipbuilding) was significant for two cases, 10/20 and 11/22 years, with z values of 1.862 and 2.412); and one industry pair (Electricity / Shipbuilding), the Paired Industries and the Total Industries were significant for only for the 11/22 years case. Further, the Shipping Lines/Shipbuilding case alone showed a significant relationship between discontinuity type and the preceding competence-enhancing discontinuity with levels of confidence of 90% and z values of -1.662 and -1.797, for 10/20 and 11/22 years cases respectively.

The results consistently showed increasing levels of confidence and increasing z values for the longer time periods, thus demonstrating that the GLM has sensitivity to the time periods selected for this hypothesis.

The following table lists the results.

Table 48: Summary Hypothesis Five sensitivity tests, truncated decision matrix, Pr(>|z|)

Industry	Interaction	0-10 years	0-8 years	0-11 years	Significant
Airlines v Aircraft Manufacturing	CE	0.1073	0.99225	0.1101	NS
	CE.CE	0.1980	0.99246	0.1240	NS
Data Communications v Telecommunications Manufacturing	CE	0.141802	0.139201	0.159422	NS
	CE.CE	0.037686	0.095614	0.025053	S
Electricity v Shipbuilding	CE	0.23838	0.261693	0.22942	NS
	CE.CE	0.22308	0.399010	0.08395	NS
Shipping Lines v Shipbuilding	CE	0.096603	0.11335	0.072354	S
	CE.CE	0.062651	0.21986	0.015849	S
Paired Industries	CE	0.324817	0.204	0.319139	NS
	CE.CE	0.134055	0.271	0.021734	S
Total Increasing Returns/Constant Returns Industries	CE	0.881	0.641	0.761748	NS
	CE.CE	0.166	0.463	0.018962	S

where S denotes a significant result in at least one case and NS denotes no significant result in any case.

Hypothesis Six

The final hypothesis, Hypothesis Six, considered the correlation between a competence-enhancing discontinuity 11-20, 9-16 and 12-22 years preceding a discontinuity being correlated with discontinuity distribution. The three cases were consistent in finding no significant correlation. Therefore the GLM is insensitive to time period selection for this hypothesis. The results are listed in the following table:

Table 49: Summary Hypothesis Six sensitivity tests, Pr(>|z|)

Industry	Interaction	11-20 years	9-16 years	12-22 years	Significant
Airlines v Aircraft Manufacturing	CE	0.995	0.274	0.995	NS
	CE.CE	0.995	0.176	0.995	NS
Data Communications v Telecommunications Manufacturing	CE	0.4973	0.4973	0.4973	NS
	CE.CE	0.5614	0.3237	0.7061	NS
Electricity v Shipbuilding	CE	0.6473	0.13889	0.3398	NS
	CE.CE	0.2477	0.16209	0.6983	NS
Shipping Lines v Shipbuilding	CE	0.6473	0.3073	0.9031	NS
	CE.CE	0.5214	0.2021	0.6122	NS
Paired Industries	CE	0.4610	0.539	0.762054	NS
	CE.CE	0.3312	0.264	0.683334	NS
Total Increasing Returns/Constant Returns Industries	CE	0.52549	0.738455	0.96050	NS
	CE.CE	0.22028	0.219082	0.46071	NS

Conclusion

First, the sensitivity tests showed that the findings had some sensitivity to the time periods selected, with Hypothesis Three showing a greater number of significant results for longer time periods, Hypotheses Four and Five showed improved levels of confidence and deteriorating z values for longer time periods and Hypothesis One showing the opposite, with decreased levels of confidence and improved z values for longer time periods.

Second, support was found for Hypothesis One, though there is some risk of a false positive in this result, which is partially mitigated by the consistent finding over four GLMs. The significant findings were restricted to the Total Pairs for both analyses and three industry pairs only for the truncated analysis, suggesting that a larger dataset may have found a more robust result. No robust support was found for Hypotheses Two or Six. Evidence was found to support Hypothesis Three for both type and distribution of discontinuity, and for Hypothesis Four for the distribution of discontinuity only, though the support for Hypothesis Four was less robust and exhibited greater sensitivity to the time period selected. There was some sound support for Hypothesis Five for both discontinuity distribution and type.

By combining the findings with observations of the data reported in table 9, which clearly shows a trend for a higher number of discontinuities following a competence-destroying discontinuity exists in the data, and the values of *p* revealed in the Binomial Distribution testing, we can deduce that there is evidence that: (1) the presence of increasing returns are associated with higher frequency of change; (2) a competence-destroying discontinuity increases the likelihood for further discontinuities for twenty years; (3) while influencing the type of discontinuity experienced for up ten years; and (4) a competence-enhancing discontinuity increases the likelihood of further discontinuities for ten years; (5) while influencing discontinuity type for ten years. The data in table 9 would suggest that the additional discontinuities experienced through the change of distribution following a discontinuity would be primarily competence-enhancing, thus leading to the findings of change of discontinuity type.

It follows that: (1) discontinuities are not independent; (2) that the frequency of change must vary over time as change induces more change; and (3) that increasing returns industries will more prominently exhibit these variations through their greater likelihood of discontinuities inducing a greater likelihood of further change during the period following a discontinuity. These time periods observed were consistent with the eras of ferment observed by Anderson and Tushman (1990).

Thus, a discontinuity in an industry may induce more frequent change through generation of a variation of frequency of change for a period of time. This could result in periods when industries enter and exit periods of heightened change. This pattern of change is in addition to the change triggered by each discontinuity. Industries with increasing returns would be more susceptible to these patterns, through their intrinsically greater likelihood of a discontinuity occurring in any case.

5. Discussion

5.1 Introduction

The research has examined the impact of increasing returns on industry-level change. A literature review of the strategy and economics literature has been followed by a collection of secondary source data, an analysis of that data to examine the relationship and the formulation of conclusions linking the research to the literature.

5.2 Results

The data were ordered into a time series for analysis. A yearly period was used, providing a minimum of eighty-five observations for each industry. The data were tested using Binomial Distribution, Fisher's Exact Test and GLM techniques.

These analyses provided five insights: (1) industries with increasing returns have greater frequency of change than industries with constant returns; (2) a competence-destroying discontinuity increases the likelihood of discontinuities for twenty years; (3) a competence-enhancing discontinuity increases the likelihood of a discontinuity for ten years; (4) additional discontinuities tend to be competence-enhancing for ten years following a discontinuity; (5) the frequency of change varies over time; and (6) the presence of increasing returns in an industry can be associated with a greater variation of frequency of change, otherwise termed turbulence, through greater change inducing greater fluctuation of change.

5.3 Linking into the Literature

The results demonstrate that the frequency of change of an industry is associated with the presence of increasing returns in the output of the industry. This finding is compatible with the literature.

Brown and Eisenhardt (1997, 1998) in their research of the computer industry, an industry with increasing returns derived from information output and complementarity, describe high-velocity change, where high frequency of change results in a rapid series of changes that generate repeated enhancement of industry knowledge. This form of change is consistent with D'Aveni's (1999, 2001) fluctuating equilibrium, where change is a rapid form of equilibrium. The short three-year period of Brown and Eisenhardt's (1997, 1998) research reduced the opportunity to examine the industry during a competence-destroying discontinuity and throughout an era of ferment following such a discontinuity.

However, by chance, Brown and Eisenhardt's (1997) research period of 1993-5 bracketed the period including the 1994 competence-destroying discontinuity of HTML. Their failure to detect competence-destroying change may be associated with their research selection of market incumbents who were resisting the discontinuity and the early stage of the diffusion of the technology in the market. Thus, their finding was influenced by their selection of case studies and their termination of the research in 1995. Hence the apparent anomaly was partially determined by the restrictions of the research design.

D'Aveni (1994) found that some industries thrived through destroying their own competencies and creating new ones. D'Aveni (1999) acknowledges that this form of change is equivalent to disequilibrium, which is a high frequency form of punctuated equilibrium. The research does not find robust support for increasing returns being correlated with the types of discontinuities experienced, and hence, increasing returns are not proven to be more likely to lead to the radical change experienced in disequilibrium.

However, the research finding of increasing returns being correlated with higher frequency of change does address the anomalies posed by D'Aveni (1994) and Brown and Eisenhardt (1997, 1998) by providing an explanation regarding why some industries have experienced high frequency of change, and hence reconciles these authorities with D'Aveni (1999) and Gersick's (1991) punctuated equilibrium paradigm. Therefore, as the frequency of change of the industry is correlated with the increasing returns of the industry's output, the types of change experienced by an industry is also correlated with the presence of increasing returns within the industry output.

Second, as the evidence found that discontinuities were more likely in the twenty year period following a competence-destroying discontinuity and the ten year period following a competence-enhancing discontinuity, and a destabilised deep structure requires time to fit into a new alignment and is more susceptible to further change during this process, it follows that the literature implies causality, where a discontinuity may induce a greater number of discontinuities during the subsequent ten or twenty year period. This finding suggests path dependency in discontinuities and variation of frequency of change. The finding is consistent with Anderson and Tushman's (1990) finding of a longer era of ferment for competence-destroying discontinuities than competence-enhancing discontinuities, as the industry clock would be reset by a competence-destroying discontinuity and thereby is more likely to induce further discontinuities than a competence-enhancing discontinuity, with a consequential longer average period of time before a new platform design can dominate the market.

Third, the findings that a preceding discontinuity can increase the likelihood of a further discontinuity for a period of up to twenty years and that discontinuities are not independent are compatible with the literature. D'Aveni (1999, 2001) suggested that high frequency of change would lead to different forms of change, with fluctuating equilibrium replacing equilibrium and disequilibrium replacing punctuated equilibrium in highly turbulent industries. Turbulence is the change of the frequency of change, and as the frequency of change varies as change induces more change, thus industries with greater frequency of change will be more turbulent.

Fourth, as increasing returns result in higher frequency of change and a discontinuity can increase the likelihood of a further discontinuity, it follows that the evidence suggests that increasing returns are correlated with a greater likelihood of change for a period following a discontinuity. However, it is uncertain whether the scale of the increasing returns has an impact upon the frequency of change experienced by an industry. In any case, the evidence is consistent with path dependency and variation of change.

Fifth, if an industry experiencing discontinuities is more prone to further discontinuities, then the results provide some understanding of why an industry can enter a period of continuing change, while others remain more stable. This is consistent with Schumpeter's concept of waves of creative destruction, and the notion that the frequency of change varies in industries over time in some form of systemic pattern. The presence of a state of continuing change may also partially explain Brown and Eisenhardt's (1997, 1998) findings of high velocity change.

Further, a change in frequency of change over time implies a change in the amount of change between given segments of that time period. Therefore the varying frequency of change due to path dependency is evidence of turbulence in the dataset, where measure of turbulence is the change in the rate of change of a measure, as used by Cameron *et al.* (1987). The findings above support two patterns of turbulence in the data: a short-term turbulence pattern following a competence-destroying discontinuity resetting the industry clock and thereby triggering a short-term cycle of change; and a longer-term turbulence pattern as a result of change inducing further change consistent with waves of creative destruction.

5.4 Considerations for further research

The results have ramifications for not only the study of industry-level change, but also the strategy literature in general.

First, only a single unreliable result shows a significant relationship between increasing returns and the type of discontinuity experienced. More detailed research tracking the scale of returns over sufficient time to include multiple competence-enhancing discontinuities may confirm the relationship between the scale of increasing returns in an industry and the ratios of types of discontinuities experienced in industries with sufficiently high scale of returns. This research could be conducted with a greater number of industries, to provide more data for the GLM and thus enable a more robust result. It is suggested that industries with high information output may prove to be such industries.

Second, the finding that increasing returns are associated with higher levels of industry frequency of change provides a framework for selecting firm-level strategies, such as defined in D'Aveni (1994) and Brown and Eisenhardt (1997, 1998). The trend towards higher information output in many industries will change the returns of those industries. Previously constant returns industry can be expected to exhibit an increasing level of returns while industries with increasing returns may attain a higher scale of returns. Hence, we can expect a change over time in the environment of such industries, with ramifications for both research and practice.

Third, the scale of the increasing returns may be correlated to the effect of increasing returns upon frequency of change. Some industry studies, such as Ohashi (2003), have demonstrated varying scale of increasing returns, and varying effects upon the market. Further research may provide a scale of the correlation between frequency of change and the different sources of increasing returns, namely direct network effects, indirect network effects or complementarity, and information.

Fourth, this research focused on industry-level change, where it has been assumed that all internal effects from an industry are realised during the era of ferment. The fate of any firm is unimportant in the industry-level analysis, as only the frontier that emerges is used to measure the effect of the discontinuity. However, at the firm-level, firm outcomes are critical. Increasing returns sourced from within the firm, such as bandwagon effects, economies of scale in production and learning effects play a significant part in the firm's ability to compete in its marketplace. There is the opportunity for further research to explore the relationship between these internally sourced increasing returns and change.

Fifth, the era of ferment has been inadequately explored to date. The duration of the era of ferment is known to be longer for competence-destroying discontinuities than for competence-enhancing discontinuities. There is the possibility than the duration of the era of ferment may vary with the scale of increasing returns. Such a finding would enable refined models of change.

Sixth, the era of ferment is the period of time before a new platform design dominates its industry. Successive discontinuities represent new platform designs displacing earlier platform designs, thus renewing competition within the industry. Further research can explore the interaction of platform designs with increasing returns and integrate the findings of this research that increasing returns are correlated with more rapid change into the platform design research literature.

Seventh, the effect that change has upon subsequent change has been inadequately considered to date. The assumption of independence in the literature appears to be invalid. There is an opportunity to consider the effects that temporal proximity and type of change have upon the likelihood and nature of change. The finding of path dependency and variation of frequency of change suggests that change may vary as a system, with change inducing more change, moving from Schumpeter's waves of creative destruction to periods of relative calm and back again over time.

Eighth, limitations in the dataset prevented the relationship between increasing returns and turbulence patterns being fully examined in this research. Further research could examine the nature of turbulence and any correlation with the scale of increasing returns. The finding of two patterns of turbulence may require two different forms of research to fully investigate the phenomenon.

Ninth, there is scope to consider the relationship between increasing returns and uncertainty. Uncertainty destabilises deep structure, and thus can induce change more rapidly and more radically than situations with less uncertainty. Further research could consider whether increasing returns, through its association with greater frequency of change, is also associated with greater uncertainty, and the nature of that association.

Tenth, uncertainty may be associated with a greater proportion of competence-destroying change. Uncertainty weakens the links of deep structure, thereby undermining the deep structure and triggering more radical change than would otherwise be experienced.

Eleventh, analysing the output of the industry is important to understand the frequency of change that can be expected over time. A change of output from information usage, such as information embodiment in a physical product to information being separately leveraged as a good in its own right, can change the scale of returns experienced by an industry. This perspective is consistent with Arrow (1996, 1999), but is distinct from both the mainstream economics and strategy literature, which focus on an industry's inputs as the drivers of productivity and superior organisational performance. There is an opportunity for future research examining productivity and strategy to link industry output into mainstream theory.

Twelfth, the observation in information economics that information is a commodity in its own right has ramifications for all of strategic management. The separation of industry output into information and non-information components can provide improved understanding of strategy in any industry and for any firm that uses information to create wealth. The emerging importance and potential dominance of information in the economy provides new opportunities for creating competitive advantage.

Finally, this research is based upon the transformation school of strategy. There is the opportunity to consider these findings from the context of other strategy schools, such as the resource based view of the firm community and the positioning school. It may prove useful to incorporate increasing returns into these fields, as a method to better understand how organisations can create competitive advantage and achieve superior organisational performance.

6 Conclusion

The research has examined nine industries to compare industries with increasing returns output with industries with constant returns output. The increasing returns were derived from network effects and information content in the industry output.

The research found that the presence of increasing returns of an industry's output is associated with a greater frequency of discontinuous change within that industry. A second finding is that the presence of increasing returns is not associated with the type of discontinuity experienced in an industry.

These two results reconcile two anomalies (Brown & Eisenhardt, 1997, 1998; D'Aveni, 1994) to the punctuated equilibrium paradigm by associating increasing returns with higher frequency of change. The forms of change of these anomalies are consistent with D'Aveni's (1999, 2001) framework where high frequency of change was present, with Brown and Eisenhardt (1997, 1998) equating to fluctuating equilibrium and D'Aveni (1994) equating to disequilibrium conditions.

A further finding is that a competency-destroying discontinuity is associated with greater frequency of change for a period of up to eleven years. This is consistent with the finding that increasing returns is associated with greater variability in frequency of change. Together these findings suggest long-term cycles between calm periods of little change and periods of waves of creative destruction triggered by a competency-destroying discontinuity, which should be more prevalent in industries with increasing returns.

This research suggests that researchers and practitioners should analyse the returns from their industries when determining effective research strategies and corporate strategies. The presence of increasing returns in an industry output is an increasingly important factor as industries create a growing proportion of their value in information products, which intrinsically encompass increasing returns as a result of the commodity nature of the information contained in the product, and can therefore expect to experience higher frequency of change.

Further, application of this research can provide practitioners with a new toolset to better understand the types of situations where strategic models and concepts can be best applied. An industry with constant returns is the more traditional model, and would be suitable for the application of the majority of business models, whether from the strategic management discipline or elsewhere. Further, the types of strategies recommended by authors such as Brown and Eisenhardt (1997) and D'Aveni (1994), based upon their research of industries with high rates of change would in all likelihood not be as applicable to a constant returns industry as traditional models, and thus the strategist can avoid applying a model purely as a result of fashion.

However, if the industry of interest exhibits increasing returns, the use of a traditional model will in all likelihood produce inferior results, and the strategist should look to apply models more suitable for a high change environment. Both Brown and Eisenhardt (1997, 1998) and D'Aveni (1994) offer strategies for competing in a high frequency of change environment.

In addition, an understanding of industry change and the importance of increasing returns opens new areas for competition. A strategist, for example, could convert an historically constant returns industry into an increasing returns industry by separating information from a physical product, and then use techniques for competing in high frequency of change industries, such as Brown and Eisenhardt's (1997, 1998) time pacing, to achieve superior organisational performance within that industry. Further, an understanding of the change process can alert the strategist to emerging competence-destroying discontinuities as opportunities to enter new industry areas, and to competence-enhancing discontinuities as a method of consolidating a position within one's own industry.

This research has demonstrated a link between increasing returns and the change experienced in an industry. Strategists should take account of the industry's output when selecting strategies and analysing industry and firm level performance, or risk suboptimal performance or inaccurate findings. Increasing returns influence the change experienced by industry and, by extension, all organisations within an industry, and thus need to be taken into account when understanding any industry or organisation.

Appendices

The Appendices consist of: (1) the nine case studies detailing the researched industries; (2) the datasets; and (3) the results.

The case studies are in the order of:

- Airlines
- Aircraft Manufacturing
- Data Communications
- Telecommunications Manufacturing
- Electricity
- Shipping Lines
- Ship Building
- Software
- Information Storage

The datasets consist of:

Datasets:

- Total discontinuities
- Competence-destroying discontinuities
- Competence-enhancing discontinuities

Dichotomous Datasets:

- Total discontinuities
- Competence-destroying discontinuities
- Competence-enhancing discontinuities

The GLM Data vectors consist of:

- 0-10 and 11-20 year data vectors
- 0-8 and 9-16 year data vectors
- 0-11 and 12-22 year data vectors

The Results have a single section.

The GLM results consist of:

- Hypothesis One
- Hypothesis Two
- Hypotheses Three to Six
- Hypothesis One Sensitivity Tests
- Hypothesis Two Sensitivity Tests
- Hypothesis Three to Six Sensitivity Tests
- Hypothesis Five Sensitivity Tests - Truncated

Case Study: Airline Industry

Introduction

This case study (1) reviews the background within which the airline industry developed, (2) specifies the industry's key performance parameter, (3) lists the discontinuities experienced by the industry are described in chronological order and (4) presents the results in a tabular summary.

Industry Background

The airline industry roots began with the first trials with airmail in Britain and France in 1912. However, the intervention of World War I both delayed the introduction of commercial services and also gave impetus to a substantial improvement in aviation technology. At the end of World War I large numbers of surplus bomber aircraft were available for the fledgling airline industries. In 1919 the first London-Paris air route was established, while in the United States the Post Office introduced air mail services. From these routes evolved modern air services.

The aircraft types in use at any time represent variations upon the available technology. The initial vertical integration between aircraft manufacturers and airlines largely disappeared in 1925, as a result of forced mergers and regulations in the United States following the Kellog Act (Ward, 2003) and the formation of Imperial Airways in Britain – though as late as 1933 Boeing refused to supply aircraft to an airline competing against their subsidiary. Subsequently, each technological change has manifested in multiple aircraft by competing manufacturers selling to a relatively independent customer base.

The market was initially partitioned into short-haul markets being serviced by land planes and trans-oceanic flights being serviced by seaplanes and flying boats. The intervention of World War II provided high quality airfields throughout most of the world, and seaplanes continued to provide service post-war only in the South Pacific – an area with poor support facilities and plentiful seaplane anchorages. In the rest of the world, the differentiation between long-haul and short-haul routes lessened over time, with similar aircraft with different configurations filling the two niches.

Industry's Key Performance Parameter

The industry initially relied on mail contracts for profitability, resulting in an emphasis on smaller aircraft with higher speeds that met the time dependent mail market's requirements. Relatively slow aircraft, such as the Handley Page Heracles of 1930, were at a competitive disadvantage, while fast aircraft such as the Fokker F.7A of 1925 were widely adopted as standard types (afriqonline, 2003). Hence, speed was initially the key performance parameter.

However, aircraft economics also demonstrate that once the mail contract had paid for the aircraft's operating costs, any additional revenues were primarily profit. Hence, planes became progressively larger during the 1920s and 1930s, carrying increasing passenger numbers in addition to mail. Passenger capacity between aircraft of equal speed became an essential basis for competition in 1935, when the Douglas DC-3 was designed to generate up to 50% more revenues for only 10% more cost compared with the earlier DC-2 (Petzinger, 1995, p.11), and by 1938 passengers revenue had grown equal to mail revenue in the United States market (p. 12). By 1973 mail contracts had become so eclipsed in terms of competition that at least one airline refused mail contracts as it could cause delays to passenger services (p. 44).

Mass air travel was firmly established post-World War II, when the majority of airlines re-equipped with inexpensive war surplus Douglas DC-3s (Ward, 2003). The trend for a combination of higher speeds and larger passenger loads continued until the 1969 emergence of the Boeing 747, as demonstrated by the dominance of jet travel over turboprop aircraft during the late 1950s and 1960s. However, the 1970s' failure of the Concorde and competing supersonic aircraft showed that merely competitive speeds around 575-600mph had become sufficient and large passenger numbers had become the single dominant factor – hence the post-1970 dominance of widebody jets such as the Boeing 747. By the 1980s, the most widely accepted yardstick of airline performance was total passenger miles (Petzinger, 1995, p. 124).

Hence, the airlines industry key performance parameter started with an emphasis on speed as a result of airmail demands, but by the 1970s the key performance parameter had changed to emphasise passenger numbers and speed had become a secondary, though necessary, factor for competition. In 1986 the key performance parameter changed to yield management, as a result of computerised reservation systems and the slowing of improvement in aircraft operations economics.

Discontinuities

The standard aircraft type upon niche opening was the two-seat De Havilland DH4a, a war surplus aircraft. This aircraft was a fabric covered biplane with two open cockpits and good speed. The airmail was carried in front of the forward seat. A converted DH4 flew the first scheduled international passenger flight between England and France in 1919 (EAA Aviation Center, 2003).

The conversion of heavy bomber designs to airliners was the first discontinuity. The British Handley Page O/400 entered service in 1919, seating ten passengers in an enclosed fuselage cabin with windows. This aircraft was so dominant that all large airliners were called 'Handley Pages' by the British public during the inter-war period, regardless of manufacturer (Beth, 2000).

The Fokker F.7A provided the next discontinuity with its monoplane design. In 1925 Fokker modified an early single engine F.7A to a tri-motor configuration and convincingly won an air contest in the United States. The Fokker F.7B\3M was put into production and provided the pattern for later popular aircraft such as the Ford Tri-Motor and Junkers 52.

Boeing introduced the ten-seat 247 in 1933, the first all-metal aircraft, the first aircraft equipped with a retractable undercarriage and the first aircraft with a variable pitch propeller. The result was a fast aircraft that rendered existing air fleets obsolete. Douglas followed with the larger fourteen seat DC-2 in 1934, which proved uneconomic (Petzinger, 1995), and then the twenty-one seat DC-3 in 1936. The DC-3 defined the standard passenger transport prior to World War II and in the post-war period.

Turboprop aircraft, such as the Lockheed Constellation and Douglas DC-7, appeared from 1952. They introduced pressurised cabins, allowing flights above the weather, and their sixty-seat capacities were much larger than the Douglas DC-3. However, these types were overshadowed by the Comet jet airliner in 1951. In the event, tragic manufacturing defects led to the Comet's withdrawal and the first continuous jet service was provided from 1954 by the Tupolev Tu-40 and, in western countries, by the Sud Est Caravelle (France), Comet 4 (Britain) and Boeing 707 (USA) (Ward, 2003). Hence, the turboprops were overshadowed by the coming jet age and, their use in large numbers was merely a precursor to effective jet aircraft.

The Boeing 707 that emerged in 1959 was substantially larger and faster than its competitors and became the most common airliner in the early 1960s. The Boeing 707 and its competitors were only eclipsed in 1969 when Boeing introduced the widebody 747. This aircraft had a similar speed to the 707, but carried approximately three times as many passengers. Various sized widebody aircraft rapidly replaced the earlier narrow bodied jets.

In 1972 the turbofan was introduced, but the Lockheed Tristar's unreliability led to turbofans not become universally accepted in aircraft types until the mid-1980s – in response to rising fuel prices and demands for quieter aircraft. However, from that time, turbofan-equipped aircraft rendered earlier aircraft uneconomic to operate.

Computerised reservation systems first appeared in 1957, with real-time administration being launched in 1962 (Petzinger, 1995) – enabled by new solid-state computers with core memories (Campbell-Kelly & Aspray, 1996). The extension of the booking services from 1976 (Petzinger, 1995, p. 70) into the travel agents increased the reservation systems capability, allowing manipulation of marketshare through screen bias, incentivising travel agency commissions, discounting for advanced bookings and rewarding business travellers for patronage. The reservation systems proved valuable to the operator, as they increased marketshare in local markets by up to 83%, but did not prove essential as some airlines without computerised reservation systems still competed successfully against airlines with such systems. Hence these systems did not represent a sufficient change to constitute a discontinuity.

However, by 1985 the reservation system enabled customer 'yield management' (Petzinger, 1995, p. 272) utilising historical data, where an airline varied pricing per seat by individual flight to maximise revenue from the higher-paying business traveller, while ensuring the remaining seats in each aircraft were filled with discount flyers. The combination of yield management and the computerised reservation system proved a discontinuity, as airlines without similar capabilities were forced from the market.

A further discontinuity followed in 1996, when the first reservation systems were connected to the Internet (Ziemba, 1996). Internet booking utilised customer labour and eliminated the Travel Agents' fees of approximately ten per cent of the flight value (Petzinger, 1995) - an amount greater than the majority of airlines return on capital, and hence represents a discontinuity.

Nature of the Discontinuities

The airline discontinuities are all technological in nature. Economic changes, such as the oil crises in the 1970s and political events such as the World Wars and regulation have distorted the market for long periods of time, creating intense periods of readjustment in their aftermath. However, non-technological change has not changed the basis for competition of the industry, the types of aircraft in use or the access to customers for the industry at large.

Table 50: Airline Discontinuities 1919-2003

Date	Discontinuity	Platform Design	Performance	Type
1919	First Airlines	De Havilland DH4a	1 passenger (PAX), 110mph	Niche opening
1919	Enclosed Cabin	Handley Page W.8b	10 PAX, 85 mph	CE
1925	Monoplane; higher speed	Fokker F.7A	8 PAX, 112 mph	CE
1933	Metal structure, retracting wheels, controllable pitch propeller	Boeing 247	10 PAX, 160 mph	CE
1936	Larger aircraft; passenger transport economic	Douglas DC-3	21 PAX, 170 mph	CE
1951	Turbojet engine	De Havilland Comet 1	40 PAX, 465 mph	CE
1959	Bigger Jet aircraft	Boeing 707	100 PAX, 550 mph	CE
1969	Widebody Jet	Boeing 747	385 PAX, 583 mph	CE
1973	Turbofan engine	Lockheed Tristar	250 PAX, 589 mph	CE
1985	Computerised Yield Management	Sabre		CE
1996	Online Booking	Internet		CE

Conclusion

The airline industry has experienced twelve competence-enhancing discontinuities since niche opening over its 85-year history, or one change every 7.1 years on average. Nine of these discontinuities were created by aircraft technological change during a 55-year period, while the remaining two changes are computer induced changes over the last twenty-year period. Hence, the airline industry history can be split into two periods; the first with a rate of change every six years and the second with a rate of change every 10 years.

The continuing global reduction in numbers of major airlines is consistent with Tushman and Anderson's (1986) findings that numbers of competitors decline with each competence-enhancing change.

However, the airline industry has become influenced by information technology and communications, and hence the industry is no longer independent of the computer or telecommunications industries.

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Case Study: Aircraft Manufacturing Industry

Introduction

The aircraft manufacturing industry emerged as a significant industry during World War I. The industry had access to current manufacturing techniques, and adopted those concepts that could be applied to the manufacture of relatively large and sophisticated products. The airline industry origins are entwined with aircraft manufacturers, as the manufacturers attempted to create a civilian market for their products in the post-World War I environment.

This case study first outlines the background to the industry. Second, the industry's key performance parameter is defined as labour productivity. Third, the discontinuities in the industry are described in chronological order. Fourth the competence-enhancing or destroying nature of the discontinuities is determined. Finally, a conclusion is drawn regarding the nature of change in the industry.

Industry Background

The history of the civilian aircraft manufacturing industry is closely related to the airline industry, with both industries servicing the same end customers. During periods when customer demand was depressed, the airlines cancel orders, defer investment and sell surplus aircraft, resulting in difficult trading conditions for aircraft manufacturers.

Second, the ongoing development of aircraft technology has continuously led to increasing customer productivity from new aircraft types, stimulating demand. These aircraft types have introduced new materials, from wood to aluminium to carbonfibre, but these changes have not changed the basic knowledge required: the design of new, sophisticated products and the management of labour to construct the products.

However, despite the changes in aircraft technology, the manufacturing industry techniques have changed little. The main Boeing 747 factory still used the same manual production techniques in 2003 as used when the first 747 was built in 1969 (Discovery, 2003), and is similar to earlier wartime factories. Indeed, the moving production line and widespread use of robotics has not yet significantly penetrated the aircraft manufacturing industry, possibly due to the limited manufacturing quantity and complexity of the products.

Industry's Key Performance Parameter

The management of labour is the key performance parameter. Semi-skilled labour has been used throughout the industry's history as the basic method of production.

Discontinuities

The aircraft manufacturing industry started with access to manufacturing techniques from the automobile and other manufacturing industries. Machine tools and jigs were used from the beginning to mass produce first military aircraft and later civilian airliners. The concepts of industrial management and welfare capitalism were already in vogue when the fledgling industry was started.

The first discontinuity was the development of quality assurance in the telecommunications manufacturing industry in 1924 (Adams & Butler, 1999). The aircraft industry only fully adopted quality approaches post-World War II, when the

Comet I disasters led regulators to require high levels of product testing in aircraft manufacturing (EAA Aviation Center, 2003).

The second discontinuity was the introduction of the all metal aircraft, the Boeing 247, in 1933. This change had the effect of devaluing existing skills in cloth and wood construction, and created the modern aircraft factory. Many small manufacturers were forced out of the industry at this time, while other organisations with metal working skills entered (Serling, 1991; Blohm und Voss, 2004).

Advanced production control techniques were introduced from 1940 to streamline military aircraft production. These techniques were later applied to civilian aircraft manufacture, as well as other industries (Chida & Davies, 1990, p. 112).

The final technological discontinuity was the introduction of software design tools to fully design and test new aircraft types, eventually eliminating the need to build expensive mockup models with the Boeing 777 development (Boeing, 2003). These computer aided design tools were later adopted by many other industries.

Nature of the Discontinuities

The discontinuities described above all become industry norms over time.

Table 51: Aircraft Manufacturing Industry Discontinuities 1919-2003.

Date	Discontinuity	Effect on Basis for Competition	Type
1919	Niche opening		
1924	Quality Assurance	More reliable products	CE
1933	Aluminium aircraft	Stronger and lighter material	CD
1940	Production Control	Improved productivity	CE
1990	Computer design and simulation	Efficient, rapid and superior product design	CE

With one exception, the discontinuities reflect changes in the design of management practices rather than changes in manufacturing technology. The significance of these discontinuities stems from the industry's key performance parameter being management of labour. The emphasis on design reflects an industry with sophisticated products where labour input and quality are designed into the product and then enabled in practice in the industrial plant.

Conclusion

The aircraft manufacturing industry has experienced four discontinuities over an eighty-five period, giving a frequency of one discontinuity every 21.3 years. Seventy-five per cent of these discontinuities were competence-enhancing in nature.

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Case Study: Data Communications Industry

Introduction

The history of data communications can be said to have started in the depths of time, with signal beacons and smoke signals in occasional use in many areas. The continuous use of data communications services began with Chappe's building the first optical telegraph line from Paris to Lille in 1794. From that time there has been uninterrupted use of data communications services, with technology changing from the optical to the electric telegraph, to facsimile and finally to electronic messaging.

This case study first reviews the background within which the data communications industry has evolved. Second, the industry's key performance parameter is specified, noting the difference between transmission of individual messages and the network capacity. Third, the discontinuities experienced by the industry are described in chronological order, separating the network capacity and speed of transmission equipment. Fourth, the results are presented in a tabular form as a summary.

Industry Background

The data communications industry has passed through four eras, during which different communications technologies dominated communications. These four eras are: optical telegraph, electric telegraph, facsimile and electronic message.

However, each era took several years to become fully established. Optical telegraphy was introduced in 1794, but only became permanently entrenched after the end of the Peace of Amiens in 1804. Electric Telegraphy was invented in 1837, but the first permanent service was Morse's Washington D.C. to Baltimore route in 1844 (Oslin, 1992, p. 31). Facsimile printing (fax) was invented in 1934 (Oslin, 1992, p. 322) and was initially available through the Telefax service in 1935, but it was only with the

1948 introduction of a small and low-cost fax enabling direct communications that fax began to significantly replace the electric telegraph (Oslin, 1992, p. 323) – a process accelerated by the 1968 Group 1 facsimile standard, that operated independently from the telegraph network, and completed by the 1980 Group 3 facsimile standard with its high speed communications. Electronic messaging between different computers was invented in 1971 but the first commercially available Internet service was only introduced in 1990 and electronic messaging has not yet fully replaced facsimile.

Hence, while accepting that there is a significant transition period at the beginning of each era as the old technology is gradually replaced by the new technology, the eras when each technology dominated data communications transmission can be defined as:

1791-1843	Optical Telegraph
1844-1967	Electric Telegraph
1968-1989	Facsimile
1990-2000	Electronic Messaging

Industry's Key Performance Parameter

The data communications network industry's key performance parameter is the speed of communications. Substantially faster new technologies rapidly replaced preceding technologies, while alternative technologies with marginal advantage in speed but some other disadvantage could co-exist with the earlier technologies, but did not displace those technologies. An example is the 1848 House printing machine that complemented but did not replace the Morse telegraphy key perfected in 1838.

The communications rate is determined by two factors: the transmission equipment and the capability of the communications circuit. The resulting transmission capability is a multiplier of these factors: the speed that the transmitter can send data and the number of circuits that can be simultaneously handled by the network. Advances in both transmission equipment rates and number of circuits impact on the transmission speed of the network.

Discontinuities

Network

The data communications industry began its uninterrupted service with Chappe's 1791 testing and 1794 deployment of the semaphore, the French optical telegraph system. The optical telegraph was predominately used by governments during wars, but was also used for peacetime communications and for in commercial applications, particularly shipping. France had the largest optical telegraph network, comprising in 1852 556 telegraph stations covering 4800km, linking the 29 largest French cities and employing over 1,000 people. The French network was replaced by an electric telegraph network in 1855. The last optical telegraph networks were decommissioned in Prussia in 1849, in the USA in 1850, in Britain in 1860, in Australia in 1880, in the Dutch possession of Curacao in 1917 (Holzman & Pehrson, 1994) and in Sweden in 1881 (Tahvannainen, 1997, 1995).

The optical telegraph relied upon operators observing signals by telescope and then conveying the same message. The electric telegraph, however, had physically connected telegraph stations - iron wires carried electrical current, over which telegraph technologies sent messages. Initially the electric telegraph, like the optical telegraph, could handle only one message at a time. The first electric telegraph was laid in England in 1839, but Morse's 1844 line in the USA was the first permanent line.

In 1871 Kelvin invented duplex that doubled the capacity of equipped circuits. This discontinuity had the effect of a 100% improvement in network capability, i.e. the amount of words that could be transmitted in a given time period. In 1873 Edison invented quadruplex that allowed four channels down a single cable, providing a 100% improvement over duplex (Oslin, 1992).

In 1878 Baudot developed synchronous communications, with a capacity of five channels down one cable – a 25% improvement over quadruplex. By 1881 six channels were available, a further 20% improvement (Oslin, 1992).

In 1915 Western Union introduced an eight-channel time division multiplex installation – a 33% improvement over six channel synchronous communications. This was followed by eight-channel frequency multiplexing in 1933 (Oslin, 1992).

A Wideband AM frequency multiplexing system was introduced in 1936 with 22 channel capacity, a 175% improvement over eight-channel multiplexing. The following year, 1937, coaxial cable was introduced capable of carrying forty circuits – a further 82% improvement. The Armstrong FM system followed in 1940 with 288 circuits – a 620% improvement over coaxial cable (Oslin, 1992).

The first commercial microwave circuit was installed in 1945, capable of operating 2000 circuits – a 594% improvement. Cable amplifiers then increased cable capacity to 6000 circuits in 1950 – a 200% improvement over microwave (Oslin, 1992).

The next major step was the introduction of fibre optic technology. The first circuits using graded fibre optics and gallium arsenide lasers were installed in 1977 (Hecht, 1999, p. 182) – with a 140MBps capability allowing 872% more telegraph type traffic than the fastest earlier technology. Single-mode 400Mbps fibres were introduced in 1982 (Hecht, 1999), with a further 186% increase in capacity. 1.7Gbps circuits appeared in 1987 (Hecht, 1999), with a 325% increase in capacity over the first single mode fibre circuits. Bell Labs then increased the capacity further in 1990 by another 47% to 2.5Gbps (Force, 2003). Dense wavelength-division multiplexing (DWDM) was developed in 1998 with a 10GB/s capacity per channel - a further 300% improvement in capacity (Force, 2003).

Over a period of 213 years network capacity has increased over 17 million-fold. This capacity has been complemented by the increase in the ability of transmission equipment to use the network capacity available.

Transmission Equipment

The invention of the electric telegraph by Wheatstone and Cooke in Britain in 1837 (Oslin, 1992, p. 10) and Vail in the USA in 1838 (p. 22) represented a dramatic improvement in speed and reduction in cost over the optical telegraph. The first British telegraph route was used in 1839 for train signalling, but soon failed. In 1844 Morse created the first commercially successful service with his Baltimore-Washington D.C. route. Initially used for news reporting and train signalling, the electric telegraph spread rapidly throughout the United States - New York was connected in 1845 (Oslin, 1992, p. 35), Boston and Albany in 1846 (p. 40) Cincinnati in 1847 (p. 49) and New Orleans by 1848 (p. 48). The first transcontinental telegraph line was completed in 1861. Morse operators using the Morse key and sounder could send 25 words per minute (p. 299).

The House printing machine was developed in 1848 (p. 71), raising the speed that telegraphs could be printed to 43.3 words per minute. In 1855 Hughes invented a transmitter keyboard and this was combined with the House printer into a single machine in 1859 (p. 297). However, the House printing machine represented only 73% performance improvement over the Morse key and the Hughes/House systems failed to displace it from the market – both technologies remaining in use concurrently.

The invention of the typewriter and its introduction into telegraph offices in 1873 spurred the creation of the Philips code, allowing an operator using a Morse key to handle around 48 words per minute (p. 202). This marginal increase of 11% over the House/Hughes system ensured the continuing use of the Morse key technology.

In 1883 Wheatstone developed a perforator/transmitter/recorder that could send 80-150 per minute in each direction over a duplex circuit (p. 298). This increased transmission rate of 80 words per minute represented a 234% improvement over the Phillips code and marks the beginning of the replacement of manual transmission with automated equipment. In 1903 the Buckingham-Barclay printer was introduced, an improvement upon the Wheatstone model, raising the minimum speed further to 100 words per minute in both directions (p. 299) – a 25% boost to the basic transmission speed. A strike in 1907 stimulated the largest telegraph company, Western Union, to convert from manual to automated operations on its major circuits – 24,888 miles (p. 299) out of the 1910 total of 213,360 miles (p. 262).

In 1925 Morkum-Kleinschmidt (later Teletype) perfected their low-volume printer, suitable for use in company offices connected to the telegraph network by leased lines (p. 304). This printer technology had a single directional speed of around 490 words per minute, or 50 characters per second, representing a 145% improvement over the Buckingham-Barclay printer transmission capability. Teletype machines quickly replaced the older equipment and became the standard equipment for small office use. The Teletype printer represented the peak of the telegraph industry, replacing manual transmission in small offices - with manual operators falling from 63.1% to 15.5% of total lines during the 1925-1931 period (p. 305). The Teletype printer technology was still common in offices in the 1980s.

1935 saw the introduction of facsimile technology, with Western Union's Telefax service (p. 323). Facsimile allowed the sending of original documents, pictures and handwriting, and hence represented a major technological change from the incumbent text only telegraph technology. Telefax operated over telegraph circuits and was only available at large telegraph offices. Telefax was followed by small and low-cost facsimile machines in 1948 and high speed facsimile in 1951, capable of 7.5 characters per second. Facsimile machines became rapidly popular, rivalling Teletype machines within a few years (p. 323). However, the relatively low transmission speeds of facsimile ensured that text only telegraph systems continued in regular usage.

In 1968 a new Group 1 facsimile standard was introduced with 13.4 characters per second capability, followed in 1976 by Group 2 with 53.8 characters per second and Group 3 in 1980 with 322.5 characters per second capability (BT Archives and Historical Information Centre, 2000). Group 3 facsimile represented a 500% improvement in transmission speed over the Teletype telegraph system and facsimile rapidly replaced telegraph during the 1980s. By 1990 the telegraph was rapidly becoming extinct, replaced by facsimile (Oslin, 1992, p. 419).

Meanwhile, computer to computer communication had been invented in 1969 (Gates, 1998; Davila, 2000) and electronic messaging in 1971 (Campbell, 1998). The introduction of microcomputers in 1975 started the diffusion of computers onto desks, but computer to computer messaging was delayed by the lack of a messaging exchange. The first public electronic message exchange appeared in 1990 (Zakon, 2003) with the first commercial Internet Service Provider, and electronic messaging rapidly diffused from that time. Computer access speed over the telephone system had been available from 1984 using 9.6kbps modems (Dunn, 2000), capable of sending 1200 characters per second – a 272% increase of Group 3 facsimile. Modem speed increased a further 50% with the introduction of 14.4kbps modems in 1991 (Dunn, 2000). The 28.8kbps modem followed in 1994 (Dunn, 2000), representing a further 100% improvement in speed with 3600 characters per second. ISDN for Internet access became available around 1995, with a capability of 8000 characters per second. ADSL Internet access became available in 1998 (Wired News, 1998), with the G.Lite standard supporting 512kbps transmission speeds – or 64,000 characters per second. Finally, in 2003 the ADSL 2 standard is approaching ratification with transmission speeds of 1Mbps (DSL Forum, 2003), or 128,000 characters per second, expected. The rapid pace of improvement in computer communications resulted in facsimile declining in importance, but as of 2003, facsimile still exists as a complement to computer messaging.

The 213 year history of data communications has seen message transmission capacity grow by over 500,000 times – from to 0.23 to 128,000 letters per second

Nature of the Discontinuities

The changes were all technological in nature and introduced improved methods for providing the industry's economic value to its customers - communications across distance.

Those changes that did not achieve at least 100% improvement over earlier technology generally failed to oust that technology from use. For example, synchronous communications failed to oust quadruplex, despite a higher capacity. A second example demonstrates the impact of pricing; the Morse key was perfected in 1838, but despite a series of improving printing technologies, it was only the Teletype printer of 1925 that reduced Morse keys' penetration below 50% of lines – after which, the usage of Morse keys fell rapidly to around 15% six years later. Morse keys survived in the meantime on large numbers of lines, despite equipment such as the Buckingham-Barclay printer having over twice the transmission speeds. Hence, the Buckingham-Barclay printers had only conditional dominance (Jovanovic, 1995) over the Morse Key and were priced above the point at which they could achieve dominance. The teletype printer, however, rapidly diffused and replaced the Morse key, and thus was presumably priced below the price point at which it could dominate the Morse key.

Hence, the industry's key performance parameter can be considered to be constrained by the costs of technology – with expensive technology only dominating large offices with high utilisation of equipment. The following table lists only those discontinuities that achieved 100% or greater improvement on the preceding technology, and hence achieved at least conditional dominance in the industry. Furthermore, the discontinuity is judged to be competence-enhancing (CE) or competence-destroying (CD) based on whether the discontinuity strengthened or weakened, respectively, the incumbent network operators' control of the industry.

Table 52: Data Communications Network Discontinuities 1791-2003.

Date	Discontinuity	Improvement over preceding technology	Type
1791	Optical Telegraph	N/A	Niche opening
1837	Wheatstone and Cooke five-needle telegraph	+118%	CD
1838	Morse Telegraph	+409%	CE
1871	Duplex	+100%	CE
1873	Quadruplex	+100%	CE
1883	Wheatstone printer/transmitter	+145%	CE
1925	Teletype printer/transmitter	+175%	CE
1936	Wideband AM	+175%	CE
1940	Armstrong FM	+620%	CE
1945	Microwave	+594%	CE
1950	Cable Amplifier	+200%	CE
1977	Graded fibre optics, gallium arsenide lasers, 140Mbps	+872%	CE
1980	Group 3 facsimile	+500%	CD
1982	400Mbps single mode	+186%	CE
1987	1.7Gbps single mode	+325%	CE
1990	Computer messaging plus Internet ISP Access	+272%	CD
1994	28.8kbps modem	+100%	CE
1995	ISDN Internet access	+872%	CE
1998	10GBps DWDM	+300%	CE
1998	ADSL G.Lite	+700%	CE
2003	ADSL 2	+100%	CE

The data communications industry has experienced 20 discontinuities since the niche opened with the development of the optical telegraph in 1791. During this time transmission equipment has experienced three competence-destroying discontinuities in addition to the niche opening. The first replaced the optical telegraph with the electrical telegraph – leading to the telegraph operator industry. In the second discontinuity facsimile operating over the telephone network replaced the telegraph, with end-users usually communicating directly with one another. The third discontinuity was the introduction of commercial access to the Internet messaging service, and the emergence of the Internet Service Provider as the main supplier of data communications services.

However, with the exception of the replacement of the optical telegraph by the electric telegraph, the competence-destroying discontinuities have not coupled network and transmission equipment changes at the same time, and the incumbents have managed to leverage their vertically integrated position in the network business to retain their position in the industry as network service suppliers, albeit with their message handling business completely redefined by each competence-destroying discontinuity.

Conclusion

The data communications industry has experienced a total 20 discontinuous changes over the 213-year since niche opening, of which three, or 15%, were competence-destroying and 85% were competence-enhancing. The rate of change averaged approximately one change every 10.7 years

If one splits the industry history by the four eras identified above, i.e. optical telegraph, electric telegraph, facsimile and electronic messaging, then the frequency of change and nature of the total discontinuities (including the niche opening or competency destroying discontinuity that starts each era) can be represented as per the following table:

Table 53: Frequency of change of data communications transmission equipment 1791-2003

Era Start Date	Telecommunications Industry Era	Discontinuity Quantity	Frequency of change	% Competence-enhancing
1791	Optical Telegraph	1	0.02 p.a.	0%
1844	Electric Telegraph	10	0.083 p.a.	90%
1968	Facsimile	4	0.125 p.a.	75%
1990	Electronic Messaging	6	0.429 p.a.	83%

The table shows that despite a similar proportion of competence-enhancing versus competence-destroying change during the four periods, while the industry is becoming increasingly turbulent over time.

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Case Study: Telecommunications Manufacturing Industry

Introduction

The telecommunications manufacturing industry emerged to supply products to the growing communication network operators and, later, to end-consumers to access those networks. The two industries are linked as they share a common end-user of their products and services.

This case study first outlines the background to the industry, demonstrating the unusual situation where one company, Western Union, dominated the industry through its near monopoly of the largest market for approximately one century. Second, the industry's key performance parameter is defined as labour productivity until the late 1960s, when it switched to management of materials. Third, the discontinuities in the industry are described in chronological order. Fourth the competence-enhancing or destroying nature of the discontinuities is determined. Finally, a conclusion is drawn regarding the nature of change in the industry.

Industry Background

The history of the manufacturing industry supplying data communications is closely related to the data communications history itself. The privately-owned telecommunications industry expanded more rapidly than the publicly owned European operators. By 1887 the dominant American network, Western Union, carried 47 million messages compared to 40 million messages handled in Britain by the Post Office (Oslin, 1992, p. 242) – a denser and wealthier market that should have diffused more rapidly.

First the electric telegraph and later the telephone network operators created the demand for large volumes of electrical equipment, while encouraging innovations that reduced costs or improved quality.

The American manufacturers developed leading manufacturing capabilities and, despite a lack of protection from imported equipment, they maintained dominance in the most advanced telecommunications market for over a century. US manufactured equipment dominated the US market from the time that the equipment for Morse's first network between New York and Washington was manufactured in small New York jobbing shops (Oslin, 1992) in 1845 until Japanese equipment began to be imported in volume in 1969 (Adams & Butler, 1999).

The 1909 takeover of the largest data communications network operator, Western Union, by the dominant voice communications operator, AT&T, created a single dominant network operator for both data and voice communications in the USA (Oslin, 1992, p. 262-5). However, in the first effective intervention by government in the US industry, AT&T was forced to spin-off Western Union in 1913. Despite the spin-off though, AT&T had used the four-year period of control of Western Union to build a dominant position in both voice and data communications that it did not relinquish until the 1984 divestiture of the Bell Regional Operating Companies.

Hence, Western Electric, through its sole supplier arrangement with AT&T, had also achieved a dominant position in the American communications manufacturing industry by 1913. This dominance continued until the Bell system began importing substantial volumes of quality- and cost-competitive Japanese equipment in 1969 to supplement production (Adams & Butler, 1999, 196). By 1978 substantial competition had re-emerged with Northern Telecom providing large switches to Bell operating companies (p. 199). The end of the Bell system in 1984 removed trade restrictions and fostered competition between former parts of AT&T and new entrants, resulting in both Western Electric losing its dominance in the United States market, as foreign competitors won substantial marketshare, and the emergence of an international market for telecommunications equipment.

Industry's Key Performance Parameter

The management of labour was the key performance parameter from the industry's creation until electronics began to diffuse throughout the industry's product lines in the mid-1960s. From that point, skilled labour replaced semi-skilled labour as the dominant labour type and the basis of competition changed to the management of materials (Adams & Butler, 1999, p. 187).

Hence, unlike the communications industry it supplied, many of the discontinuities that affected the communications manufacturing industry were related to the management of people. The technological discontinuities were less common.

Discontinuities

The most advanced techniques available to the embryonic manufacturing industry were derived from the techniques first used for shipbuilding in the Venetian Arsenal from 1418 (Wikipedia, 2003; Hoppenfeld, 2003), with products built using standardised parts on an assembly line. Le Blanc attempted to introduce these techniques into France in the mid-1700s (Wikipedia, 2003), but failed to gain acceptance due to opposition from artisans. Hence, when Chappe built the first optical telegraph line in 1794, the prevailing manufacturing system available was based on traditional techniques where skilled labour produced custom equipment to a standard design. In the event, Chappe sought the expertise of a watchmaker to construct the first optic telegraph line (Holzmann & Pehrson, 1994).

The so-called American System was developed by Whitney in 1799 (Wikipedia, 2003) to overcome a skilled labour shortage. He developed a range of new machine tools and jigs to allow semi-skilled labour to create interchangeable parts, and separated manufacture from assembly to free skilled labour from the assembly process to focus on manufacture. The American System was first used for musket manufacture, setting the standards for American armament manufacture. Hence, this manufacturing standard was well established prior to the electric telegraph industry starting in the USA in 1843 (Oslin, 1992, p. 29). Furthermore, the inventor of the Morse telegraph key and code, Vail, built the first Morse instruments at his family ironworks, which had armaments and railway locomotive manufacturing experience (p. 19), while another family member from the same ironworks was the Bell company's leader who led the company from infancy in 1879 to provide universal telephone service across the United States. Hence, the fledgling communications industry was embedded in knowledge of current manufacturing techniques and had access to the American System manufacturing expertise. Furthermore, after the end of the American Civil War 1861-5, several under-employed arms suppliers entered the electrical manufacturing industry as subcontractors, including Remington in 1873 (Adams & Butler, 1999, p. 34; Oslin, 1992, p. 202).

The rotative steam engine was invented in 1781 and first applied to powering factory machinery directly in a corn mill in England in 1786 (Lord, 1923). However, it was not until after 1800 that steam engines had any significant use in industry and became dominant motive power.

In 1867 the standard manufacturing facility was the jobbing and model shop, where semi-skilled workers built standard models of telegraph, and later, telephone equipment (Adams & Butler, 1999, p. 21). The exchange equipment used in larger offices was usually manufactured to individual office requirements. From 1887 products were increasingly standardised to eliminate diseconomies of scale for larger exchange systems (p. 59).

The 1881 introduction of the first electric power plant (Hannah, 1979) and the related invention of viable electric motors changed the primary method of supplying power to machines in factories. Factories were redesigned to power machines directly rather than via belts from a central power source, and central power utilities proved more economic than individual factories generating their own power (Dunn, 2003). By

1899 electric motors represented five per cent of all horse power in American factories, rising to fifty per cent by 1919 (Gordon, 2000).

Scientific Management was introduced in 1897 by Western Electric, the largest and most influential manufacturer in the United States. The contract system for complete product manufacture at multiple small shops was eliminated (Adams & Butler, 1999, p. 76-77) and functions were moved to specialised plants (p. 79). Improved economies of scale were achieved by locating plants in new industrial complexes. University educated engineers were recruited to design new products, raising the standards of the industry (p. 100).

The increasingly specialised nature of labour, as a result of scientific management, had a secondary effect of decreasing the transferability of staff between tasks. Welfare Capitalism was introduced in 1913 to both reduce the costs of staff turnover (p. 96) and to stem unionisation (p. 97) of labour. A major consequence was the introduction of the promotion-from-within policy (p. 99), providing a career path for an employee and increased job security with seniority (p. 132).

Also in 1913, the moving production line was introduced in the motor vehicle industry (Wikipedia, 2003). The moving assembly line was applied late in Western Electric, and then only to mass production items such as telephones. Customised products, such as exchanges, continued to be produced by the American system (Adams & Butler, 1999, p. 77).

The third 1913 change was technological in nature. The Vacuum tube was developed and used to reengineer telecommunications products (p. 5). The result was a series of new innovations with higher performance and lower costs. The vacuum tube devalued knowledge in electrical manufacturing by introducing different knowledge requirements. Hence, the vacuum tube represents a competence-destroying discontinuity to the data communications manufacturing industry.

Western Electric developed quality assurance in 1924, when it recognised that processes had a significant impact on product quality. Statistical control techniques and the total quality movement stem from this discontinuity. However, the American industry was slow to adopt this innovation and the Japanese industry eventually capitalised on quality to compete against American industry from 1968.

The 1947 invention of the transistor led to a further reengineering of products. However, unlike vacuum tubes, applying the transistor changed manufacturing processes (p. 161) and shifted the key performance parameter in the industry from management of labour to management of materials (p. 187). The change to solid state manufacturing required cleanrooms and single storey buildings for more efficient workflow.

The workers assembling electronic devices originally used microscopes for hand assembly in specialised shops within the manufacturing plants. However, increasing miniaturisation led to smaller devices and required automation. The result was the replacement of large general-purpose plants with smaller specialised plants, and the replacement of a large labour force with a smaller, more highly educated workforce (p. 189) and from 1970 increasing levels of automated manufacturing, utilising industrial robots first applied in the car industry in 1962. The increasingly specialised skills, however, devalued welfare capitalism as merit replaced loyalty as the primary measure of employability (p. 193).

The final technological discontinuity was the incorporation of software into products, beginning with switches in 1978 (p. 199). Software allows equipment to be upgraded over time through software upgrades, transforming electronic equipment into more flexible computing systems tailored to installation-specific requirements (Toffler, 1985). Hence, software allows more effective competition on the new key performance parameter; i.e. management of materials. This transformation is still diffusing through the industry today, with many systems remaining hardwired.

Twelve discontinuities occurred over the period of 1791-2000. The nature of these discontinuities can be determined by their effects on the industry, with competence-enhancing discontinuities industries consolidating industry incumbents and competence-destroying discontinuities increasing the number of industry competitors.

Nature of the Discontinuities

The discontinuities described above all become industry norms within usually one decade of introduction. Hence, while the paucity of accurate data cannot substantiate the actual effect on the industry's key performance parameter, it can be determined that these changes were significant enough to become common practice and drive the earlier practice out of the industry. By definition, the nine competence-enhancing discontinuities reflect order of magnitude improvements over the preceding situation, while the competence-destroying discontinuities represent devaluation of existing knowledge and skills (Tushman & Anderson, 1986)

Table 54: Data Communications Industry Discontinuities 1791-2003.

Date	Discontinuity	Effect on Basis for Competition	Type
1791	First telegraph built	Niche Opening	
1799	American System	New manufacturing methods	CE
1800	Rotative Steam Engine	New form of motive power	CE
1881	Electric Power	Replaced steam	CE
1887	Product Standardisation	Eliminated diseconomies of scale	CE
1897	Scientific Management	Dominant during 20th century	CE
1913	Welfare Capitalism	20% improvement in profitability	CE
1913	Moving Production Line	Dominant for standardised products	CE
1913	Vacuum Tube	Enabled new products, required new knowledge	CD
1924	Quality Assurance	Dominant by 1970s	CE
1947	Transistor	Immediate dominance	CD
1962	Automation	Dominant	CE
1978	Software	New basis for product design	CD

Half of the discontinuities reflect changes in management practices rather than changes in technology. The significance of these discontinuities stems from the industry's key performance parameter being management of labour. However, since the development of the transistor, the discontinuities have been mainly technological in nature. The latest discontinuity, software, is represented by an increasing number of functions once provided by dedicated equipment being performed by software on general purpose platforms, though the continuing hard-wired nature of telephone exchange mainframes suggests that the diffusion is not yet compete.

Hence, the change of the key performance parameter appears to have changed the industry dynamics of change. This change appears to have coincided with a change in the information content of the products, from merely design to incorporating some microcode as the transistor and then software diffused into the industry.

Conclusion

The communications manufacturing industry has experienced twelve discontinuities over a two hundred and seven year period, giving a frequency of one discontinuity every 17.5 years. Eighty-three per cent of these discontinuities were competence-enhancing in nature.

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Case Study: Electricity Generation

Introduction

This case study first reviews the background within which the electricity generation industry has evolved. Second, the industry's key performance parameter is specified as fuel efficiency. Third, the discontinuities experienced by the industry are described in chronological order. Fourth, the results are presented in a tabular form as a summary. Finally a conclusion is drawn.

Industry Background

The electricity industry frontier from 1882 to 1988 was dominated by fossil fuel powered steam generating technology. Hydro and geothermal capacity provided a useful alternative only in those areas where geography allowed its deployment, while nuclear, solar and wind generation have yet to achieve the economic frontier level and are hence more expensive than fossil fuel powered steam generation. Only after 1989 did cogeneration become economic, and even at the end of the researched period, steam continued to play an important role.

The steam generator power frontier is based upon the British industry primarily due to a lack of accurate American data. The British industry initially lagged behind the US industry in terms of thermal efficiency during the post-World War I era, but the two industries were on a par by 1938 (Hannah, 1979, p. 137). The Second World War disrupted British development and by the immediate post-war era a lag between Britain and the USA had grown to "eleven years between the trial of a new technology in America and its first adoption in Britain" (Hannah, 1982, p. 107). Further, the French industry surpassed the British industry in average thermal efficiency from 1955 and caught up with average US efficiency levels (Hannah, 1982) and remained ahead of Britain throughout the 1960s and 1970s (p. 283). Yet, British frontier designs were typically equal or ahead of American designs at time of order, but the average 2-year longer British construction time led to Britain falling 1-2 years behind the US frontier in the mid-1950s (p. 119).

Thus, the analysis provides a reasonable measure of the frequency of change and discontinuity types during the industry's lifespan, despite some timing issues over specific discontinuities.

Industry's Key Performance Parameter

The economic cost for producing electricity is the basis for electrical utility competition. This cost has been influenced by more efficient utilisation of generation capacity coupled with improved efficiency in converting resources from their original form into electricity. Approximately eighty per cent of the economic cost of electricity is related to the cost of fuel (Hannah, 1979).

Discontinuities

The electricity generation niche opened with the first dynamo in Belgium in 1870. This generator was used to provide power for an electro-plating plant (Neberker, 2003).

The first discontinuity was the establishment of a central power station to supply multiple customers with electricity. The first such power station was established in 1881 at Godalming in Surrey, Britain and was powered by a waterwheel (Hannah, 1979, p. 7).

The first steam-driven power plant was opened in London at Holborn Viaduct in January 1882 (Hannah, 1979), supplying 60 Watts of direct current (DC) electricity (Dunn, 2003). The first US plant that followed in New York in October 1882 also produced DC current (Dunn 2003) and had a thermal efficiency of 2.5 per cent (Smithsonian Institute, 2002).

The first transmission lines were possibly built in Germany between Miesbach and Munich in 1882 (Dunn, 2003), linking suppliers with remote customers. By 1891 a 100 mile line existed in Frankfurt, Germany, while the 150 mile Shoshone line connecting the Colorado River and Denver followed in 1909 (Neberker, 2003).

The transformer was invented in 1883, allowing electricity voltage to be stepped up and down (Dunn, 2003) and allowing more efficient electricity distribution.

In 1886 Westinghouse built the first alternating current (AC) power plant. AC suffers lower power loss as electricity is carried to remote users, and thus provides a more efficient power technology. The first US major hydro power station, built at Niagara Falls during 1893-1895, was an AC plant and represented a major step towards AC technology's dominance over DC (IEEE History Center, 2003).

By 1890 the optimal power station had eight reciprocating steam engines powering generators of 0.1MW capacity each and supporting up to 26000 lamps in the nearby vicinity (Hannah, 1979, p.10). Early electricity generation was expensive compared with alternative lighting, costing 7d per kWh in the mid-1890s (p. 9) and the typical power plant consumed ten pounds of coal per kWh produced (p. 13).

Parsons invented the steam turbine in 1884 (Parsons, 1911) and the first steam turbine generator was installed in Newcastle in 1888 (Hannah, 1979). An improved condensing turbine was installed at Cambridge in 1892, and turbines had become the dominant technology by 1912. The first large all-turbine power station was opened in 1903 at Carville, with two 1.5MW and two 3.5MW steam turbines – the latter twice the size of any prior turbine (p. 30). Turbine power stations typically consumed five pounds of coal per kWhr by 1907.

The first grid systems linked customers over a wide area to the central generating plant. From 1903 NESCo in north-east England installed an underground 6kV AC grid, raising the voltage to 20kV in 1906 to reduce efficiency losses, and by 1914 supplied services to 1400 square miles (Hannah, 1979, p. 32). The interconnection of several power stations allowed lower levels of spare plant to cover emergency situations (p. 30), with an average load capacity achieved in 1908 of 45 per cent compared with 20 per cent achieved elsewhere (p. 33). In North America the Niagara hydro systems were linked in 1910 to a wide area throughout southern Ontario, Canada, by a high voltage transmission line network (IEEE History Center, 2003) rated at 11kV (Smithsonian Institute, 2002).

Improved turbine generators followed the introduction of the grid. Carville B was opened in Britain in 1914 with five 11MW turbines (p. 30) consuming four pounds of coal per kWhr and represented the thermal frontier of around 17 per cent thermal efficiency until the mid-1920s (Hannah, 1979. p. 31).

The original British national grid was built between 1926 and 1931, and operated at 132kV. The national grid allowed a more efficient use of power generation capacity, and spare capacity fell from 70 per cent to 26 per cent in 1936, while the improved use of larger and more efficient plants reduced the average cost of generation from 0.42d/kWh to 0.19d/kWh (Barnes, 1969). However, the grid was still limited in that its designed purpose was primarily interconnection rather than transmission (Hannah, 1979, p. 296).

The first 25MW plant was proposed during the 1914-18 war and had become the standard type in the post-war expansion period (Hannah, 1979, p. 133). A 1926 British plant operated at 350 pounds per square inch of steam pressure (psi) and had a thermal efficiency of 21.5 per cent (p. 132).

Transmission costs tend to decrease as voltage increases (Barnes, 1969). A 275kV supergrid was established in Britain from 1950 to increase power transfer efficiency (Hannah, 1982), and allowing the spare plant to be reduced to 17 per cent of the total electricity generation capability (Barnes, 1969).

The national grid provided the opportunity to utilise larger and more efficient generators. The 30MW steam generator using 600 psi was first introduced in Britain in 1929. The system's average annual thermal efficiency was 25.5 per cent, while the capital cost was 75.5 million 1957 pounds (Hannah, 1982). Scaled-up 50MW and 75MW plants followed (Hannah, 1979, p. 133).

The next major advance in British power station design was the 1935 105MW generator also operating at 600 psi. This generator achieved thermal efficiency of 27.5 per cent, but its large size led to its deployment only around London, and it failed to supplant earlier technologies. Hence, the generator's bulk prevented the design's dominance over smaller generators.

The post-war 60MW generator operated at 900 psi and was first installed in 1950. The 60MW set's average annual thermal efficiency was 28.0 per cent, while its capital cost was 61.9 million 1957 pounds (Hannah, 1982). The increased steam pressure provided the thermal efficiency gains, while the increased generation capacity reduced the capital cost per KW (p. 105).

The 100MW set introduced hydrogen cooling of the rotor, originally developed pre-war in the USA and allowing a reduction of generator size. The first 100MW set was commissioned in 1956 and used 1500 psi to create a thermal efficiency of 30.5 per cent.

In 1952 the first electricity was developed from a nuclear pile in the USA (Hannah, 1982, p. 170), and in 1956 the first nuclear power station was commissioned (Edison Electric Institute, 2003). The first British nuclear power plant of 92MW generating capability was commissioned in October, 1956. However, the electricity from the early nuclear power stations was 50 per cent more expensive than the then-average steam generators and nearly 2.5 times the cost of the frontier coal-fired generators (p. 243). Nuclear power required a credit for the plutonium byproduct to be economical (p. 173), which by the late 1960s was realised to not exist as there was no economic use for the plutonium (p. 231). The first reactor operated at 116psi, the second set of reactors operated at 145spi and produced 137-150MW each and the next generation used twin reactors of 250-290MW and 276psi. Hence the nuclear programme represented low thermal efficiency compared with steam generators (p. 239) due to its relatively low steam pressures.

Reheat technology was introduced into steam generators with the 120MW set in 1958. The set used 1500 psi steam and had a thermal efficient of 31 per cent.

The first 200MW steam generator was installed in Britain in 1959. The steam operated at 2350 psi and the unit was rated at an average annual thermal efficiency of 32 per cent. 200MW steam generators consumed 5 per cent less fuel per MWhr than the 120MW sets and 20 per cent less fuel per MWhr than the 60MW sets (Hannah, 1982).

The 275MW steam generating set in Britain was introduced in 1962, with a thermal efficiency of 33.5 per cent.

Gas turbines were derived from aircraft jet engines and were first used for power generation in 1949 (Edison Electric Institute, 2003). The first British gas turbine plants used 50MW and 70MW sets and were ordered for installation in 1964. However, while the gas turbine plant's capital cost per MW was half of steam generators, the running costs were three times those of steam sets (Hannah, 1982, p. 251).

The first supercritical British power stations rated at 375MW were ordered in 1960 for completion in 1965, with 3500psi steam pressure. The US had already been experimenting for several years by this time. However, supercritical technology failed to achieve the efficiencies expected (Hannah, 1982).

In 1960 the first 500MW generator sets were ordered, using new 36 inch turbine blades for increased efficiency (p. 249). These sets required 600 men to operate, compared with 2000 men for similar capacity of 60MW sets (p. 281).

The grid was upgraded from 275kV to 400kV from 1965 (Barnes, 1969), to allow more efficient transfers and increased loads from large 2000MW stations comprising 4x 500MW generators to remote consumers (Hannah, 1982, p. 253).

In 1965 the US installed the first 1000MW steam generator, followed in 1972 by a 1300MW set. However, these sets no longer derived improved economies of scale from increasing generator size. The maximum efficiency achieved by steam plants in this period was around 40 per cent (Smithsonian Institute, 2002, 2002a), with turbines of 1000MW and larger enduring greater maintenance costs than smaller turbines and proving less economic than smaller 500-900MW sets (2002a).

Cogeneration systems appeared in 1989 (Solar Turbine, 1997), comprising of a gas turbine running on natural gas producing waste heat, which in turn drove a steam turbine. Cogeneration systems typically achieve over 50 per cent thermal efficiency (Smithsonian Institute, 2002b).

The first generation of High Temperature Superconductor (HTS) wire became available in 1987 (American Superconductor, 2003). However, it was some five times more expensive than copper-based wire, which restricted its diffusion. Second generation HTS wire was available in commercial quantities from 2003, and with a capacity of three to five times the load of standard wires for grid applications while reducing transmission losses (American Superconductor, 2003a) and at a similar price-performance ratio to copper wire technology (American Superconductor, 2003). Hence, second generation HTS represents a discontinuity and should displace copper-based technology. Furthermore, HTS can also be used to build more efficient generators, reducing the generator losses by one-half to two-thirds (American Superconductor, 2003b), The first 25MW set available for shipborne applications from 2005 can be expected to be matched with cogeneration sets for increased power station efficiency relatively soon afterwards.

Nature of the Discontinuities

The discontinuities have been described as competence enhancing (CE) or competence destroying (CD) depending upon their impact on existing organisations.

Table 55: Electricity Generation Technological Discontinuities 1870-2003.

Date	Discontinuity	Improvement over preceding technology	Type
1870	Dynamo	Niche opening	
1881	Utility power station	Provided access to multiple customers with economies of scale	CE
1882	Reciprocating Steam Generator	2.5 per cent thermal efficiency	CE
1882	Transmission Line	Transmit power to remote customers	CE
1883	Transformer	Improves efficiency of power distribution	CE
1886	AC generator	More efficiently support distant customers	CD
1890	0.1MW Reciprocating Steam Generator	7 per cent thermal efficiency – 180 per cent improvement	CE
1892	Condensing Steam Turbine Generator	14 per cent thermal efficiency – 50 per cent improvement	CE
1903	High Voltage Transmission Grid	Improved power station utilisation by 125 per cent	CE
1914	11MW Steam Turbine Generator	17 per cent thermal efficiency – 21 per cent improvement	CE
1926	National Grid	Increased power station utilisation by 64 per cent over 1903 grid	CE
1926	25MW 600 psi Steam Turbine Generator	26 per cent improvement in thermal efficiency	CE
1950	60MW 900 psi Steam Turbine Generator	30 per cent improvement in thermal efficiency	CE
1956	100MW with hydrogen cooling	9 per cent improvement in thermal efficiency	CE
1958	200MW with reheat and 1500psi	5 per cent improvement in thermal efficiency	CE
1962	275 MW	5 per cent improvement in thermal efficiency	CE
1965	500MW-900MW	19 % improvement in thermal efficiency	CE
1989	Cogeneration gas turbine	25% improvement in thermal	CE

	and steam turbine	efficiency	
2003	Superconductor Wire	2% improvement in generation efficiency, +400% grid capacity	CE

Conclusion

The electricity industry has experienced at total of eighteen discontinuities during the 134 year period from niche opening in 1870 to 2003. Only one discontinuity has been competence destroying, that of AC power.

Hence, the industry has experienced frequency of change at the average rate of one discontinuity every 7.4 years and 95.6% of all changes have been competence-enhancing.

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Case Study: Shipping Lines

Introduction

This case study first outlines the background to the shipbuilding industry. Second, the industry's key performance parameter is defined as cargo carrying productivity. Third, the discontinuities in the industry are described in chronological order. Fourth the competence-enhancing or destroying nature of the discontinuities is determined. Finally, a conclusion is drawn regarding the nature of change in the industry.

Industry Background

Shipping lines initially grew from the need for timetabled services for transporting messages and high value cargo. In the early nineteenth century Britain's maritime empire was linked by the Royal Mail, which was initially carried by sailing naval vessels. In the 1820s the Post Office developed a network of small steamers (Harcourt, 1997) for mail services around coastal Britain, including the first all the year round steamer service from the end of May 1821 (Bagwell, 1988, p. 54). Naval steamers carried the mail on longer routes, such as the Mediterranean.

However, from 1834 political pressure aimed at reducing the Post Office's costs encouraged the outsourcing of mail routes (Harcourt, 1997, p. 33). By 1840 three major long distance contracts had been let for the North Atlantic, West Indies and South America and the Mediterranean (to connect to India via Egypt) routes. The mail subsidy reduced the risk and created a sound economic base for entrepreneurs to invest in establishing coaling stations and building a fleet of large and fast ships for the service (p. 34). The initial subsidy rate averaged around 25 per cent of total capital required to establish and maintain the route (p. 35). The result was "steam ships have been constructed of a size and power that, without Government aid, could hardly at least for many years, have been produced" (p. 38).

The mail contract system was later adopted by other countries to promote new liner routes, including the United States (1847-1850), Canada and France. Shipping was regarded as an extension of national power and hence the contract mail system spread throughout the world (p. 41). The resulting liners provided a regular and punctual service between designated ports, with linking services adding value to the established liner network.

Consequently, the diffusion of the steam ship led to a division of shipping in two categories: liners supported by mail, passengers and high value freight; and tramps for other cargoes (Broeze, 1997). Tramp steamers gradually displaced sail for carrying bulk cargoes and low value passengers, until in turn containerisation and air travel displaced tramps from these markets. Today's liners still carry freight in the form of container ship services.

The liner business enjoyed some network externalities derived from the structure of its network built upon the subsidised mail route. The subsidies gradually declined over time, with the subsidy for the shipping line that serviced the Mediterranean and India routes (P&O) falling from 37% of gross receipts in 1845-50 to 9% in 1910-1914 (Harcourt, 1997, p. 38).

Industry's Key Performance Parameter

The industry's key performance parameter was the vessel's cargo carrying capacity as a fraction of its size. This cargo carrying efficiency is primarily influenced by machinery, fuel and ship weights. In addition, from 1961 crew costs became a significant cost and assumed a position of a secondary basis for competition within the industry.

Discontinuities

Sailing vessels built from wood have provided an important and inexpensive method to transport bulky goods and people from early times. However, the vagaries of weather and tide ensured that sail could provide only an unreliable service, and high value freight and passengers preferred to travel by land rather than using coastal sail (Bagwell, 1988).

The introduction of steam propulsion in the shipping industry enabled the creation of reliable shipping schedules for the carriage of valuable cargos. The first commercial steamer service was a river service in the USA from 1807 using a paddle steamer with a wooden hull, simple boilers and engines (Bellis, 2004). By 1821 steamers on the Edinburgh to Aberdeen route in Scotland each maintained a reliable weekly return service, compared with an average three week return voyage with sailing vessels (Bagwell, 1988). Thus, steamers represented a 200% service improvement over sail.

The first discontinuity was the replacement by wood with all iron ships. Iron fittings had been used to strengthen wooden hulls since 1670 (Goodwin, 1997), allowing the building of stronger and larger hulls. In 1823 the SS *Aaron Manby* was the first iron-hulled steamship, and she was used on a cross-English Channel service (Steamertrunkmerchants, 2004). All wooden hulls larger than 40m length and heavier than 500 tons tend to suffer from structural problems (Tri-Coastal Marine, 2002). Iron hulls removed the construction limits on hull size. As "a ship's capacity increases as the cube of the hull's dimensions, the power required to drive it increases only as the square of the dimensions" (Houghton Milfflin, 2003), larger iron hulls enable a greater cargo carrying capacity for the same performance, and thus represent a substantial improvement over a similar capacity of smaller wooden hulls.

The side lever engine was first introduced in 1835 and used in Royal Mail packets (Thurston, 1878). These engines were the dominant form of engines used in the large paddle steamers and they surpassed other seagoing steamships in speed and comfort until being replaced in turn by propeller-driven steamships. The 1340 gross registered ton 2300 net tonnage (Houghton Mufflin, 2003) wooden-hulled *Great Western* carried two side lever engines (Griffiths, 2004) in her maiden trans-Atlantic voyage in 1838, and used 460 tons (VRCurassow, 2004) of her 660 tons of coal to propel her 450 horsepower (Thurston, 1878) for fifteen days, equating to 6.4 pounds of coal per hour per horsepower.

The first commercially significant railway was the Liverpool & Manchester, opening in 1830 (Pollins, 1971). The line's success unleashed a wave of railway investment to link major centres previously serviced primarily by coastal shipping. Railways were built that linked the most important British port London (Bagwell, 1987) to the important ports of Liverpool via Birmingham in 1837, Newcastle in 1839, Southampton in 1840 and Bristol in 1841 (Freeman & Aldcroft, 1985; Pollins, 1971). British coastal passenger steamship traffic peaked in the early 1840's, and was subsequently displaced by rail (Bagwell, 1987). By 1885 only the wealthiest steam packet companies were still providing significant coastal passenger services in Britain (p. 65). Subsequent liner services principally serviced overseas routes.

Long distance liner services depended upon ships being able to navigate across oceans. However iron disrupts the ship's magnetic field, and hence rendered unusable the magnetic compass then used for navigation. In 1838 a correction for magnetic deviation was found and ocean navigation for iron ships became practical (University of Michigan, 1997). The first steamers that steamed continuously across the Atlantic used wooden construction (Griffiths, 2004), but iron ships followed from 1845 with the first ocean-going iron ship *Great Britain*'s maiden trans-Atlantic voyage (Houghton Mufflin, 2003a). Thus, the magnetic deviation enabled trans-oceanic liner services by iron hulled ships and was a competence-enhancing discontinuity for steamship operators, by increasing the practical ship size in non-coastal routes. By 1873 British steam tonnage on overseas trade had exceeded sailing tonnage (Bagwell, 1988).

The first ocean-going propeller-driven steamer was the warship USS *Princeton* built in 1840 with a 950 displacement tonnage (Thurston, 1878). Propellers provided greater propulsive efficiency and an immense increase in economy, while also clearing up deck space and enabling improved cargo storage and handling (Thurston, 1878). Propellers rapidly diffused in new construction, and by 1850 had displaced paddlewheels almost completely (Thurston, 1878).

Further, the propeller prompted the shift from heavy, long stroked, low speed engines to light engines with small cylinders and high piston speed. The new geared engines used simple wooden cogs (Parsons, 1911), developed 5-15 pounds of steam pressure and consumed 7-10 pounds of coal per hour for each horsepower. The smaller and lighter engines enabled greater cargo carrying capacity while greater fuel efficiency reduced the ship capacity allocated to carrying fuel and improved economics through lower fuel costs (Thurston, 1878).

The direct acting engine with jet condensation followed, with steam at 20 pounds of pressure and consuming 5-6 pounds of coal per horsepower (Thurston, 1878). The engine operated at a higher speed to allow it to be directly connected to the propeller (Parson, 1911). The 2936 gross registered ton iron-hulled *Great Britain* was completed in 1844 with a direct acting engine driving one propeller via a drive chain (Houghton Mifflin, 2003a).

Forced draft boilers followed in 1851 (USGennet, 2003) and surface condensation allowed increased steam pressures to rise to 75 pounds or higher, while coal consumption dropped to 3-4 pounds of coal per horsepower (Thurston, 1878).

The compound engine uses two cylinders and passes steam from a high pressure cylinder to a low pressure cylinder. The engine was slowly perfected over many years and proved successful once surface condensation allowed higher steam pressures. In 1853 the small vessel *Brandon* required only 3.25 pounds of coal per horsepower per hour, and by 1858 larger compound engines were running on 2.25 to 2.5 pounds of coal per horsepower per hour. Later models of compound engines in 1881 ran at around 77 pounds of pressure and used a little under 2 pounds of coal per horsepower per hour (1911 Encyclopedia, 2003).

The water tube boiler was first introduced in the USA in 1867 and was initially considered to have only minor advantages over the fire tube boilers in use (Thurston, 1878). However, as steam pressures increased, water tube boilers became the dominant boiler technology as it enabled higher steam pressure, which improves fuel efficiency.

The triple expansion engine is a redesigned compound engine with a third cylinder. Kirk introduced the engine, which was first fitted to the *Aberdeen* in 1869 (USGennet, 2003). Steam pressure rose to 150-200lbs of pressure and coal consumption dropped to circa 1.5 (1911 Encyclopedia, 2003) to 1.54 pounds of coal per horsepower per hour (Baker, cited in Locock, 2001).

Mild steel was introduced for hull construction in 1877, and quickly become the dominant material in Britain (University of Michigan, 1997). Steel diffused into other countries' industries and had replaced iron as the dominant material in the fledgling Japanese shipbuilding industry by 1890 (Chida & Davies, 1990). The first Cunard Line steel ship, *Servia* built in 1881, reduced 620 tons from its 3971 net tonnage, or 15%, from total ship weight, through the use of mild steel (Robbins & Innola, 2003).

Oil fuel was first used in 1886, with the launch of the *Himalaya* in Britain. Oil fuel replaced coal for heating water into steam to power the ship's engines. Fletcher (1997) claimed that oil fuel required one-eighth the space and one-third the weight of coal and hence significantly improved the cargo carrying capacity of the ship, while the Energy and Planning Office (2004) gives thermal conversion rates that equates I tonne of oil to 2.39 tonnes of coal. However, oil fuel was initially difficult to source and more costly than coal, and it required almost thirty years for distribution stations to become widely established and to diffuse in new shipbuildings. In 1914 only around three per cent of total world non-sailing gross tonnage used oil fuel, but war changed some national priorities and by 1919 eighty per cent of US ships burnt oil fuel (Fletcher, 1997), while globally almost 26 per cent of non-sailing gross tonnage used oil fuel in 1922 and 49 per cent in 1935. Oil's diffusion was aided by the wartime construction of oil storage facilities in many ports to support naval activities.

The turbine was first demonstrated on the 44.5 ton *Turbinia* in 1897, followed in 1901 by the 650 ton merchant ship *King Edward* and in 1904 by the 3000 ton cruiser HMS

Amethyst (Parsons, 1911). The early turbines typically used 200 pound steam pressure and were directly connected to the propeller. However, due to propeller cavitation problems, the direct turbine was suitable only for faster vessels (Parsons, 1911). Some installations solved this problem by using turbines in conjunction to triple expansion engines as a booster engine for higher speeds only. One such ship, the 20,000 ton line *Laurentic*, achieved a 14 per cent saving in fuel consumption compared with her reciprocating engine powered sistership *Megantic* (Parsons, 1911).

The 4350 ton *Vespian* was altered from triple expansion engine to a geared turbine in 1908. Extensive trials demonstrated a twenty-two per cent reduction in fuel consumption compared with the original machinery. Further, geared turbines enabled turbines to be applied to slow vessels unsuited to the directly driven turbine and replaced the need for triple expansion engines for slow speeds. Hence, the geared turbine was more economic than the direct turbine and the triple expansion engine, while it was also smaller in size than the triple expansion engine. In 1920 the efficiency of geared turbines using coal as a fuel was estimated at 2.4 pounds of coal per horsepower per hour at low speeds, reducing to 1.2 pounds of coal per horsepower per hour at high speeds, but with a 2 per cent loss in efficiency from the gearing (Baker, cited in Locock, 2001). Hence, the geared turbine operating at high revolutions was up to 29 per cent more efficient than the triple expansion engine.

The first sea-going diesel engine was the tanker 1179 ton *Vulcanus* in 1909 and by 1914 diesel engines powered approximately one-half of one per cent of the world's merchant gross tonnage (Fletcher, 1997). By 1927 over half of new construction was diesel powered and by 1950 25 per cent of all gross tonnage comprised of motorships (Fletcher, 1997). The two stroke diesel engine in the 1920s consumed fuel at the rate of 0.47 pounds of oil per horsepower per hour, while the four stroke engine consumed 0.44 pounds of oil per horsepower per hour (Baker, cited in Locock, 2001). Thus, using Locock's (2001) 1920 estimates and the Energy and Planning Office (2004) conversion factors between the weights of coal and oil sources, the two stroke diesel engine was 7 per cent more efficient than the oil fuel driven geared steam turbine at maximum efficiency, while the four stroke engine was up to 14 per cent more efficient in the same conditions.

Small tube boilers were available by 1912 and weighed two-thirds of the earlier water tube designs (Henneman, 2004). These boilers reduced machinery weight and thus allowed a greater cargo capacity for the same sized hull and speed.

The first turbo-charged diesel engined ship was completed in Germany in 1925, while the first turbocharged ocean-going vessel was built in Britain in 1928 (Virginia Tech, 2004). Turbo-charging technology was in widespread use in the Second World War. Modern turbocharged diesel engines commonly achieve fuel consumption levels lower than 200 g/kWhr (Gee, 2001), or 0.323 pounds per horsepower per hour. Thus, the geared turbocharged diesel provide at least a 56 per cent efficiency improvement over geared turbines when operating in their most efficient mode and a 46 per cent improvement over the non-turbocharged diesel engine.

The first trans-oceanic airline routes were created in 1927, with the US carrier Pan American Airways providing a service to South America, and later across the Pacific and Atlantic oceans (Afriqonline, 2003). Britain's Imperial Airways also established routes from Britain to South Africa and used mail contracts to establish the new routes, in a repetition of the founding of the steamship routes (Afriqonline, 2003a). However, trans-oceanic air travel was initially substantially more expensive than sea travel and hence was the domain of the high value passengers only.

Superheated steam turbines were introduced by the German Navy in 1934 in the Type 1934 Destroyer (Lienau, 2000; Blohm und Voss, 2002) to improve fuel efficiency and reduce machinery weights. Steam pressures were increased to 1028 pounds per square inch (psi) (Flixco, 2004), but the engines initially suffered from poor reliability. The engines developed 23.7 horsepower per ton, compared with 17.4 horsepower per ton achieved by the contemporary British J class with 300 psi boilers (Flixico, 2004a) and the earlier Type 24's 18.1 horsepower per ton with 268 psi boilers (Flixico, 2004b). Hence, the superheated steam pressures improved steam turbine machinery efficiency by over 31 per cent. By the 1950s the US Navy finally perfected superheated steam turbine technology using 1200psi steam pressures and earlier steam technologies were superseded (Gardiner, Chumbley & Budzbon, 1996).

The first trans-Atlantic jet air service was introduced by BOAC in October 1958 with a De Havilland Comet 4, followed by Pan American with the Boeing 707 jet airliner three weeks later (Afriqonline.con, 2003b). Long-haul jet services were rapidly introduced around the world, with passenger numbers crossing the Atlantic by plane surpassing liner passenger numbers by 1960 (National Air Traffic Services, 2004). By the late 1960s jet aircraft had largely displaced ocean liner passenger and high value freight services. The world's fastest liner SS *United States* was withdrawn from its trans-Atlantic service in 1969 (SS-United-States.com, 2003), while the largest British liner company, P&O, ended its services to East Africa in 1969, New Zealand in 1969 and India in 1970. The remaining passenger liners were redeployed into the cruise ship market from 1969, with purpose-built cruise ships being built from 1972 onwards (Howarth & Howarth, 1986).

In 1961 the world's first automated ship, the *Kinokasan Maru* of 9800 gross tons, was delivered in Japan. Crew numbers were reduced from 51 to 36 (Childa & Davies, 1990). Further automation allowed crews to be reduced further to 14 man crews from 1977.

Containerisation was introduced in Japan in 1968. By 1973 all cargo routes from Japan were containerised and non-containerised cargo traffic had been superceded by the more efficient container system (Childa & Davies, 1990). Containerisation diffused rapidly to other markets and soon dominated international freight. The first OCL containerships built from 1969 replaced 4-5 general cargo ships each, with substantial savings in crewing costs (Howarth & Howarth, 1986).

In 1990 ABB introduced the electric azimuthing pod drive system (Azipod). The Azipod quickly replaced propellers as the dominant drive in large passenger vessels, and has since increased penetration in freight vessels (ABB, 2002). The Azipod has proven to be more fuel efficient in vessels where transit time represents no more than 65 per cent of total operating time. The Azipod system is eight percent less efficient than a mechanical drive when operating at maximum power (ABB, 2003). However, electric propulsion does not require long shafting, enabling engines to be placed in novel locations leading to more efficient hull designs and allowing a power station concept in ships, where engines can used at their most efficient levels.

The first large trimaran *Triton*, of 1200 tons displacement, was launched in 2000. The stabilised narrow hull form is 25% more efficient than the non-stabilised monohull form, and is beginning to become adopted in commercial traffic (Vosper Thornycroft, 2003).

The first high temperature superconductor motor was built in 2003. The first naval vessel with these drives is intended to be ordered in 2005 for delivery in 2012 and it is expected that these motors will rapidly diffuse into the larger passenger vessel market (American Superconductor, 2003). Super conductors have lower resistance than standard electric motors, with a 25MW motor suited for larger ships rated at 97 per cent efficiency at full power and 99 per cent efficiency at one third power, while the 25MW generator is rated at 98.6% efficiency (Kalsi, 2002). Hence, the superconductor motor and generator combination operates at 95.6 per cent efficiency compared with 97 per cent efficiency for a geared diesel installation - 1.4% less efficient at full speed. However, superconductors are a similar weight to geared engines, and hence provide the opportunity for Azipods and other electric propulsors to replace geared diesels over time.

Nature of the Discontinuities

The shipping industry has experienced a series of discontinuous changes over time, that have changed the economics of ship operation and often obsoleted much of the existing shipping stock. In practice, any change that provided a performance advantage has diffused over time, while those changes that could be retrofitted to existing stock, such as magnetic deviation and oil fuel boilers, have progressed rapidly.

The industry's key performance parameter has traditionally focused on cargo efficiency, which is influenced by the weight and space allocated to the hull, machinery and fuel. The increase of personnel costs from the 1960s has led to labour costs becoming an important secondary issue.

The discontinuities have been described as competence enhancing (CE) or market disrupting (MD) depending upon their impact on existing shipping organisations.

Table 56: Shipping Technologies Discontinuities 1807-2005.

Date	Discontinuity	Improvement over preceding technology	Type
1807	Wooden Paddle steamer	N/A	Niche opening
1823	Iron Hull	Variable	CE
1835	Side lever engine	Significant	CE
1837	Railway network begins linking ports	Replaced coastal steamship passenger traffic	MD
1838	Magnetic Deviation	Significant	CE
1840	Propeller	Significant	CE
1841	Geared Engines	Significant	CE
1844	Direct Acting Engines	+55% fuel economy	CE
1851	Surface Condensation	+57% fuel economy	CE
1854	Compound Engine	+50% fuel economy	CE
1867	Water tube boiler	Became significant	CE
1869	Triple Expansion Engine	+25% fuel economy	CE
1877	Mild Steel Hull	+18.5% cargo capacity	CE
1886	Oil Fuel	+138% energy from same fuel weight	CE
1897	Steam Turbine	+16% fuel economy	CE
1908	Geared Steam Turbine	+12% fuel economy	CE
1908	Diesel Engine	+ 7% economy	CE
1927	Long range trans-oceanic aircraft	Replaced mail and high value passengers	MD
1928	Turbocharged Diesel Engine	+46% fuel economy over non-turbocharged diesel	CE
1934	Superheated High Pressure Steam Turbine	+30% power from steam turbine weight	CE
1958	Long-range jet passenger aircraft	Replaced long distance passenger traffic	MD
1961	Automated Ship	Reduce crew by 72%	CE
1968	Containerisation	Replace general cargo vessels	CE
1990	Azimuthing electric pod	More efficient when transit times no more than 65 % total operating time; -8% at full power; efficient hull design	CE
2000	Trimaran hull form	+25% fuel economy	CE
2005	High temperature superconductor motor	-1.4% at full power	CE

Conclusion

There have been a total of 22 competence-enhancing and 3 market-disrupting discontinuities during the 199 year 1807-2005 period, excluding the niche opening. The market-disrupting changes were all created by new industries depriving the shipping industry of one of its original sources of customers: railways displaced coastal passenger services; flying boats long range mail; and jet aircraft trans-oceanic passengers and high value freight.

The rate of change in the shipping industry since niche opening has been 1 discontinuity per 8.0 years and 88 per cent of discontinuous changes were competence-enhancing. The industry can be divided into four eras split by the market-disrupting discontinuities, as displayed in the following table:

Table 57: Frequency of change of Shipping Industry

Era	Industry Era	Competence-enhancing Discontinuity Quantity	Frequency of change
1807-1837	Coastal Passenger	3	0.067 p.a.
1838-1927	Oceangoing Passenger, Mail, High Value Cargo	14	0.156 p.a.
1928-1959	Oceangoing low value passengers, mail, cargo	1	0.031 p.a.
1960-2005	Low value Cargo	4	0.087 p.a.

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Case Study: Shipbuilding Industry

Introduction

The shipbuilding industry has one of the longest of industrial histories. Wooden shipbuilding was originally centred in areas with access to supplies of raw materials and nearby markets for completed vessels. The industry was, and is, a major input to the shipping industry, and the two industries share common end-users for their respective products.

This case study first outlines the background to the industry. Second, the industry's key performance parameter is defined as material and labour productivity. Third, the discontinuities in the industry are described in chronological order. Fourth, the competence-enhancing or destroying nature of the discontinuities is determined. Finally, a conclusion is drawn regarding the nature of change in the industry.

Industry Background

The eighteenth and early nineteenth shipbuilding industry had been established to supply predominately sailing vessels for coastal and ocean-going trade. In Britain, the leading maritime nation of the period, the coal trade had grown as wood become a more scarce and expensive fuel, and dominated Britain's coastal trade for 350 years, with over 40 million tons of coal being imported by London alone between 1670 and 1750 (Bagwell, 1988, p. 47).

Thus, coal provided both the foundation of the shipbuilding industry in the supply of hulls and the fuel later required for steamships to establish liner routes. The increased use of iron led to the focus of shipbuilding moving from sources of supply of wood to supply of iron, and later steel, following access to competitively priced material. The shift from wood to iron partially explains the loss of a competitive position for the American merchant marine around the US civil war period.

Further, the shipbuilding industry established modern factory methods and has been a leader in many aspects of heavy manufacturing.

The frontier nation for shipbuilding from 1800 to 1955 was Britain, based in part upon its competitive position with plentiful and cheap coal supplies. However, Japan replaced Britain as the largest shipbuilder in 1956 (Chida & Davies, 1990) and since then Japan has operated at the frontier in shipbuilding, though under increasing challenge from other Asian nations in recent years.

Industry's Key Performance Parameter

The management of resources has been the key performance parameter since the fifteenth century. Semi-skilled labour has been the dominant labour type throughout the period, and the management of these costs are an input resource input for the shipbuilding firm.

Discontinuities

The Venetian Arsenal introduced factory techniques to shipbuilding in 1418, with products built using standardised parts on an assembly line (Wikipedia, 2003; Hoppenfeld, 2003). Earlier ships were built by small numbers of skilled craftsmen and with designs based upon experience. In 1800 ships were built from wood, though iron fastenings were first used in warships on the *Royal James* in 1670 to strengthen the hull (Goodwin, 1997) and iron rivets had been in use as early as the 7th century (Centre for Marine Archaeology, 1999).

Steam power for machinery was first used in mines in the late eighteenth century and by 1800 had been applied to iron works and ropemaking, but not the shipbuilding industry (Lord, 1923). The first smelting facility at a British naval dockyard was built in 1803 and a new metal mill with purpose built machinery was opened in 1806 (Goodwin, 1997). One of these events is most likely to have been the first application of steam power to shipbuilding. The completion of the first effective steamship in 1807 (Bellis, 2004) would have provided further practical experience with steam machinery to spur steam adoption in shipbuilding.

The first all-iron hull was completed in 1819 (University of Michigan, 1997), the first iron-hulled steamship in 1823 (Steamertrunkmerchants, 2004) and the first iron-hulled ocean-going steamship in 1844 (Houghton Mifflin, 2003). Iron eliminated the need for carpentry skills for essential hull components and allowed the construction of larger ships – though also requiring access to large quantities of iron for construction purposes.

Steam railways appeared from 1830, supplying coal and iron to shipyards. The simplified transport system significantly reduced the costs of raw materials, though as shipbuilding is, by necessity, a coastal activity, shipyards also had access to sea transport for raw materials from other coastal regions. By 1865 railways in Britain carried 50 million tons of coal plus 13 million tons of all other minerals, predominately iron, compared to 32 million tons of general merchandise, though rail only surpassed sea for coal imports into London during the period 1867-1897 (Bagwell, 1988). Hence, railways were an important transport system for moving raw materials at least from inland regions.

Composite iron-ribbed and wooden hulled vessels were popular during 1860-1880, as they proved lighter than iron-hulled vessels (Sunderland Marine Heritage, 2003). The *Sobraon* launched in 1866 was the largest composite ship built, measuring 2131 gross registered tons (Clipper Ship Museum, 1997). The use of iron ribs allowed larger vessels to be built than was feasible with wooden construction, which is limited to 500 tons displacement (Tri-Coastal Marine, 2002). The structural limit for wooden ships is generally considered as 61m in length, though a 1950s US minesweeper type was 69m long (University of Michigan, 1997).

Steel was introduced in hull construction in 1877 and quickly become the dominant material in Britain through its greater strength and easier working (University of Michigan, 1997). Steel diffused into other countries' industries and had replaced iron as the dominant material in the fledgling Japanese shipbuilding industry by 1890 (Chida & Davies, 1990). The first Cunard Line steel ship, *Servia* built in 1881, used mild steel to reduce hull weight by 620tons, or 15% of total ship weight (Robbins & Innola, 2003).

DC Electric Motors were available from the 1870s, but were never widely used (Hannah, 1979, p. 15). However, the invention of the AC polyphase motor in 1887 allowed electric power to replace steam as the power source for factory machinery (p. 15) and found increasing factory applications by the early 1890s (p. 18). In Britain electric motors represented one-ninth of motor capacity in the manufacturing and mining segments by 1907, growing to one-fourth by 1912 (p. 19). By 1908 all shipbuilders on the north bank of the Tyne received at least 95 per cent of their power requirements from an electrical utility (Hannah, 1979, p. 32-3). In the US electric motors supplied fifty per cent of all factory horse power by 1919 (Gordon, 2000).

The first diesel powered ship was built in 1909 and diesel propulsion achieved one-half of one per cent of gross tonnage by 1914 (Fletcher, 1997). By 1918 many Scandinavian shipyards had converted to diesel construction and gained an advantage over traditional steamship yards in the new technology (p. 163). However, diesel power only fully displaced steam for new construction in the 1970s when oil prices increased rapidly – with a few niche market exceptions.

The first welding was used during the First World War to assist the assembly of pre-constructed components. The first all-welded ship was finished in Britain in 1920 (University of Michigan, 1997) and reduced the hull weight by five per cent. However, welding required specialised and expensive labour, so riveting remained the dominant construction technique.

Production control was developed by Western Electric in the telecommunications manufacturing industry and introduced into shipbuilding during the Second World War. The Kaiser yard in the USA built standardised merchantships during 1940-5 as part of the emergency shipbuilding programme. Post-war American engineers diffused these techniques into the Japanese shipbuilding industry and they became widely adopted by the 1960s.

Block (or section) building was also introduced in 1940, to facilitate the American emergency shipbuilding programme. Pre-manufactured blocks were built in covered halls and only shifted to the slipway for assembly into the finished vessel. Consequently, the slipway was occupied for a shorter period of time, increasing slipway efficiency and raising the shipbuilding capacity of the shipyard.

Killed steel was introduced in 1950, and, as this form of steel allowed easier and more precise welding than the earlier rimmed steel, it reduced the labour cost in welded ships (Chida & Davies, 1990, p. 110). Consequently, welding rapidly replaced riveting.

Pre-outfitting was introduced in the mid-1950s (University of Michigan, 1997), allowing more rapid fitting out of a vessel after launching.

The flowline system was developed at the NBC shipyard at Kure Japan during the 1951-61 period, and introduced aircraft manufacture techniques into ship building. The emphasis shifted from 'what to build' to 'how to build', with every process pre-planned and integrated into a production plan. The flowline system increased productivity, the quality of output and allowed more sophisticated vessels to be built (Chida & Davies, 1990, p. 112).

In 1959 drydocks were first introduced for building commercial ships. Since that time, all new major shipyard facilities have used drydocks, and this technology has replaced end-launching as the main method for launching new ships (University of Michigan, 1997).

Automation was introduced in the 1960s in the shipbuilding industry. Automatic cutting of steel plate and automatic welding significantly improved productivity (Chida & Davies, 1990, p. 92, p. 111)

Megablocks were introduced in the 1990s for greater efficiency. The *Triton* was built in 1998-2000 of five megablocks of 200 tons each (DERA, 2001), and new construction warships are being built of 500 ton blocks. The result is shorter construction periods and greater efficiency for the shipyard, with the *Triton* being delivered a year earlier than possible with traditional techniques.

Nature of the Discontinuities

The discontinuities described above all become industry norms within usually one decade of introduction. Hence, while the paucity of accurate data cannot substantiate the actual effect on the industry's basis for competition, it can be determined that these changes were significant enough to become common practice and drive the earlier practice out of the industry. By definition, the nine competence-enhancing discontinuities reflect order of magnitude improvements over the preceding situation, while the competence-destroying discontinuities represent devaluation of existing knowledge and skills (Tushman & Anderson, 1986).

Table 58: Shipbuilding Industry Discontinuities 1807-2003.

Date	Discontinuity	Effect on Basis for Competition	Type
1417	Venetian Arsenal		
1670	Iron fastenings		
1803	Steam power		
1807	Steam propulsion	Niche Opening	N/A
1819	All iron hull	Allowed bigger ships	CE
1830	Railroads	Cheaper access to inland resources	CE
1860	Composite Hull	Lighter than iron, stronger than wood	CE
1877	Steel	Easier to use, 15% lighter than iron	CE
1887	AC Electric Motor	Reduced machinery costs	CE
1908	Widespread electric utilities	Lower power cost	CE
1909	Diesel engine	Different engine design and construction	CD
1920	Welding	Reduced ship weight	CD
1940	Production Control	Improved productivity	CE
1940	Section Building	Double shipbuilding capacity of slipway	CE
1950	Killed Steel	Reduced construction times	CE
Mid-50s	Pre-outfitting	Reduced construction times	CE
1959	Drydocks	Replaced slipway	CE
1960s	Automation	Significant manpower reduction	CE
1990s	Megablocks	Reduced construction times	CE

Conclusion

The shipbuilding industry experienced 15 discontinuities from the beginning of the steamship era in 1807 to 2003. The diesel engine and welding both significantly devalued existing skills, and it is not surprising the then dominant shipbuilding nation was slow to adopt these innovations (Fletcher, 1997) and was superseded as both technologies became dominant in the 1950s.

The industry frequency of change was one discontinuity every 13 years and 87 per cent of discontinuities were competence enhancing.

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Case Study: Software Industry

Introduction

The manipulation of numbers by devices dates back to ancient times with the abacus. However, the manipulation of data by programmed instruction is a newer phenomenon.

The first programmable device was the Jacquard loom invented in 1802 (Campbell-Kelly & Aspray, 1996), which used punch cards to program intricate patterns for weaving cloth. Babbage adopted the same concept to program his analytical machine in 1833, and spent two years from 1833-5 developing the software programs for his mechanical computer.

However, the continuous history of computer programming began only with Hollerith's tabulating machines, which collated data by using pre-programmed punched cards. Hollerith's company later merged with two other complementary firms to form the forerunner of IBM and developed a succession of technologies that has enabled IBM to dominate the computer industry for much of its history. The technique of programming has become more sophisticated as successive computer technologies have enabled new techniques.

This case study first reviews the background within which the software industry has evolved. Second, the industry's key performance parameter is specified, noting the impact of techniques on software development capability. Third, the discontinuities experienced by the industry are described in chronological order. Fourth, the results are presented in a tabular form as a summary.

Industry Background

The software development industry has passed through two eras. The first era was characterised by mechanical computers collating data fed by punched cards, or sometimes by paper tape. These computers, originally called tabulating machines, replaced human computers who had previously manually calculated statistics and scientific calculations. The system's software was bundled with the relatively expensive hardware systems, and hence the returns to software were restricted to the economics of the computer hardware.

The second era began with the development of the stored program computer in 1949, which allowed software to be reproduced independently from the computer equipment. Software exhibits high development costs and negligible reproduction costs, and hence provides increasing returns.

Industry's Key Performance Parameter

Early software was incorporated in the computer design and thus did not compete independently from the computer. However, during the industry's second period, software's inherent increasing returns have encouraged developers to maximise customer numbers to maximise returns on investment. The industry's economics are driven by the number of users contributing to the returns from the software development investment.

The unbundling of software from hardware and the emergence of industry standard platforms improved the economics of the software industry by providing larger customer bases. Other discontinuous changes have improved the productivity of programmers or extended the software development technology, thereby reducing costs and increasing potential customers.

Thus, since 1949 market size has been the software industry's key performance parameter.

Discontinuities

The software industry began with the Hollerith tabulating machine used in the 1890 US Census. The tabulated machine used punched cards containing data on each individual. The software program component of the tabulating machine was the design of the card, while the data were held on the cards. The recording of data onto the cards was no faster than alternative manual systems, but the tabulating machine could tabulate the results ten times faster than manual methods (Campbell-Kelly & Aspray, 1996, p. 22-23).

The first discontinuity occurred in 1908 when Hollerith's company, Tabulating Machines Company (TMC), introduced its automatics line using a 45 column card. Each card could contain 45 digits of numerical information and became established as the industry standard card for twenty years (p. 46).

In 1928 TMC's corporate successor, International Business Machines (IBM), introduced an 80 column card (p. 50) with 78% more capacity than the original card, and hence greater scope for the design of data layout. The 80 column card continued to affect software designs decades after its replacement by later storage technologies.

The third discontinuity occurred in 1943 when the first useful digital computer was completed. The Harvard Mark I was a mechanical device where short programs of approximately one hundred operations were entered by punched paper tape. Repetitive operations could be run by gluing the ends of the paper tape together, to form a continuous loop that would be completed about once a minute (p. 73). This first digital computer offered the first opportunity to program sophisticated mathematical functions, such as nonlinear equations (p. 70), but unfortunately could not handle conditional loops (p. 73) and hence was cumbersome to program. The Harvard Mark I was rapidly followed by the faster electronic computers, such as the British Colossus completed in 1943 (p. 99) and ENIAC in the United States. However, despite differences in hardware design, all of these computers were similar in that they stored their instructions in hardware and hence represent variants of the same generation of software technology.

The next discontinuity was enabled by the stored-program computer, introduced in 1949, that treated its programming as data for the first time and loaded the instructions into memory prior to execution – eliminating the bottleneck of access to instructions. The EDSAC computer was programmed in binary code that, while an advance over ENIAC, was still time-consuming to develop. Hence, subroutine libraries were rapidly developed in 1949 to eliminate duplication by programmers for commonly used functions (p. 185-6). "The idea of reusing existing code was and remains the single most important way of improving programmer productivity and program reliability" (p. 186).

In 1951 the first real-time computer was operational (p. 166-167). The significance of real-time computing is the representation of time dependent information, such as the original aircraft defence co-ordination system and the first commercial real-time system commissioned in 1964, the SABRE passenger reservation system (p. 175). Over time real-time systems gradually displaced the earlier batch processing designs, and enabled the monitor-based interactive systems that became prevalent in the 1970s (p. 168).

However, binary was, and still is, a slow method of programming a computer. In 1953 "half the cost of running a computer center was accounted for by the salaries of programmers, and ... from one-quarter to one-half of the average computer's available time was spent in program testing and debugging" (p. 188). The first effective programming language, FORTRAN, appeared in 1957, and produced programs that were 90% as efficient as programmer written programs, in terms of memory usage, but could be written more quickly. "Programs that had taken days or weeks to write and get working could now be completed in hours or days" (p. 190).

1961 saw the first time-sharing computer completed at MIT, initially supporting only three users (p. 209). Time-sharing allows multiple people to access the same computer concurrently, and eliminated lengthy delays while people waiting in queue for a computer that was being used for only a few minutes in each hour monopolised by one user (p. 208). Hence, time-sharing dramatically increased the efficiency of software developers whilst also improving computer usage efficiency.

The BASIC programming language introduced in 1964 for the first time enabled non-software development professionals to directly assess computing capability without a professional intermediary (p. 211). Hence, in addition to software developers and computer users, BASIC created a third group of computer users: "users who could develop their own programs and for whom the computer was a personal information tool" (p. 212). By changing the scope of access to computing, BASIC created the seeds of change that eventually led to personal computing.

In 1967 IBM introduced OS/360, the first stable industry platform (p. 203). IBM's standardisation on one operating environment for all mainframe models and IBM's domineering 75% marketshare (p. 147) effectively created an industry standard (p. 150), with such commitment from customers and suppliers that IBM cancelled its proposed new generation mainframe in 1975 (p. 150) in favour of evolutionary improvement of the existing standard. "Software compatibility forced IBM to remain wedded to its 360 architecture" (p. 150). Hence, OS/360 both provided a secure environment for software development and retarded development in mainframe computing.

Further, the IBM OS/360 architecture triggered two additional discontinuities. First, the complexity of the OS/360 development and other major software projects stimulated the invention of software engineering in 1968. Structured design, formal methods and development models were introduced to manage the "inherent complexity of writing large programs" (p. 201). Second, the increasing cost of software relative to hardware incentivised IBM and the other mainframe manufacturers to unbundle software from hardware. Consequently, following IBM's 1968 decision to unbundle software applications from their computer systems (p. 203), the software industry was established as a separate industry within three years (p. 204). The new software company channel allowed developers to access larger numbers of customers and significantly improved the returns for software investments.

The first personal computer was released in 1975 (p. 242), but it was only in 1977 that practical microcomputers became available (p. 247). The limited programming platform was unattractive to the mainframe software companies, and instead during 1977-1983 large numbers of new entrants tried to establish themselves in the new microcomputer software market (p. 251, p. 262). Hence, the personal computer software industry represented a competence-destroying discontinuity for the software industry.

IBM launched its personal computer (PC) model (p. 255) in 1981 in competition to existing microcomputer manufacturers. The release of the IBM PC legitimised the PC as a business tool, thus endorsing PC software for business use, and the market rapidly grew from US$140 million in 1981 to US$1600 million in 1984. Further, the IBM PC simultaneously established an industry standard during 1982-1983 (p. 257) that most other manufacturers quickly adopted. Technology, knowledge and access to customers rapidly became barriers to entry for new entrants (p. 261). Hence, the IBM PC represented a competence-enhancing discontinuity for the software industry.

The IBM PC standard was replaced in 1990 by Microsoft's Windows 3.0 graphical user interface (GUI) operating on the industry standard platform (p. 280). Earlier attempts at GUI technology had used more expensive hardware than the IBM PC standard, and hence had failed to replace the PC standard. The most successful of these challenges had achieved a peak market share of only ten per cent of the microcomputer installed base (p. 276). The Windows standard platform provided a standard interface, allowing users to more easily learn new applications. The use of GUI software development toolsets simplified the programming of GUI applications and improved development productivity, thereby allowing more sophisticated software to be developed. By 1993 the microcomputer software industry had grown to almost US$7000 million of annual revenues and was growing at 20 per cent per annum (p. 281-2).

The next discontinuity derived from changes in data communications technology. The emergence of the commercial Internet from 1990 (Zakon, 2003) created new applications for computer messaging and information retrieval. However, these new applications only became popularised with the release of Netscape 2.0 in 1994, which provided an integrated web browser, e-mail client and news group reader downloadable from the Internet. Netscape's HTML programming language devalued existing skills and the Internet was used as a new distribution channel. Hence, the Internet represented a competence-destroying discontinuity. In 1998 Microsoft incorporated Internet technology into their latest Windows version, signalling the dominance of Internet technologies.

Finally, in 1999 most remaining mainframe computer systems were replaced by new microcomputer-based software in preparation for the beginning of the year 2000. The year dates in early mainframe software had been abbreviated to two digits and there were widespread predictions of software failure. Consequently, the 'Y2K bug' discontinuity signalled the end of the mainframe era, with remaining mainframes continuing in use as servers for microcomputer networks and for supporting specific large applications currently beyond microcomputer capabilities, and enhancing industry knowledge of large-scale client-server systems.

Nature of the Discontinuities

During its history, software development technology has moved from layout of data storage to code controlling sophisticated computerised operations. While it is not feasible to measure the productive change in terms of programming efficiency in all discontinuities or marketshare captured over time, each of these discontinuities fostered a new dominant technology or technique that displaced the earlier technologies or techniques. Hence, they each represent a change in productivity of at least an order of magnitude (Tushman & Anderson, 1987) for competence-enhancing discontinuities, or devalued established knowledge by elevating new knowledge as the primary driver of wealth creation in the software industry in the case of competence-destroying discontinuities.

The following table lists the discontinuities, which each judged to be competence-enhancing (CE) or competence-destroying (CD) based on whether the discontinuity strengthened or weakened, respectively, the incumbents' control of the industry.

Table 59: Software Discontinuities 1890-2003.

Date	Discontinuity	Type
1890	Punched Cards for data collection	Niche opening
1908	45 column punched card	CE
1928	80 column punched card	CE
1943	First digital computer, paper tape programming	CE
1949	First stored program computer, binary programming	CD
1949	Subroutines invented, reusable code	CE
1951	First real-time computer	CE
1957	First programming language, FORTRAN	CE
1961	First time-sharing computer, multiple access	CE
1964	BASIC developed, users can now program computers	CD
1967	OS/360 first standard platform	CE
1968	Software industry established	CE
1968	Software Engineering invented	CE
1977	First useful microcomputer; small platform	CD
1980	IBM PC-DOS: second standard platform	CE
1990	Windows GUI : third standard platform	CE
1994	Netscape: Internet software, HTML programming	CD
1999	Y2K bug: old systems replaced by client-server systems	CE

Conclusion

The software industry has experienced a total of 17 discontinuous changes over the 114-year since niche opening, of which four, or 24%, were competence destroying and 76% were competence-enhancing. The rate of change averaged approximately one change every 6.3 years.

However, if one splits the industry history by the two eras identified above, i.e. the era when software was incorporated in hardware and when software code was distinct from the computer, then the frequency of change and nature of the discontinuities can be represented as the following table:

Table 60: Frequency of change of software industry 1890-2003

Era Start Date	Software Industry Era	Discontinuity Quantity	Frequency of change	% Competence-enhancing
1890	Hardware incorporating software	3	0.051 p.a.	100%
1949	Separate software code	14	0.254 p.a.	71%

The table shows that the industry has been both more turbulent and has had greater percentage of competence-destroying discontinuities during the second of the two periods, with a rate of change of one discontinuity every 3.9 years compared with one discontinuity every 19.7 years for the first period.

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Case Study: Information Storage Industry

Introduction

Information storage has been used for millennia, with clay tablets, papyrus scrolls and books providing the frontier storage technology at various times. However, all of these technologies required manual interpretation of symbols to convey the stored information. Machine readable information storage was first introduced with the Jacquard loom in 1802 (Campbell-Kelly & Aspray, 1996) and provided the inspiration for the punched cards used in the first automated computing systems.

This case study first reviews the background within which the information storage industry has evolved. Second, the industry's key performance parameter is specified. Third, the discontinuities experienced by the industry are described in chronological order. Fourth, the results are presented in a tabular form as a summary.

Industry Background

The information storage data industry has passed through two eras, equating to the two eras experienced by the software development industry. The first era was characterised by mechanical computers collating data fed by punched cards, or sometimes by paper tape. These computers, originally called tabulating machines, replaced human computers whom had previously manually calculated statistics and scientific calculations. The system's storage and software were intertwined in the same hardware technology. The second era began with the development of the stored program computer in 1949, which separated software and storage.

Information storage technology uses physical devices, with its value derived directly from a complementary product (software) that encompasses increasing returns.

Ohashi (2003) demonstrated that such an industry creates significant indirect network externalities, and hence the information storage exhibits increasing returns in at least the industry's second era.

Industry's Key Performance Parameter

Early storage was provided by quantities of punched cards or paper tape fed into the computer system as it performed its calculations. However, during the industry's second era the information storage industry has been driven by the needs of software for increasing capacity, speed and reliability.

The key performance parameter in the industry has been defined by the capability of information storage products to store information, which can be characterised by the storage density of the products. The more dense information can be stored, the greater the capacity of a product of a given size and, due to smaller distances between the data and the data reading device, the faster the information storage device.

However, the industry has also experienced five platform technologies that defined competition until displaced by the next platform: punched cards, digital tape, moving head fixed disks, removable disk packs and Winchester disks. Hence, the key performance parameter can be defined as storage density within the dominant platform design.

Discontinuities

The information storage industry commenced when the Hollerith tabulating machine was used in the 1890 US Census. The tabulated machine used punched cards containing data on each individual. The recording of data onto punch cards was no faster than alternative manual systems, but the tabulating machine could tabulate the results ten times faster than manual methods (Campbell-Kelly & Aspray, 1996, p. 22-23).

The first discontinuity occurred in 1908 when Hollerith's company, Tabulating Machines Company (TMC), introduced its automatics line using a 45 column card. Each card could now contain 45 digits of numerical information and became established as the industry standard card for twenty years (p. 46).

In 1928 TMC's corporate successor, International Business Machines (IBM), introduced an 80 column card (p. 50) with 78% more capacity than the original card, and hence greater scope for the design of data layout. The 80 column card remained the dominant storage technology for the first digital computers, including the ENIAC that used IBM punched card readers and punches for feeding information and outputting results (p. 97).

The fourth discontinuity was the development of the digital magnetic tape drive for the UNIVAC computer delivered in 1951 (p. 109). The drives used newly developed tape coating materials on a metal tape, to avoid stretching by the high speed servos (p. 109). IBM adopted the tape drive for the IBM model 702, IBM's flagship commercial computer released in 1955 (p. 125), and the tape drive remained the dominant storage and retrieval device until 1963 (Christensen, 1993, p. 532).

The digital tape drive predated the magnetic drums that IBM introduced in 1953 with the IBM model 650, the most common commercial computer in the late 1950s, and enabled higher performance than the magnetic drum - thus the magnetic drum failed to achieve frontier technology status and is not classified as a separate frontier technology, in contradiction to Christensen (1993).

The fifth discontinuity was the development of the moving head, fixed disk drive in 1955. The IBM 350 RAMAC provided the first random access storage device (Rostky, 1998), and thus speeded access to data by avoiding rewriting entire databases to modify one data element. The IBM 350 reversed the earlier paradigm that used fixed heads and moveable media. UNIVAC had a similar drive available for the market by 1956.

Bryant introduced the first disk drive with zoned recording in 1961. The Bryant Computer 4240 had 1320% the storage density of the IBM 350 (Disk/Trend, 2002).

In 1963 IBM introduced the removable disk pack drive, establishing a new platform design that surpassed the capability and flexibility of the moving head, fixed disk drive paradigm (Christensen, 1993, p. 532). The IBM 1311 Low Cost File system was a competence-destroying discontinuity that enabled multiple entrants into the information storage industry (p. 532), despite its slight reduction of 7% in storage density compared with the Bryant 2240 (Disk/Trend, 2002).

The IBM 2310 Ramkit introduced the voice coil actuator in 1965, which provided a 112% improvement in density over the Bryant 2240 (Disk/Trend, 2002). Next, IBM introduced ferrite core heads in the IBM 2314 in 1966, with a 159% improvement in density over the IBM 2310 (Disk/Trend, 2002). Then, in 1971 the IBM 3330-1 Merlin introduced a track following servo system, with a further 243% improvement in density over the IBM 2314.

The IBM 3340 Winchester introduced the next platform technology in 1973, using low mass heads and lubricated disks in a sealed assembly (Rosktky, 1998), which improved reliability and performance. Generically called 'Winchester' disks, the IBM 3340 drives were thirty per cent less expensive than equivalent removable disk pack drives (Christensen, 1993, p. 532) and had 93% greater density than the IBM 3330-1, and hence rapidly displaced the earlier paradigm.

The IBM 3350 introduced fixed disk media in 1976, with a 127% improvement in information density over the IBM 3340.

The IBM 3370 New File Project introduced thin film heads and 2,7 encoding in 1979. IBM had begun exploring thin-film technology in 1965, and as it required new engineering competencies, new manufacturing equipment and a different process flow, Christensen (1997) has described thin film as a competence-destroying discontinuity (p. 536). However, as Christensen (1993) also notes, all new entrants in the later PC hard disk industry that entered with thin film manufacturing failed, while the new entrant survivors all entered the market with ferrite heads and later switched to thin film technology (p. 536). Hence, this evidence suggests that ferrite head experience assisted new entrants to gain market share at a time when it was not necessary to meet the thin film technology's higher fixed costs (Christensen & Raynor, 2003, p.7) to compete in the PC industry, where products are manufactured at 40-50% of the frontier technology's density compared with 75-100% for mainframes and servers (Porter, 2002). Therefore, while the IBM 3370 improved frontier density by 106% over the IBM3350, the embryonic PC disk drive industry had a narrow window of opportunity to enter the industry without utilising the more expensive thin-film manufacturing technology.

In 1979 IBM introduced the IBM 62PC, the first 8inch drive with a density of only 60% of the IBM 3370 (Disk/Trend, 2002). However, while the 8inch hard drive was unattractive for mainframe users, it was targeted at the small minicomputer market that had lower storage requirements and was more cost sensitive than mainframe users (Christensen, 1993, p. 538), By the end of 1979 six firms were offering 8inch drives, of which four were entrants. The result was a new market distinct from the mainstream hard drive market, but as the 8inch drives improved at a rate of 50% per annum (p. 539), the drives began to displace larger sized drives from the bottom end of the mainframe market. Hence, as the 8inch drives improved their capacity at a faster rate than customer requirements, the 8inch drives threatened the incumbents access to existing and new customers, thus creating a market disruption (Abernathy & Clark, 1985; Christensen, 1993, p. 539) and threatened the incumbent's access to resources, creating the conditions for revolutionary change (Gersick, 1991).

In 1980 Seagate Technology introduced the ST506 5.25inch disk drive, the first drive configured to the standard size of the floppy, or flexible, disk drives introduced by Shugart Associates in 1976 (Disk/Trend, 2002) and used in early microcomputers. The ST506's low capacity and density of 11% of the IBM 3370 was unattractive to the mainframe and minicomputer market, but the drive's size and relatively low cost was attractive to the new microcomputer market. The release of the IBM PC in 1981 legitimised the microcomputer and created an industry standard microcomputer design (Campbell-Kelly & Aspray, 1996, p. 255), thus defining the new market. Hence, like the 8inch drives, the 5.25inch drives accessed a new market and by improving drive size at a similar rate to 8inch drives (Christensen, 1993), entered the lower end of the 8inch drive market. Therefore, the 5.25inch drive created a second market disruption.

In 1983 the first 3.5inch disk drive was introduced by Rodtime, with their RO352 model (Disk/Trend, 2002). The 3.5inch drive was more rugged than the 5.25inch drive, and its small size enabled it to be fitted into the new portable computer market. Hence, by accessing a different market with different attributes, but with a similar improvement rate to 8inch and 5.25inch hard drives, the 3.5inch drive created a third market disruption (Christensen, 1993) and gradually displaced the larger drives from the microcomputer market.

In 1986 Conner Peripherals introduced the CP340, the first 3.5inch disk drive with voice coil actuators. The CP340 had 90% greater density than the immediately preceding technology and 292% greater than the IBM 3370 (Disk/Trend, 2002).

IBM released the IBM 0663 Corsair 3.5inch drive in 1991, the first drive with magnetoresistive heads and featuring a density 291% greater than the immediately preceding technology and 528% greater than the CP340 (Disk/Trend, 2002).

The first 3inch rigid disk drive, the JTS N0640-2Arm was released in 1995. However, the 3inch and 2.5inch drives were targeted at laptop computers manufacturers, which represented the same market as the original 3.5inch drive market. As a result, the 3.5inch manufacturers rapidly entered the market

(Christensen, 1993) and there was no market disruption. The JTS drive had a density 104% greater than the immediately preceding technology and 248% greater than the IBM 0663 drive (Disk/Trend, 2002).

IBM then introduced the IBM Deskstar 16GP Titan 3.5inch hard drive in 1997 with giant magnetoresistive heads and 669% greater density than the JTS 3inch drive (Disk/Trend, 2002).

Finally, in 2000 Seagate Technologies released the first 15,000 rpm drive, the Cheetah X15, with a 188% improvement in density over the preceding technology and 257% greater than the IBM Deskstar 16GP (Disk/Trend, 2002).

Nature of the Discontinuities

Each of the discontinuities identified represented a change in the dominant design paradigm, and improvement of the key performance parameter of at least 90% or a market disruption. The dominant paradigms represent the five distinct designs that defined competition during their period and enabled new competition to enter in their early stages, and hence were competence-destroying discontinuities. Tushman and Anderson (1986) identified an order of magnitude as a test for competence-enhancing discontinuities and the 90% test had been adopted to include the Conner Peripherals CP340 as it dominated the industry in its time. Market disruptions have been identified by Abernathy and Clark (1985) as creating conditions for change, while Christensen (1993) and Bower and Christensen (1995) identified that change of markets can cause radical change when the disruption occurs in a new market and has an ability to invade an existing market over time with technological improvement.

Hence, the following table lists the discontinuities, which each judged to be competence-enhancing (CE), competence-destroying (CD) and market disruption (MD), based on whether the discontinuity strengthened or weakened the incumbents' control of the industry, or created a new market with potential to invade the established market.

Table 61: Information Storage Discontinuities 1890-2002.

Date	Discontinuity	% Improvement	Type
1890	Punched Cards for data collection		Niche opening
1908	45 column punched card		CE
1928	80 column punched card	78%	CE
1951	Digital Magnetic Tape Drive		CD
1961	Zoned Recording	1700%	CE
1963	Removable Disk Pack	-7%	CD
1965	Voice Coil Actuator	112%	CE
1966	Ferrite Core Heads	159%	CE
1971	Track following servo system	243%	CE
1973	Winchester Disk	93%	CD
1976	Fixed Disk media	127%	CE
1979	Thin Film heads	106%	CE
1979	8inch Drives		MD
1980	5.25inch Drives		MD
1983	3.5inch Drives		MD
1986	Voice coil actuator 3.5inch drive	90%	CE
1991	Magnetoresistive heads	291%	CE
1995	3inch rigid disk drive	104%	CE
1997	Giant magnetoresistive heads	669%	CE
2000	15,000 rpm hard drives	188%	CE

Conclusion

The storage industry has experienced a total of 19 of discontinuous changes over the 113-year since niche opening, of which seven , or 36.8%, were competence destroying or market disrupting and 63.2% were competence-enhancing. The rate of change averaged approximately one change every 5.9 years.

However, if one splits the industry history by the two eras identified above, i.e. the era when software and storage were both integrated in hardware and when software and storage were independent, then the frequency of change and nature of the discontinuities can be represented as per the following table:

Table 62: Frequency of change of software industry 1890-2003

Era Start Date	Information Storage Industry Era	Discontinuity Quantity	Frequency of change	% Competence-enhancing
1890	Hardware incorporating software and storage	2	0.034 p.a.	100%
1949	Separate software and storage	17	0.314 p.a.	61.1%

The table shows that the industry has been both more turbulent and has had a reduced percentage of competence enhancing change during the second period, with a rate of change of one discontinuity every 3.2 years compared with one discontinuity every 29.5 years for the first period.

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Data

DataSets

Total Discontinuities

The dataset for total discontinuities is listed in the following table.

Table 63: Total Discontinuities

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1791			1	1					
1792			0	0					
1793			0	0					
1794			0	0					
1795			0	0					
1796			0	0					
1797			0	0					
1798			0	0					
1799			0	1					
1800			0	1					
1801			0	0					
1802			0	0					
1803			0	0					
1804			0	0					
1805			0	0					
1806			0	0					
1807			0	0		1	1		
1808			0	0		0	0		
1809			0	0		0	0		
1810			0	0		0	0		
1811			0	0		0	0		
1812			0	0		0	0		
1813			0	0		0	0		
1814			0	0		0	0		
1815			0	0		0	0		
1816			0	0		0	0		
1817			0	0		0	0		

1818			0	0		0	0			
1819			0	0		0	1			
1820			0	0		0	0			
1821			0	0		0	0			
1822			0	0		0	0			
1823			0	0		1	0			
1824			0	0		0	0			
1825			0	0		0	0			
1826			0	0		0	0			
1827			0	0		0	0			
1828			0	0		0	0			
1829			0	0		0	0			
1830			0	0		0	1			
1831			0	0		0	0			
1832			0	0		0	0			
1833			0	0		0	0			
1834			0	0		0	0			
1835			0	0		1	0			
1836			0	0		0	0			
1837			1	0		1	0			
1838			1	0		1	0			
1839			0	0		0	0			
1840			0	0		1	0			
1841			0	0		1	0			
1842			0	0		0	0			
1843			0	0		0	0			
1844			0	0		1	0			
1845			0	0		0	0			
1846			0	0		0	0			
1847			0	0		0	0			
1848			0	0		0	0			
1849			0	0		0	0			
1850			0	0		0	0			
1851			0	0		1	0			
1852			0	0		0	0			
1853			0	0		0	0			
1854			0	0		1	0			
1855			0	0		0	0			
1856			0	0		0	0			
1857			0	0		0	0			
1858			0	0		0	0			
1859			0	0		0	0			
1860			0	0		0	1			
1861			0	0		0	0			
1862			0	0		0	0			
1863			0	0		0	0			
1864			0	0		0	0			
1865			0	0		0	0			
1866			0	0		0	0			
1867			0	0		1	0			
1868			0	0		0	0			
1869			0	0		1	0			

1870			0	0	1	0	0		
1871			1	0	0	0	0		
1872			0	0	0	0	0		
1873			1	0	0	0	0		
1874			0	0	0	0	0		
1875			0	0	0	0	0		
1876			0	0	0	0	0		
1877			0	0	0	1	1		
1878			0	0	0	0	0		
1879			0	0	0	0	0		
1880			0	0	0	0	0		
1881			0	1	1	0	0		
1882			0	0	2	0	0		
1883			1	0	1	0	0		
1884			0	0	0	0	0		
1885			0	0	0	0	0		
1886			0	0	1	1	0		
1887			0	1	0	0	1		
1888			0	0	0	0	0		
1889			0	0	0	0	0		
1890			0	0	1	0	0	1	1
1891			0	0	0	0	0	0	0
1892			0	0	1	0	0	0	0
1893			0	0	0	0	0	0	0
1894			0	0	0	0	0	0	0
1895			0	0	0	0	0	0	0
1896			0	0	0	0	0	0	0
1897			0	1	0	1	0	0	0
1898			0	0	0	0	0	0	0
1899			0	0	0	0	0	0	0
1900			0	0	0	0	0	0	0
1901			0	0	0	0	0	0	0
1902			0	0	0	0	0	0	0
1903			0	0	1	0	0	0	0
1904			0	0	0	0	0	0	0
1905			0	0	0	0	0	0	0
1906			0	0	0	0	0	0	0
1907			0	0	0	0	0	0	0
1908			0	0	0	2	1	1	1
1909			0	0	0	0	1	0	0
1910			0	0	0	0	0	0	0
1911			0	0	0	0	0	0	0
1912			0	0	0	0	0	0	0
1913			0	3	0	0	0	0	0
1914			0	0	1	0	0	0	0
1915			0	0	0	0	0	0	0
1916			0	0	0	0	0	0	0
1917			0	0	0	0	0	0	0
1918			0	0	0	0	0	0	0
1919	2	1	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	1	0	0
1921	0	0	0	0	0	0	0	0	0

1922	0	0	0	0	0	0	0	0	0
1923	0	0	0	0	0	0	0	0	0
1924	0	1	0	1	0	0	0	0	0
1925	1	0	1	0	0	0	0	0	0
1926	0	0	0	0	2	0	0	0	0
1927	0	0	0	0	0	1	0	0	0
1928	0	0	0	0	0	1	0	1	1
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0
1933	1	1	0	0	0	0	0	0	0
1934	0	0	0	0	0	1	0	0	0
1935	0	0	0	0	0	0	0	0	0
1936	1	0	1	0	0	0	0	0	0
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1938	0	0	0	0	0	0	0	0	0
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1942	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	1	0
1944	0	0	0	0	0	0	0	0	0
1945	0	0	1	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0
1947	0	0	0	1	0	0	0	0	0
1948	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	2	0
1950	0	0	1	0	1	0	1	0	0
1951	1	0	0	0	0	0	0	1	1
1952	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	1	0	0
1956	0	0	0	0	1	0	0	0	0
1957	0	0	0	0	0	0	0	1	0
1958	1	0	0	0	1	1	0	0	0
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1960	0	0	0	0	0	0	1	0	0
1961	0	0	0	0	0	1	0	1	1
1962	0	0	0	1	1	0	0	0	0
1963	0	0	0	0	0	0	0	0	1
1964	0	0	0	0	0	0	0	1	0
1965	0	0	0	0	1	0	0	0	1
1966	0	0	0	0	0	0	0	0	1
1967	0	0	0	0	0	0	0	1	0
1968	0	0	0	0	0	1	0	2	0
1969	1	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	1
1972	0	0	0	0	0	0	0	0	0
1973	1	0	0	0	0	0	0	0	1

1974	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	1
1977	0	0	1	0	0	0	0	1	0
1978	0	0	0	1	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	2
1980	0	0	1	0	0	0	0	1	1
1981	0	0	0	0	0	0	0	0	0
1982	0	0	1	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	1
1984	0	0	0	0	0	0	0	0	0
1985	1	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	1
1987	0	0	1	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	1	0	0	0	0
1990	0	1	1	0	0	1	1	1	0
1991	0	0	0	0	0	0	0	0	1
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	1	0	0	0	0	1	0
1995	0	0	1	0	0	0	0	0	1
1996	1	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	1
1998	0	0	2	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	1	0
2000	0	0	0	0	0	1	0	0	1
2001	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0
2003	0	0	1	0	1	0	0	0	0
2004						0			
2005						1			

Competence-Destroying Discontinuities

The dataset for competence-destroying discontinuities is listed in the following table.

Table 64: Competence-Destroying Discontinuities

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1791			1	1					
1792			0	0					
1793			0	0					
1794			0	0					
1795			0	0					
1796			0	0					
1797			0	0					
1798			0	0					
1799			0	0					
1800			0	0					
1801			0	0					
1802			0	0					
1803			0	0					
1804			0	0					
1805			0	0					
1806			0	0					
1807			0	0		1	1		
1808			0	0		0	0		
1809			0	0		0	0		
1810			0	0		0	0		
1811			0	0		0	0		
1812			0	0		0	0		
1813			0	0		0	0		
1814			0	0		0	0		
1815			0	0		0	0		
1816			0	0		0	0		
1817			0	0		0	0		
1818			0	0		0	0		
1819			0	0		0	0		
1820			0	0		0	0		
1821			0	0		0	0		
1822			0	0		0	0		

1823			0	0		0	0		
1824			0	0		0	0		
1825			0	0		0	0		
1826			0	0		0	0		
1827			0	0		0	0		
1828			0	0		0	0		
1829			0	0		0	0		
1830			0	0		0	0		
1831			0	0		0	0		
1832			0	0		0	0		
1833			0	0		0	0		
1834			0	0		0	0		
1835			0	0		0	0		
1836			0	0		0	0		
1837			1	0		1	0		
1838			0	0		0	0		
1839			0	0		0	0		
1840			0	0		0	0		
1841			0	0		0	0		
1842			0	0		0	0		
1843			0	0		0	0		
1844			0	0		0	0		
1845			0	0		0	0		
1846			0	0		0	0		
1847			0	0		0	0		
1848			0	0		0	0		
1849			0	0		0	0		
1850			0	0		0	0		
1851			0	0		0	0		
1852			0	0		0	0		
1853			0	0		0	0		
1854			0	0		0	0		
1855			0	0		0	0		
1856			0	0		0	0		
1857			0	0		0	0		
1858			0	0		0	0		
1859			0	0		0	0		
1860			0	0		0	0		
1861			0	0		0	0		
1862			0	0		0	0		
1863			0	0		0	0		
1864			0	0		0	0		
1865			0	0		0	0		
1866			0	0		0	0		
1867			0	0		0	0		
1868			0	0		0	0		
1869			0	0		0	0		
1870			0	0	1	0	0		
1871			0	0	0	0	0		
1872			0	0	0	0	0		
1873			0	0	0	0	0		
1874			0	0	0	0	0		

1875			0	0	0	0	0		
1876			0	0	0	0	0		
1877			0	0	0	0	0		
1878			0	0	0	0	0		
1879			0	0	0	0	0		
1880			0	0	0	0	0		
1881			0	0	0	0	0		
1882			0	0	0	0	0		
1883			0	0	0	0	0		
1884			0	0	0	0	0		
1885			0	0	0	0	0		
1886			0	0	1	0	0		
1887			0	0	0	0	0		
1888			0	0	0	0	0		
1889			0	0	0	0	0		
1890			0	0	0	0	0	1	1
1891			0	0	0	0	0	0	0
1892			0	0	0	0	0	0	0
1893			0	0	0	0	0	0	0
1894			0	0	0	0	0	0	0
1895			0	0	0	0	0	0	0
1896			0	0	0	0	0	0	0
1897			0	0	0	0	0	0	0
1898			0	0	0	0	0	0	0
1899			0	0	0	0	0	0	0
1900			0	0	0	0	0	0	0
1901			0	0	0	0	0	0	0
1902			0	0	0	0	0	0	0
1903			0	0	0	0	0	0	0
1904			0	0	0	0	0	0	0
1905			0	0	0	0	0	0	0
1906			0	0	0	0	0	0	0
1907			0	0	0	0	0	0	0
1908			0	0	0	0	0	0	0
1909			0	0	0	0	1	0	0
1910			0	0	0	0	0	0	0
1911			0	0	0	0	0	0	0
1912			0	0	0	0	0	0	0
1913			0	1	0	0	0	0	0
1914			0	0	0	0	0	0	0
1915			0	0	0	0	0	0	0
1916			0	0	0	0	0	0	0
1917			0	0	0	0	0	0	0
1918			0	0	0	0	0	0	0
1919	1	1	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	1	0	0
1921	0	0	0	0	0	0	0	0	0
1922	0	0	0	0	0	0	0	0	0
1923	0	0	0	0	0	0	0	0	0
1924	0	0	0	0	0	0	0	0	0
1925	0	0	0	0	0	0	0	0	0
1926	0	0	0	0	0	0	0	0	0

1927	0	0	0	0	0	1	0	0	0
1928	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0
1933	0	1	0	0	0	0	0	0	0
1934	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0
1937	0	0	0	0	0	0	0	0	0
1938	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	0
1940	0	0	0	0	0	0	0	0	0
1941	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0
1947	0	0	0	1	0	0	0	0	0
1948	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	1	0
1950	0	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0	1
1952	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0
1957	0	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	1	0	0	0
1959	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	1
1964	0	0	0	0	0	0	0	1	0
1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	1
1974	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	1	0
1978	0	0	0	1	0	0	0	0	0

1979	0	0	0	0	0	0	0	0	1
1980	0	0	1	0	0	0	0	0	1
1981	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	1
1984	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0
1990	0	0	1	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	1	0
1995	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0
2004						0			
2005						0			

Competence-Enhancing Discontinuities

The dataset for competence-enhancing discontinuities is listed in the following table.

Table 65: Competence-Enhancing Discontinuities

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1791			0	0					
1792			0	0					
1793			0	0					
1794			0	0					
1795			0	0					
1796			0	0					
1797			0	0					
1798			0	0					
1799			0	1					
1800			0	1					
1801			0	0					
1802			0	0					
1803			0	0					
1804			0	0					
1805			0	0					
1806			0	0					
1807			0	0		0	0		
1808			0	0		0	0		
1809			0	0		0	0		
1810			0	0		0	0		
1811			0	0		0	0		
1812			0	0		0	0		
1813			0	0		0	0		
1814			0	0		0	0		
1815			0	0		0	0		
1816			0	0		0	0		
1817			0	0		0	0		
1818			0	0		0	0		
1819			0	0		0	1		
1820			0	0		0	0		
1821			0	0		0	0		
1822			0	0		0	0		

1823			0	0		1	0		
1824			0	0		0	0		
1825			0	0		0	0		
1826			0	0		0	0		
1827			0	0		0	0		
1828			0	0		0	0		
1829			0	0		0	0		
1830			0	0		0	1		
1831			0	0		0	0		
1832			0	0		0	0		
1833			0	0		0	0		
1834			0	0		0	0		
1835			0	0		1	0		
1836			0	0		0	0		
1837			0	0		0	0		
1838			1	0		1	0		
1839			0	0		0	0		
1840			0	0		1	0		
1841			0	0		1	0		
1842			0	0		0	0		
1843			0	0		0	0		
1844			0	0		1	0		
1845			0	0		0	0		
1846			0	0		0	0		
1847			0	0		0	0		
1848			0	0		0	0		
1849			0	0		0	0		
1850			0	0		0	0		
1851			0	0		1	0		
1852			0	0		0	0		
1853			0	0		0	0		
1854			0	0		1	0		
1855			0	0		0	0		
1856			0	0		0	0		
1857			0	0		0	0		
1858			0	0		0	0		
1859			0	0		0	0		
1860			0	0		0	1		
1861			0	0		0	0		
1862			0	0		0	0		
1863			0	0		0	0		
1864			0	0		0	0		
1865			0	0		0	0		
1866			0	0		0	0		
1867			0	0		1	0		
1868			0	0		0	0		
1869			0	0		1	0		
1870			0	0	0	0	0		
1871			1	0	0	0	0		
1872			0	0	0	0	0		
1873			1	0	0	0	0		
1874			0	0	0	0	0		

1875			0	0	0	0	0		
1876			0	0	0	0	0		
1877			0	0	0	1	1		
1878			0	0	0	0	0		
1879			0	0	0	0	0		
1880			0	0	0	0	0		
1881			0	1	1	0	0		
1882			0	0	2	0	0		
1883			1	0	1	0	0		
1884			0	0	0	0	0		
1885			0	0	0	0	0		
1886			0	0	0	1	0		
1887			0	1	0	0	1		
1888			0	0	0	0	0		
1889			0	0	0	0	0		
1890			0	0	1	0	0	0	0
1891			0	0	0	0	0	0	0
1892			0	0	1	0	0	0	0
1893			0	0	0	0	0	0	0
1894			0	0	0	0	0	0	0
1895			0	0	0	0	0	0	0
1896			0	0	0	0	0	0	0
1897			0	1	0	1	0	0	0
1898			0	0	0	0	0	0	0
1899			0	0	0	0	0	0	0
1900			0	0	0	0	0	0	0
1901			0	0	0	0	0	0	0
1902			0	0	0	0	0	0	0
1903			0	0	1	0	0	0	0
1904			0	0	0	0	0	0	0
1905			0	0	0	0	0	0	0
1906			0	0	0	0	0	0	0
1907			0	0	0	0	0	0	0
1908			0	0	0	2	1	1	1
1909			0	0	0	0	0	0	0
1910			0	0	0	0	0	0	0
1911			0	0	0	0	0	0	0
1912			0	0	0	0	0	0	0
1913			0	2	0	0	0	0	0
1914			0	0	1	0	0	0	0
1915			0	0	0	0	0	0	0
1916			0	0	0	0	0	0	0
1917			0	0	0	0	0	0	0
1918			0	0	0	0	0	0	0
1919	1	0	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	0	0	0
1921	0	0	0	0	0	0	0	0	0
1922	0	0	0	0	0	0	0	0	0
1923	0	0	0	0	0	0	0	0	0
1924	0	1	0	1	0	0	0	0	0
1925	1	0	1	0	0	0	0	0	0
1926	0	0	0	0	2	0	0	0	0

1927	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	1	0	1	1
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0
1933	1	0	0	0	0	0	0	0	0
1934	0	0	0	0	0	1	0	0	0
1935	0	0	0	0	0	0	0	0	0
1936	1	0	1	0	0	0	0	0	0
1937	0	0	0	0	0	0	0	0	0
1938	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	0
1940	0	1	1	0	0	0	2	0	0
1941	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	1	0
1944	0	0	0	0	0	0	0	0	0
1945	0	0	1	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0
1948	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	1	0
1950	0	0	1	0	1	0	1	0	0
1951	1	0	0	0	0	0	0	1	0
1952	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	1	0	0
1956	0	0	0	0	1	0	0	0	0
1957	0	0	0	0	0	0	0	1	0
1958	1	0	0	0	1	0	0	0	0
1959	0	0	0	0	0	0	1	0	0
1960	0	0	0	0	0	0	1	0	0
1961	0	0	0	0	0	1	0	1	1
1962	0	0	0	1	1	0	0	0	0
1963	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	1	0	0	0	1
1966	0	0	0	0	0	0	0	0	1
1967	0	0	0	0	0	0	0	1	0
1968	0	0	0	0	0	1	0	2	0
1969	1	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	1
1972	0	0	0	0	0	0	0	0	0
1973	1	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	1
1977	0	0	1	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0

1979	0	0	0	0	0	0	0	0	1
1980	0	0	0	0	0	0	0	1	0
1981	0	0	0	0	0	0	0	0	0
1982	0	0	1	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0
1985	1	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	1
1987	0	0	1	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	1	0	0	0	0
1990	0	1	0	0	0	1	1	1	0
1991	0	0	0	0	0	0	0	0	1
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	1	0	0	0	0	0	0
1995	0	0	1	0	0	0	0	0	1
1996	1	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	1
1998	0	0	2	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	1	0
2000	0	0	0	0	0	1	0	0	1
2001	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0
2003	0	0	1	0	1	0	0	0	0
2004						0			
2005						1			

Dichotomous Datasets

Total Discontinuities - Dichotomous

The dichotomous version of the dataset for total discontinuities is listed in the following table.

Table 66: Total Discontinuities - dichotomous

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1791			1	1					
1792			0	0					
1793			0	0					
1794			0	0					
1795			0	0					
1796			0	0					
1797			0	0					
1798			0	0					
1799			0	1					
1800			0	1					
1801			0	0					
1802			0	0					
1803			0	0					
1804			0	0					
1805			0	0					
1806			0	0					
1807			0	0		1	1		
1808			0	0		0	0		
1809			0	0		0	0		
1810			0	0		0	0		
1811			0	0		0	0		
1812			0	0		0	0		
1813			0	0		0	0		
1814			0	0		0	0		
1815			0	0		0	0		
1816			0	0		0	0		
1817			0	0		0	0		
1818			0	0		0	0		

1819			0	0		0	1		
1820			0	0		0	0		
1821			0	0		0	0		
1822			0	0		0	0		
1823			0	0		1	0		
1824			0	0		0	0		
1825			0	0		0	0		
1826			0	0		0	0		
1827			0	0		0	0		
1828			0	0		0	0		
1829			0	0		0	0		
1830			0	0		0	1		
1831			0	0		0	0		
1832			0	0		0	0		
1833			0	0		0	0		
1834			0	0		0	0		
1835			0	0		1	0		
1836			0	0		0	0		
1837			1	0		1	0		
1838			1	0		1	0		
1839			0	0		0	0		
1840			0	0		1	0		
1841			0	0		1	0		
1842			0	0		0	0		
1843			0	0		0	0		
1844			0	0		1	0		
1845			0	0		0	0		
1846			0	0		0	0		
1847			0	0		0	0		
1848			0	0		0	0		
1849			0	0		0	0		
1850			0	0		0	0		
1851			0	0		1	0		
1852			0	0		0	0		
1853			0	0		0	0		
1854			0	0		1	0		
1855			0	0		0	0		
1856			0	0		0	0		
1857			0	0		0	0		
1858			0	0		0	0		
1859			0	0		0	0		
1860			0	0		0	1		
1861			0	0		0	0		
1862			0	0		0	0		
1863			0	0		0	0		
1864			0	0		0	0		
1865			0	0		0	0		
1866			0	0		0	0		
1867			0	0		1	0		
1868			0	0		0	0		
1869			0	0		1	0		
1870			0	0	1	0	0		

1871			1	0	0	0	0		
1872			0	0	0	0	0		
1873			1	0	0	0	0		
1874			0	0	0	0	0		
1875			0	0	0	0	0		
1876			0	0	0	0	0		
1877			0	0	0	1	1		
1878			0	0	0	0	0		
1879			0	0	0	0	0		
1880			0	0	0	0	0		
1881			0	1	1	0	0		
1882			0	0	1	0	0		
1883			1	0	1	0	0		
1884			0	0	0	0	0		
1885			0	0	0	0	0		
1886			0	0	1	1	0		
1887			0	1	0	0	1		
1888			0	0	0	0	0		
1889			0	0	0	0	0		
1890			0	0	1	0	0	1	1
1891			0	0	0	0	0	0	0
1892			0	0	1	0	0	0	0
1893			0	0	0	0	0	0	0
1894			0	0	0	0	0	0	0
1895			0	0	0	0	0	0	0
1896			0	0	0	0	0	0	0
1897			0	1	0	1	0	0	0
1898			0	0	0	0	0	0	0
1899			0	0	0	0	0	0	0
1900			0	0	0	0	0	0	0
1901			0	0	0	0	0	0	0
1902			0	0	0	0	0	0	0
1903			0	0	1	0	0	0	0
1904			0	0	0	0	0	0	0
1905			0	0	0	0	0	0	0
1906			0	0	0	0	0	0	0
1907			0	0	0	0	0	0	0
1908			0	0	0	1	1	1	1
1909			0	0	0	0	1	0	0
1910			0	0	0	0	0	0	0
1911			0	0	0	0	0	0	0
1912			0	0	0	0	0	0	0
1913			0	1	0	0	0	0	0
1914			0	0	1	0	0	0	0
1915			0	0	0	0	0	0	0
1916			0	0	0	0	0	0	0
1917			0	0	0	0	0	0	0
1918			0	0	0	0	0	0	0
1919	1	1	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	1	0	0
1921	0	0	0	0	0	0	0	0	0
1922	0	0	0	0	0	0	0	0	0

1923	0	0	0	0	0	0	0	0	0
1924	0	1	0	1	0	0	0	0	0
1925	1	0	1	0	0	0	0	0	0
1926	0	0	0	0	1	0	0	0	0
1927	0	0	0	0	0	1	0	0	0
1928	0	0	0	0	0	1	0	1	1
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0
1933	1	1	0	0	0	0	0	0	0
1934	0	0	0	0	0	1	0	0	0
1935	0	0	0	0	0	0	0	0	0
1936	1	0	1	0	0	0	0	0	0
1937	0	0	0	0	0	0	0	0	0
1938	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	0
1940	0	1	1	0	0	0	1	0	0
1941	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	1	0
1944	0	0	0	0	0	0	0	0	0
1945	0	0	1	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0
1947	0	0	0	1	0	0	0	0	0
1948	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	1	0
1950	0	0	1	0	1	0	1	0	0
1951	1	0	0	0	0	0	0	1	1
1952	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	1	0	0
1956	0	0	0	0	1	0	0	0	0
1957	0	0	0	0	0	0	0	1	0
1958	1	0	0	0	1	1	0	0	0
1959	0	0	0	0	0	0	1	0	0
1960	0	0	0	0	0	0	1	0	0
1961	0	0	0	0	0	1	0	1	1
1962	0	0	0	1	1	0	0	0	0
1963	0	0	0	0	0	0	0	0	1
1964	0	0	0	0	0	0	0	1	0
1965	0	0	0	0	1	0	0	0	1
1966	0	0	0	0	0	0	0	0	1
1967	0	0	0	0	0	0	0	1	0
1968	0	0	0	0	0	1	0	1	0
1969	1	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	1
1972	0	0	0	0	0	0	0	0	0
1973	1	0	0	0	0	0	0	0	1
1974	0	0	0	0	0	0	0	0	0

1975	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	1
1977	0	0	1	0	0	0	0	1	0
1978	0	0	0	1	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	1
1980	0	0	1	0	0	0	0	1	1
1981	0	0	0	0	0	0	0	0	0
1982	0	0	1	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	1
1984	0	0	0	0	0	0	0	0	0
1985	1	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	1
1987	0	0	1	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	1	0	0	0	0
1990	0	1	1	0	0	1	1	1	0
1991	0	0	0	0	0	0	0	0	1
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	1	0	0	0	0	1	0
1995	0	0	1	0	0	0	0	0	1
1996	1	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	1
1998	0	0	1	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	1	0
2000	0	0	0	0	0	1	0	0	1
2001	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0
2003	0	0	1	0	1	0	0	0	0
2004						0			
2005						1			

Competence-Destroying Discontinuities - Dichotomous

The dichotomous form of the dataset for competence-destroying discontinuities is listed in the following table.

Table 67: Competence-Destroying Discontinuities - dichotomous

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1791			1	1					
1792			0	0					
1793			0	0					
1794			0	0					
1795			0	0					
1796			0	0					
1797			0	0					
1798			0	0					
1799			0	0					
1800			0	0					
1801			0	0					
1802			0	0					
1803			0	0					
1804			0	0					
1805			0	0					
1806			0	0					
1807			0	0		1	1		
1808			0	0		0	0		
1809			0	0		0	0		
1810			0	0		0	0		
1811			0	0		0	0		
1812			0	0		0	0		
1813			0	0		0	0		
1814			0	0		0	0		
1815			0	0		0	0		
1816			0	0		0	0		
1817			0	0		0	0		
1818			0	0		0	0		
1819			0	0		0	0		
1820			0	0		0	0		
1821			0	0		0	0		

1822			0	0		0	0		
1823			0	0		0	0		
1824			0	0		0	0		
1825			0	0		0	0		
1826			0	0		0	0		
1827			0	0		0	0		
1828			0	0		0	0		
1829			0	0		0	0		
1830			0	0		0	0		
1831			0	0		0	0		
1832			0	0		0	0		
1833			0	0		0	0		
1834			0	0		0	0		
1835			0	0		0	0		
1836			0	0		0	0		
1837			1	0		1	0		
1838			0	0		0	0		
1839			0	0		0	0		
1840			0	0		0	0		
1841			0	0		0	0		
1842			0	0		0	0		
1843			0	0		0	0		
1844			0	0		0	0		
1845			0	0		0	0		
1846			0	0		0	0		
1847			0	0		0	0		
1848			0	0		0	0		
1849			0	0		0	0		
1850			0	0		0	0		
1851			0	0		0	0		
1852			0	0		0	0		
1853			0	0		0	0		
1854			0	0		0	0		
1855			0	0		0	0		
1856			0	0		0	0		
1857			0	0		0	0		
1858			0	0		0	0		
1859			0	0		0	0		
1860			0	0		0	0		
1861			0	0		0	0		
1862			0	0		0	0		
1863			0	0		0	0		
1864			0	0		0	0		
1865			0	0		0	0		
1866			0	0		0	0		
1867			0	0		0	0		
1868			0	0		0	0		
1869			0	0		0	0		
1870			0	0	1	0	0		
1871			0	0	0	0	0		
1872			0	0	0	0	0		
1873			0	0	0	0	0		

1874			0	0	0	0	0		
1875			0	0	0	0	0		
1876			0	0	0	0	0		
1877			0	0	0	0	0		
1878			0	0	0	0	0		
1879			0	0	0	0	0		
1880			0	0	0	0	0		
1881			0	0	0	0	0		
1882			0	0	0	0	0		
1883			0	0	0	0	0		
1884			0	0	0	0	0		
1885			0	0	0	0	0		
1886			0	0	1	0	0		
1887			0	0	0	0	0		
1888			0	0	0	0	0		
1889			0	0	0	0	0		
1890			0	0	0	0	0	1	1
1891			0	0	0	0	0	0	0
1892			0	0	0	0	0	0	0
1893			0	0	0	0	0	0	0
1894			0	0	0	0	0	0	0
1895			0	0	0	0	0	0	0
1896			0	0	0	0	0	0	0
1897			0	0	0	0	0	0	0
1898			0	0	0	0	0	0	0
1899			0	0	0	0	0	0	0
1900			0	0	0	0	0	0	0
1901			0	0	0	0	0	0	0
1902			0	0	0	0	0	0	0
1903			0	0	0	0	0	0	0
1904			0	0	0	0	0	0	0
1905			0	0	0	0	0	0	0
1906			0	0	0	0	0	0	0
1907			0	0	0	0	0	0	0
1908			0	0	0	0	0	0	0
1909			0	0	0	0	1	0	0
1910			0	0	0	0	0	0	0
1911			0	0	0	0	0	0	0
1912			0	0	0	0	0	0	0
1913			0	1	0	0	0	0	0
1914			0	0	0	0	0	0	0
1915			0	0	0	0	0	0	0
1916			0	0	0	0	0	0	0
1917			0	0	0	0	0	0	0
1918			0	0	0	0	0	0	0
1919	1	1	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	1	0	0
1921	0	0	0	0	0	0	0	0	0
1922	0	0	0	0	0	0	0	0	0
1923	0	0	0	0	0	0	0	0	0
1924	0	0	0	0	0	0	0	0	0
1925	0	0	0	0	0	0	0	0	0

1926	0	0	0	0	0	0	0	0	0
1927	0	0	0	0	0	1	0	0	0
1928	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0
1933	0	1	0	0	0	0	0	0	0
1934	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0
1937	0	0	0	0	0	0	0	0	0
1938	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	0
1940	0	0	0	0	0	0	0	0	0
1941	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0
1947	0	0	0	1	0	0	0	0	0
1948	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	1	0
1950	0	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0	1
1952	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0
1957	0	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	1	0	0	0
1959	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	1
1964	0	0	0	0	0	0	0	1	0
1965	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	1
1974	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	1	0

1978	0	0	0	1	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	1
1980	0	0	1	0	0	0	0	0	1
1981	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	1
1984	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0
1990	0	0	1	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	1	0
1995	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0
2004						0			
2005						0			

Competence-Enhancing Discontinuities – Dichotomous

The dichotomous form of the dataset for competence-enhancing discontinuities is listed in the following table.

Table 68: Competence-Enhancing Discontinuities

Year	Airlines	Aircraft Manufacturing	Data Telecommunications	Telecommunications Manufacturing	Electricity	Shipping Lines	Ship Building	Software	Information Storage
1791			0	0					
1792			0	0					
1793			0	0					
1794			0	0					
1795			0	0					
1796			0	0					
1797			0	0					
1798			0	0					
1799			0	1					
1800			0	1					
1801			0	0					
1802			0	0					
1803			0	0					
1804			0	0					
1805			0	0					
1806			0	0					
1807			0	0		0	0		
1808			0	0		0	0		
1809			0	0		0	0		
1810			0	0		0	0		
1811			0	0		0	0		
1812			0	0		0	0		
1813			0	0		0	0		
1814			0	0		0	0		
1815			0	0		0	0		
1816			0	0		0	0		
1817			0	0		0	0		
1818			0	0		0	0		
1819			0	0		0	1		
1820			0	0		0	0		
1821			0	0		0	0		

1822			0	0		0	0			
1823			0	0		1	0			
1824			0	0		0	0			
1825			0	0		0	0			
1826			0	0		0	0			
1827			0	0		0	0			
1828			0	0		0	0			
1829			0	0		0	0			
1830			0	0		0	1			
1831			0	0		0	0			
1832			0	0		0	0			
1833			0	0		0	0			
1834			0	0		0	0			
1835			0	0		1	0			
1836			0	0		0	0			
1837			0	0		0	0			
1838			1	0		1	0			
1839			0	0		0	0			
1840			0	0		1	0			
1841			0	0		1	0			
1842			0	0		0	0			
1843			0	0		0	0			
1844			0	0		1	0			
1845			0	0		0	0			
1846			0	0		0	0			
1847			0	0		0	0			
1848			0	0		0	0			
1849			0	0		0	0			
1850			0	0		0	0			
1851			0	0		1	0			
1852			0	0		0	0			
1853			0	0		0	0			
1854			0	0		1	0			
1855			0	0		0	0			
1856			0	0		0	0			
1857			0	0		0	0			
1858			0	0		0	0			
1859			0	0		0	0			
1860			0	0		0	1			
1861			0	0		0	0			
1862			0	0		0	0			
1863			0	0		0	0			
1864			0	0		0	0			
1865			0	0		0	0			
1866			0	0		0	0			
1867			0	0		1	0			
1868			0	0		0	0			
1869			0	0		1	0			
1870			0	0	0	0	0			
1871			1	0	0	0	0			
1872			0	0	0	0	0			
1873			1	0	0	0	0			

1874			0	0	0	0	0		
1875			0	0	0	0	0		
1876			0	0	0	0	0		
1877			0	0	0	1	1		
1878			0	0	0	0	0		
1879			0	0	0	0	0		
1880			0	0	0	0	0		
1881			0	1	1	0	0		
1882			0	0	1	0	0		
1883			1	0	1	0	0		
1884			0	0	0	0	0		
1885			0	0	0	0	0		
1886			0	0	0	1	0		
1887			0	1	0	0	1		
1888			0	0	0	0	0		
1889			0	0	0	0	0		
1890			0	0	1	0	0	0	0
1891			0	0	0	0	0	0	0
1892			0	0	1	0	0	0	0
1893			0	0	0	0	0	0	0
1894			0	0	0	0	0	0	0
1895			0	0	0	0	0	0	0
1896			0	0	0	0	0	0	0
1897			0	1	0	1	0	0	0
1898			0	0	0	0	0	0	0
1899			0	0	0	0	0	0	0
1900			0	0	0	0	0	0	0
1901			0	0	0	0	0	0	0
1902			0	0	0	0	0	0	0
1903			0	0	1	0	0	0	0
1904			0	0	0	0	0	0	0
1905			0	0	0	0	0	0	0
1906			0	0	0	0	0	0	0
1907			0	0	0	0	0	0	0
1908			0	0	0	1	1	1	1
1909			0	0	0	0	0	0	0
1910			0	0	0	0	0	0	0
1911			0	0	0	0	0	0	0
1912			0	0	0	0	0	0	0
1913			0	1	0	0	0	0	0
1914			0	0	1	0	0	0	0
1915			0	0	0	0	0	0	0
1916			0	0	0	0	0	0	0
1917			0	0	0	0	0	0	0
1918			0	0	0	0	0	0	0
1919	1	0	0	0	0	0	0	0	0
1920	0	0	0	0	0	0	0	0	0
1921	0	0	0	0	0	0	0	0	0
1922	0	0	0	0	0	0	0	0	0
1923	0	0	0	0	0	0	0	0	0
1924	0	1	0	1	0	0	0	0	0
1925	1	0	1	0	0	0	0	0	0

1926	0	0	0	0	1	0	0	0	0
1927	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	1	0	1	1
1929	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0
1933	1	0	0	0	0	0	0	0	0
1934	0	0	0	0	0	1	0	0	0
1935	0	0	0	0	0	0	0	0	0
1936	1	0	1	0	0	0	0	0	0
1937	0	0	0	0	0	0	0	0	0
1938	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	0
1940	0	1	1	0	0	0	1	0	0
1941	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	1	0
1944	0	0	0	0	0	0	0	0	0
1945	0	0	1	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0
1948	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	1	0
1950	0	0	1	0	1	0	1	0	0
1951	1	0	0	0	0	0	0	1	0
1952	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	1	0	0
1956	0	0	0	0	1	0	0	0	0
1957	0	0	0	0	0	0	0	1	0
1958	1	0	0	0	1	0	0	0	0
1959	0	0	0	0	0	0	1	0	0
1960	0	0	0	0	0	0	1	0	0
1961	0	0	0	0	0	1	0	1	1
1962	0	0	0	1	1	0	0	0	0
1963	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	1	0	0	0	1
1966	0	0	0	0	0	0	0	0	1
1967	0	0	0	0	0	0	0	1	0
1968	0	0	0	0	0	1	0	1	0
1969	1	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	1
1972	0	0	0	0	0	0	0	0	0
1973	1	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	1
1977	0	0	1	0	0	0	0	0	0

1978	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	1
1980	0	0	0	0	0	0	0	1	0
1981	0	0	0	0	0	0	0	0	0
1982	0	0	1	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0
1985	1	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	1
1987	0	0	1	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	1	0	0	0	0
1990	0	1	0	0	0	1	1	1	0
1991	0	0	0	0	0	0	0	0	1
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	I	0	0	0	0	0	0
1995	0	0	I	0	0	0	0	0	1
1996	I	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	I
1998	0	0	I	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	1	0
2000	0	0	0	0	0	1	0	0	1
2001	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0
2003	0	0	1	0	1	0	0	0	0
2004						0			
2005						1			

Decision Matrices

Decision Matrix

The decision matrix is listed in the following table:

Table 69: Decision Matrix

Code	Industry	CE	CD0-10	CD11-20	CE0-10	CE11-20
IR11111	1	1	1	1	1	1
IR11110	1	1	1	1	1	0
IR11101	1	1	1	1	0	1
IR11100	1	1	1	1	0	0
IR11011	1	1	1	0	1	1
IR11010	1	1	1	0	1	0
IR11001	1	1	1	0	0	1
IR11000	1	1	1	0	0	0
IR10111	1	1	0	1	1	1
IR10110	1	1	0	1	1	0
IR10101	1	1	0	1	0	1
IR10100	1	1	0	1	0	0
IR10011	1	1	0	0	1	1
IR10010	1	1	0	0	1	0
IR10001	1	1	0	0	0	1
IR10000	1	1	0	0	0	0
IR01111	1	0	1	1	1	1
IR01110	1	0	1	1	1	0
IR01101	1	0	1	1	0	1
IR01100	1	0	1	1	0	0
IR01011	1	0	1	0	1	1
IR01010	1	0	1	0	1	0
IR01001	1	0	1	0	0	1
IR01000	1	0	1	0	0	0
IR00111	1	0	0	1	1	1
IR00110	1	0	0	1	1	0
IR00101	1	0	0	1	0	1
IR00100	1	0	0	1	0	0
IR00011	1	0	0	0	1	1
IR00010	1	0	0	0	1	0
IR00001	1	0	0	0	0	1
IR00000	1	0	0	0	0	0
CR11111	0	1	1	1	1	1
CR11110	0	1	1	1	1	0
CR11101	0	1	1	1	0	1
CR11100	0	1	1	1	0	0
CR11011	0	1	1	0	1	1
CR11010	0	1	1	0	1	0
CR11001	0	1	1	0	0	1

CR11000	0	1	1	0	0	0
CR10111	0	1	0	1	1	1
CR10110	0	1	0	1	1	0
CR10101	0	1	0	1	0	1
CR10100	0	1	0	1	0	0
CR10011	0	1	0	0	1	1
CR10010	0	1	0	0	1	0
CR10001	0	1	0	0	0	1
CR10000	0	1	0	0	0	0
CR01111	0	0	1	1	1	1
CR01110	0	0	1	1	1	0
CR01101	0	0	1	1	0	1
CR01100	0	0	1	1	0	0
CR01011	0	0	1	0	1	1
CR01010	0	0	1	0	1	0
CR01001	0	0	1	0	0	1
CR01000	0	0	1	0	0	0
CR00111	0	0	0	1	1	1
CR00110	0	0	0	1	1	0
CR00101	0	0	0	1	0	1
CR00100	0	0	0	1	0	0
CR00011	0	0	0	0	1	1
CR00010	0	0	0	0	1	0
CR00001	0	0	0	0	0	1
CR00000	0	0	0	0	0	0

where : "1" equals yes; "0" equals no; industry is a code for increasing returns industry; CE is whether the discontinuity is competence-enhancing; CD0-10 signifies a competence-destroying discontinuity in the past 0-10 years; CD11-20 signifies a competence-destroying discontinuity in the past 11-20 years; CE0-10 signifies a competence-enhancing discontinuity in the past 0-10 years; and CE11-20 signifies a competence-enhancing discontinuity in the past 11-20 years.

The code used to identify each case has been labelled IR or CR (for Increasing Returns or Constant Returns), respectively, and then 1 or 0 for each of the last five columns in the matrix, corresponding with yes or no in the respective coding, respectively.

First Extended Decision Matrix

The first extended decision matrix is listed in the following table. The coding terminology used is the same as used for the original decision matrix, with a full-stop separating each code used in a code pair name.

Table 70: First Extended Decision Matrix

Code	Industry	CE	CD0-10	CD11-20	CE0-10	CE11-20	Industry.CE	Industry.CD0.10	Industry.CD11.20	Industry.CE0.10	Industry.CE.11.20
IR11111	1	1	1	1	1	1	1	1	1	1	1
IR11110	1	1	1	1	1	0	1	1	1	1	0
IR11101	1	1	1	1	0	1	1	1	1	0	1
IR11100	1	1	1	1	0	0	1	1	1	0	0
IR11011	1	1	1	0	1	1	1	1	0	1	1
IR11010	1	1	1	0	1	0	1	1	0	1	0
IR11001	1	1	1	0	0	1	1	1	0	0	1
IR11000	1	1	1	0	0	0	1	1	0	0	0
IR10111	1	1	0	1	1	1	1	0	1	1	1
IR10110	1	1	0	1	1	0	1	0	1	1	0
IR10101	1	1	0	1	0	1	1	0	1	0	1
IR10100	1	1	0	1	0	0	1	0	1	0	0
IR10011	1	1	0	0	1	1	1	0	0	1	1
IR10010	1	1	0	0	1	0	1	0	0	1	0
IR10001	1	1	0	0	0	1	1	0	0	0	1
IR10000	1	1	0	0	0	0	1	0	0	0	0
IR01111	1	0	1	1	1	1	0	1	1	1	1
IR01110	1	0	1	1	1	0	0	1	1	1	0
IR01101	1	0	1	1	0	1	0	1	1	0	1
IR01100	1	0	1	1	0	0	0	1	1	0	0
IR01011	1	0	1	0	1	1	0	1	0	1	1
IR01010	1	0	1	0	1	0	0	1	0	1	0
IR01001	1	0	1	0	0	1	0	1	0	0	1
IR01000	1	0	1	0	0	0	0	1	0	0	0
IR00111	1	0	0	1	1	1	0	0	1	1	1
IR00110	1	0	0	1	1	0	0	0	1	1	0
IR00101	1	0	0	1	0	1	0	0	1	0	1
IR00100	1	0	0	1	0	0	0	0	1	0	0
IR00011	1	0	0	0	1	1	0	0	0	1	1
IR00010	1	0	0	0	1	0	0	0	0	1	0

IR00001	1	0	0	0	0	1	0	0	0	0	1
IR00000	1	0	0	0	0	0	0	0	0	0	0
CR11111	0	1	1	1	1	1	0	0	0	0	0
CR11110	0	1	1	1	1	0	0	0	0	0	0
CR11101	0	1	1	1	0	1	0	0	0	0	0
CR11100	0	1	1	1	0	0	0	0	0	0	0
CR11011	0	1	1	0	1	1	0	0	0	0	0
CR11010	0	1	1	0	1	0	0	0	0	0	0
CR11001	0	1	1	0	0	1	0	0	0	0	0
CR11000	0	1	1	0	0	0	0	0	0	0	0
CR10111	0	1	0	1	1	1	0	0	0	0	0
CR10110	0	1	0	1	1	0	0	0	0	0	0
CR10101	0	1	0	1	0	1	0	0	0	0	0
CR10100	0	1	0	1	0	0	0	0	0	0	0
CR10011	0	1	0	0	1	1	0	0	0	0	0
CR10010	0	1	0	0	1	0	0	0	0	0	0
CR10001	0	1	0	0	0	1	0	0	0	0	0
CR10000	0	1	0	0	0	0	0	0	0	0	0
CR01111	0	0	1	1	1	1	0	0	0	0	0
CR01110	0	0	1	1	1	0	0	0	0	0	0
CR01101	0	0	1	1	0	1	0	0	0	0	0
CR01100	0	0	1	1	0	0	0	0	0	0	0
CR01011	0	0	1	0	1	1	0	0	0	0	0
CR01010	0	0	1	0	1	0	0	0	0	0	0
CR01001	0	0	1	0	0	1	0	0	0	0	0
CR01000	0	0	1	0	0	0	0	0	0	0	0
CR00111	0	0	0	1	1	1	0	0	0	0	0
CR00110	0	0	0	1	1	0	0	0	0	0	0
CR00101	0	0	0	1	0	1	0	0	0	0	0
CR00100	0	0	0	1	0	0	0	0	0	0	0
CR00011	0	0	0	0	1	1	0	0	0	0	0
CR00010	0	0	0	0	1	0	0	0	0	0	0
CR00001	0	0	0	0	0	1	0	0	0	0	0
CR00000	0	0	0	0	0	0	0	0	0	0	0

Second Extended Decision Matrix

The second extended decision matrix is listed below, using the same coding scheme as the first extended decision matrix.

Table 71: Second Extended Decision Matrix

Code	Industry	CE	CD0-10	CD11-20	CE0-10	CE11-20	CE.CD0.10	CE.CD111.20	CE.CE0.10	CE.CD11.20
IR11111	1	1	1	1	1	1	1	1	1	1
IR11110	1	1	1	1	1	0	1	1	1	0
IR11101	1	1	1	1	0	1	1	1	0	1
IR11100	1	1	1	1	0	0	1	1	0	0
IR11011	1	1	1	0	1	1	1	0	1	1
IR11010	1	1	1	0	1	0	1	0	1	0
IR11001	1	1	1	0	0	1	1	0	0	1
IR11000	1	1	1	0	0	0	1	0	0	0
IR10111	1	1	0	1	1	1	0	1	1	1
IR10110	1	1	0	1	1	0	0	1	1	0
IR10101	1	1	0	1	0	1	0	1	0	1
IR10100	1	1	0	1	0	0	0	1	0	0
IR10011	1	1	0	0	1	1	0	0	1	1
IR10010	1	1	0	0	1	0	0	0	1	0
IR10001	1	1	0	0	0	1	0	0	0	1
IR10000	1	1	0	0	0	0	0	0	0	0
IR01111	1	0	1	1	1	1	0	0	0	0
IR01110	1	0	1	1	1	0	0	0	0	0
IR01101	1	0	1	1	0	1	0	0	0	0
IR01100	1	0	1	1	0	0	0	0	0	0
IR01011	1	0	1	0	1	1	0	0	0	0
IR01010	1	0	1	0	1	0	0	0	0	0
IR01001	1	0	1	0	0	1	0	0	0	0
IR01000	1	0	1	0	0	0	0	0	0	0
IR00111	1	0	0	1	1	1	0	0	0	0
IR00110	1	0	0	1	1	0	0	0	0	0
IR00101	1	0	0	1	0	1	0	0	0	0
IR00100	1	0	0	1	0	0	0	0	0	0
IR00011	1	0	0	0	1	1	0	0	0	0
IR00010	1	0	0	0	1	0	0	0	0	0
IR00001	1	0	0	0	0	1	0	0	0	0

IR00000	1	0	0	0	0	0	0	0	0	0
CR11111	0	1	1	1	1	1	1	1	1	1
CR11110	0	1	1	1	1	0	1	1	1	0
CR11101	0	1	1	1	0	1	1	1	0	1
CR11100	0	1	1	1	0	0	1	1	0	0
CR11011	0	1	1	0	1	1	1	0	1	1
CR11010	0	1	1	0	1	0	1	0	1	0
CR11001	0	1	1	0	0	1	1	0	0	1
CR11000	0	1	1	0	0	0	1	0	0	0
CR10111	0	1	0	1	1	1	0	1	1	1
CR10110	0	1	0	1	1	0	0	1	1	0
CR10101	0	1	0	1	0	1	0	1	0	1
CR10100	0	1	0	1	0	0	0	1	0	0
CR10011	0	1	0	0	1	1	0	0	1	1
CR10010	0	1	0	0	1	0	0	0	1	0
CR10001	0	1	0	0	0	1	0	0	0	1
CR10000	0	1	0	0	0	0	0	0	0	0
CR01111	0	0	1	1	1	1	0	0	0	0
CR01110	0	0	1	1	1	0	0	0	0	0
CR01101	0	0	1	1	0	1	0	0	0	0
CR01100	0	0	1	1	0	0	0	0	0	0
CR01011	0	0	1	0	1	1	0	0	0	0
CR01010	0	0	1	0	1	0	0	0	0	0
CR01001	0	0	1	0	0	1	0	0	0	0
CR01000	0	0	1	0	0	0	0	0	0	0
CR00111	0	0	0	1	1	1	0	0	0	0
CR00110	0	0	0	1	1	0	0	0	0	0
CR00101	0	0	0	1	0	1	0	0	0	0
CR00100	0	0	0	1	0	0	0	0	0	0
CR00011	0	0	0	0	1	1	0	0	0	0
CR00010	0	0	0	0	1	0	0	0	0	0
CR00001	0	0	0	0	0	1	0	0	0	0
CR00000	0	0	0	0	0	0	0	0	0	0

GLM Data Vectors

0-10 year and 11-20 year Data Vectors

The GLM vectors for the 0-10 year and 11-20 year period tests for the four industry pairs, the Total Industry Pairs, the Pairs and Total of Industries are listed in the following tables.

The code used to identify each data vector has been labelled IR or CR (for Increasing Returns or Constant Returns), respectively, and then 1 or 0 for each of the last five columns in the matrix, corresponding with yes or no in the respective coding, respectively for the following codes in order: CE is whether the discontinuity is competence-enhancing; CD0-10 signifies a competence-destroying discontinuity in the past 0-10 years; CD11-20 signifies a competence-destroying discontinuity in the past 11-20 years; CE0-10 signifies a competence-enhancing discontinuity in the past 0-10 years; and CE11-20 signifies a competence-enhancing discontinuity in the past 11-20 years.

Table 72: Airlines/Aircraft Manufacturing Vector

Code	Vector
IR11111	0
IR11110	0
IR11101	0
IR11100	0
IR11011	0
IR11010	1
IR11001	0
IR11000	1
IR10111	2
IR10110	0
IR10101	0
IR10100	0
IR10011	2
IR10010	1
IR10001	3
IR10000	0
IR01111	0
IR01110	0
IR01101	0

IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	0
IR00101	0
IR00100	0
IR00011	0
IR00010	0
IR00001	0
IR00000	0
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	0
CR11010	0
CR11001	1
CR11000	1
CR10111	0
CR10110	0
CR10101	0
CR10100	0
CR10011	0
CR10010	0
CR10001	0
CR10000	1
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	1
CR00101	0
CR00100	0
CR00011	0
CR00010	0
CR00001	0
CR00000	0

Table 73: Data Communications/Telecommunications Manufacturing Vector

Code	Vector
IR11111	4
IR11110	0
IR11101	0
IR11100	0
IR11011	1
IR11010	2
IR11001	0
IR11000	1
IR10111	0
IR10110	0
IR10101	0
IR10100	0
IR10011	4
IR10010	1
IR10001	1
IR10000	3
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	1
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	0
IR00101	0
IR00100	0
IR00011	0
IR00010	1
IR00001	0
IR00000	1
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	2
CR11001	1
CR11000	1
CR10111	0
CR10110	0
CR10101	0
CR10100	1
CR10011	1
CR10010	1
CR10001	0
CR10000	1

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	0
CR00100	0
CR00011	1
CR00010	0
CR00001	1
CR00000	1

Table 74: Electricity/Ship Building Vector

Code	Vector
IR11111	0
IR11110	1
IR11101	0
IR11100	0
IR11011	1
IR11010	0
IR11001	0
IR11000	0
IR10111	0
IR10110	3
IR10101	1
IR10100	1
IR10011	3
IR10010	2
IR10001	3
IR10000	2
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	1
IR00101	0
IR00100	0
IR00011	0
IR00010	0
IR00001	0
IR00000	0
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	0
CR11010	0
CR11001	0
CR11000	0
CR10111	0
CR10110	1
CR10101	0
CR10100	2
CR10011	3
CR10010	2
CR10001	2
CR10000	3

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	1
CR00100	0
CR00011	0
CR00010	1
CR00001	0
CR00000	0

Table 75: Shipping Lines/Ship Building Vector

Code	Vector
IR11111	0
IR11110	0
IR11101	0
IR11100	0
IR11011	3
IR11010	3
IR11001	1
IR11000	1
IR10111	2
IR10110	0
IR10101	0
IR10100	1
IR10011	4
IR10010	2
IR10001	4
IR10000	1
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	0
IR00101	0
IR00100	0
IR00011	1
IR00010	0
IR00001	1
IR00000	1
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	0
CR11010	0
CR11001	0
CR11000	0
CR10111	0
CR10110	1
CR10101	0
CR10100	2
CR10011	3
CR10010	2
CR10001	2
CR10000	3

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	1
CR00100	0
CR00011	0
CR00010	1
CR00001	0
CR00000	0

Table 76: Total Industry Pairs Vector

Code	Industry
IR11111	4
IR11110	1
IR11101	0
IR11100	0
IR11011	5
IR11010	6
IR11001	1
IR11000	3
IR10111	4
IR10110	3
IR10101	1
IR10100	2
IR10011	13
IR10010	6
IR10001	11
IR10000	6
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	1
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	1
IR00101	0
IR00100	0
IR00011	1
IR00010	1
IR00001	1
IR00000	2
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	1
CR11001	2
CR11000	2
CR10111	0
CR10110	2
CR10101	1
CR10100	5
CR10011	7
CR10010	5
CR10001	4

CR10000	8
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	1
CR00101	2
CR00100	0
CR00011	1
CR00010	2
CR00001	1
CR00000	1

Table 77: Paired Industries Vector

Code	Industry
IR11111	4
IR11110	1
IR11101	0
IR11100	0
IR11011	5
IR11010	6
IR11001	1
IR11000	3
IR10111	4
IR10110	3
IR10101	1
IR10100	2
IR10011	13
IR10010	6
IR10001	11
IR10000	6
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	1
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	1
IR00101	0
IR00100	0
IR00011	1
IR00010	1
IR00001	1
IR00000	2
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	1
CR11001	2
CR11000	2
CR10111	0
CR10110	1
CR10101	1
CR10100	3
CR10011	4
CR10010	3
CR10001	2

CR10000	5
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	1
CR00101	1
CR00100	0
CR00011	1
CR00010	1
CR00001	1
CR00000	1

Table 78: Total Increasing Returns Industries/Total Constant Returns Industries Vector

Code	Industry
IR11111	11
IR11110	4
IR11101	1
IR11100	0
IR11011	7
IR11010	8
IR11001	1
IR11000	4
IR10111	8
IR10110	4
IR10101	1
IR10100	4
IR10011	13
IR10010	6
IR10001	14
IR10000	6
IR01111	3
IR01110	0
IR01101	0
IR01100	0
IR01011	2
IR01010	0
IR01001	0
IR01000	0
IR00111	3
IR00110	2
IR00101	0
IR00100	0
IR00011	1
IR00010	2
IR00001	1
IR00000	3
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	1
CR11001	2
CR11000	2
CR10111	0
CR10110	1
CR10101	1
CR10100	3
CR10011	4
CR10010	3

CR10001	2
CR10000	5
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	1
CR00101	1
CR00100	0
CR00011	1
CR00010	1
CR00001	1
CR00000	1

0-8 year and 9-16 year Data Vectors

The GLM vectors for the 0-8 year and 9-16 year period tests for the four industry pairs, the Total Industry Pairs, the Pairs and Total of Industries are listed in the following tables.

The code used to identify each data vector has been labelled IR or CR (for Increasing Returns or Constant Returns), respectively, and then 1 or 0 for each of the last five columns in the matrix, corresponding with yes or no in the respective coding, respectively for the following codes in order: CE is whether the discontinuity is competence-enhancing; CD0-8 signifies a competence-destroying discontinuity in the past 0-8 years; CD9-16 signifies a competence-destroying discontinuity in the past 9-16 years; CE0-8 signifies a competence-enhancing discontinuity in the past 0-8 years; and CE9-16 signifies a competence-enhancing discontinuity in the past 9-16 years.

Table 79: Airlines/Aircraft Manufacturing Vector

Code	Vector
IR11111	0
IR11110	0
IR11101	0
IR11100	0
IR11011	0
IR11010	1
IR11001	0
IR11000	1
IR10111	1
IR10110	0
IR10101	0
IR10100	0
IR10011	2
IR10010	1
IR10001	4
IR10000	0
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0

IR01000	0
IR00111	0
IR00110	0
IR00101	0
IR00100	0
IR00011	0
IR00010	0
IR00001	0
IR00000	0
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	0
CR11010	0
CR11001	1
CR11000	1
CR10111	0
CR10110	0
CR10101	0
CR10100	0
CR10011	0
CR10010	0
CR10001	0
CR10000	1
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	1
CR00100	0
CR00011	0
CR00010	0
CR00001	0
CR00000	0

Table 80: Data Communications/Telecommunications Manufacturing Vector

Code	Vector
IR11111	2
IR11110	0
IR11101	0
IR11100	0
IR11011	3
IR11010	1
IR11001	0
IR11000	1
IR10111	1
IR10110	0
IR10101	0
IR10100	0
IR10011	3
IR10010	1
IR10001	2
IR10000	3
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	1
IR00110	0
IR00101	0
IR00100	0
IR00011	0
IR00010	1
IR00001	0
IR00000	1
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	1
CR11001	1
CR11000	1
CR10111	0
CR10110	0
CR10101	1
CR10100	1
CR10011	1
CR10010	1
CR10001	0
CR10000	1

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	0
CR00100	0
CR00011	1
CR00010	0
CR00001	1
CR00000	1

Table 81: Electricity/Ship Building Vector

Code	Vector
IR11111	0
IR11110	0
IR11101	0
IR11100	0
IR11011	2
IR11010	0
IR11001	0
IR11000	0
IR10111	0
IR10110	3
IR10101	0
IR10100	1
IR10011	3
IR10010	2
IR10001	4
IR10000	2
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	1
IR00101	0
IR00100	0
IR00011	0
IR00010	0
IR00001	0
IR00000	0
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	0
CR11010	0
CR11001	0
CR11000	0
CR10111	0
CR10110	0
CR10101	0
CR10100	1
CR10011	3
CR10010	1
CR10001	3
CR10000	5

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	1
CR00100	0
CR00011	0
CR00010	1
CR00001	0
CR00000	0

Table 82: Shipping Lines/Ship Building Vector

Code	Vector
IR11111	0
IR11110	0
IR11101	0
IR11100	0
IR11011	2
IR11010	3
IR11001	0
IR11000	2
IR10111	1
IR10110	1
IR10101	0
IR10100	1
IR10011	5
IR10010	0
IR10001	6
IR10000	1
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	0
IR00101	0
IR00100	0
IR00011	1
IR00010	0
IR00001	0
IR00000	2
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	0
CR11010	0
CR11001	0
CR11000	0
CR10111	0
CR10110	0
CR10101	0
CR10100	1
CR10011	3
CR10010	1
CR10001	3
CR10000	5

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	1
CR00100	0
CR00011	0
CR00010	1
CR00001	0
CR00000	0

Table 83: Total Industry Pairs Vector

Code	Industry
IR11111	2
IR11110	0
IR11101	0
IR11100	0
IR11011	7
IR11010	5
IR11001	0
IR11000	4
IR10111	3
IR10110	4
IR10101	0
IR10100	2
IR10011	13
IR10010	4
IR10001	16
IR10000	6
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	1
IR00110	1
IR00101	0
IR00100	0
IR00011	1
IR00010	1
IR00001	0
IR00000	3
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	0
CR11001	2
CR11000	2
CR10111	0
CR10110	1
CR10101	1
CR10100	3
CR10011	6
CR10010	3
CR10001	7

CR10000	12
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	3
CR00100	0
CR00011	1
CR00010	2
CR00001	1
CR00000	1

Table 84: Paired Industries Vector

Code	Industry
IR11111	2
IR11110	0
IR11101	0
IR11100	0
IR11011	7
IR11010	5
IR11001	0
IR11000	4
IR10111	3
IR10110	4
IR10101	0
IR10100	2
IR10011	13
IR10010	4
IR10001	16
IR10000	6
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	1
IR00110	1
IR00101	0
IR00100	0
IR00011	1
IR00010	1
IR00001	0
IR00000	3
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	0
CR11001	2
CR11000	2
CR10111	0
CR10110	1
CR10101	1
CR10100	2
CR10011	3
CR10010	2
CR10001	4

CR10000	7
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	2
CR00100	0
CR00011	1
CR00010	1
CR00001	1
CR00000	1

Table 85: Total Increasing Returns Industries/Total Constant Returns Industries Vector

Code	Industry
IR11111	6
IR11110	2
IR11101	1
IR11100	0
IR11011	12
IR11010	7
IR11001	1
IR11000	4
IR10111	6
IR10110	4
IR10101	1
IR10100	3
IR10011	14
IR10010	4
IR10001	17
IR10000	10
IR01111	2
IR01110	0
IR01101	0
IR01100	0
IR01011	1
IR01010	0
IR01001	0
IR01000	0
IR00111	3
IR00110	2
IR00101	1
IR00100	0
IR00011	2
IR00010	2
IR00001	0
IR00000	4
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	0
CR11001	2
CR11000	2
CR10111	0
CR10110	1
CR10101	1
CR10100	2
CR10011	3
CR10010	2

CR10001	4
CR10000	7
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	2
CR00100	0
CR00011	1
CR00010	1
CR00001	1
CR00000	1

0-11 year and 12-22 year Data Vectors

The GLM vectors for the 0-11 year and 12-22 year period tests for the four industry pairs, the Total Industry Pairs, the Pairs and Total of Industries are listed in the following tables.

The code used to identify each data vector has been labelled IR or CR (for Increasing Returns or Constant Returns), respectively, and then 1 or 0 for each of the last five columns in the matrix, corresponding with yes or no in the respective coding, respectively for the following codes in order: CE is whether the discontinuity is competence-enhancing; CD0-11 signifies a competence-destroying discontinuity in the past 0-11 years; CD12-22 signifies a competence-destroying discontinuity in the past 12-22 years; CE0-11 signifies a competence-enhancing discontinuity in the past 0-11 years; and CE12-22 signifies a competence-enhancing discontinuity in the past 12-22 years.

Table 86: Airlines/Aircraft Manufacturing Vector

Code	Vector
IR11111	0
IR11110	0
IR11101	0
IR11100	0
IR11011	0
IR11010	1
IR11001	0
IR11000	1
IR10111	2
IR10110	0
IR10101	0
IR10100	0
IR10011	2
IR10010	2
IR10001	2
IR10000	0
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0

IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	0
IR00101	0
IR00100	0
IR00011	0
IR00010	0
IR00001	0
IR00000	0
CR11111	0
CR11110	0
CR11101	1
CR11100	0
CR11011	0
CR11010	0
CR11001	0
CR11000	1
CR10111	0
CR10110	0
CR10101	0
CR10100	0
CR10011	0
CR10010	0
CR10001	0
CR10000	1
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	1
CR00101	0
CR00100	0
CR00011	0
CR00010	0
CR00001	0
CR00000	0

Table 87: Data Communications/Telecommunications Manufacturing Vector

Code	Vector
IR11111	4
IR11110	0
IR11101	0
IR11100	0
IR11011	0
IR11010	2
IR11001	0
IR11000	1
IR10111	1
IR10110	0
IR10101	0
IR10100	0
IR10011	4
IR10010	2
IR10001	0
IR10000	3
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	1
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	0
IR00101	0
IR00100	0
IR00011	0
IR00010	1
IR00001	0
IR00000	1
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	1
CR11010	2
CR11001	1
CR11000	1
CR10111	0
CR10110	0
CR10101	0
CR10100	1
CR10011	1
CR10010	1
CR10001	0
CR10000	1

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	0
CR01000	0
CR00111	0
CR00110	0
CR00101	0
CR00100	0
CR00011	1
CR00010	0
CR00001	1
CR00000	1

Table 88: Electricity/Ship Building Vector

Code	Vector
IR11111	0
IR11110	2
IR11101	0
IR11100	0
IR11011	0
IR11010	0
IR11001	0
IR11000	1
IR10111	1
IR10110	3
IR10101	0
IR10100	0
IR10011	4
IR10010	2
IR10001	2
IR10000	2
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	1
IR00101	0
IR00100	0
IR00011	0
IR00010	0
IR00001	0
IR00000	0
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	0
CR11010	0
CR11001	0
CR11000	0
CR10111	0
CR10110	1
CR10101	0
CR10100	2
CR10011	3
CR10010	3
CR10001	2
CR10000	2

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	1
CR01000	0
CR00111	0
CR00110	0
CR00101	0
CR00100	0
CR00011	1
CR00010	0
CR00001	0
CR00000	0

Table 89: Shipping Lines/Ship Building Vector

Code	Vector
IR11111	0
IR11110	0
IR11101	0
IR11100	0
IR11011	4
IR11010	2
IR11001	1
IR11000	1
IR10111	2
IR10110	0
IR10101	0
IR10100	1
IR10011	6
IR10010	2
IR10001	3
IR10000	0
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	0
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	0
IR00101	0
IR00100	0
IR00011	1
IR00010	0
IR00001	1
IR00000	1
CR11111	0
CR11110	0
CR11101	0
CR11100	0
CR11011	0
CR11010	0
CR11001	0
CR11000	0
CR10111	0
CR10110	1
CR10101	0
CR10100	2
CR10011	3
CR10010	3
CR10001	2
CR10000	2

CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	1
CR01000	0
CR00111	0
CR00110	0
CR00101	0
CR00100	0
CR00011	1
CR00010	0
CR00001	0
CR00000	0

Table 90: Total Industry Pairs Vector

Code	Industry
IR11111	4
IR11110	2
IR11101	0
IR11100	0
IR11011	4
IR11010	5
IR11001	1
IR11000	4
IR10111	6
IR10110	3
IR10101	0
IR10100	1
IR10011	16
IR10010	8
IR10001	7
IR10000	5
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	1
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	1
IR00101	0
IR00100	0
IR00011	1
IR00010	1
IR00001	1
IR00000	2
CR11111	0
CR11110	0
CR11101	1
CR11100	0
CR11011	1
CR11010	2
CR11001	1
CR11000	2
CR10111	0
CR10110	2
CR10101	0
CR10100	5
CR10011	7
CR10010	7
CR10001	4

CR10000	6
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	2
CR01000	0
CR00111	0
CR00110	1
CR00101	0
CR00100	0
CR00011	3
CR00010	0
CR00001	1
CR00000	1

Table 91: Paired Industries Vector

Code	Industry
IR11111	4
IR11110	2
IR11101	0
IR11100	0
IR11011	4
IR11010	5
IR11001	1
IR11000	4
IR10111	6
IR10110	3
IR10101	0
IR10100	1
IR10011	16
IR10010	8
IR10001	7
IR10000	5
IR01111	0
IR01110	0
IR01101	0
IR01100	0
IR01011	1
IR01010	0
IR01001	0
IR01000	0
IR00111	0
IR00110	1
IR00101	0
IR00100	0
IR00011	1
IR00010	1
IR00001	1
IR00000	2
CR11111	0
CR11110	0
CR11101	1
CR11100	0
CR11011	1
CR11010	2
CR11001	1
CR11000	2
CR10111	0
CR10110	1
CR10101	0
CR10100	3
CR10011	4
CR10010	4
CR10001	2

CR10000	4
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	1
CR01000	0
CR00111	0
CR00110	1
CR00101	0
CR00100	0
CR00011	2
CR00010	0
CR00001	1
CR00000	1

Table 92: Total Increasing Returns Industries/Total Constant Returns Industries Vector

Code	Industry
IR11111	12
IR11110	5
IR11101	1
IR11100	0
IR11011	6
IR11010	6
IR11001	1
IR11000	5
IR10111	11
IR10110	3
IR10101	0
IR10100	3
IR10011	16
IR10010	8
IR10001	10
IR10000	5
IR01111	4
IR01110	0
IR01101	0
IR01100	0
IR01011	1
IR01010	0
IR01001	0
IR01000	0
IR00111	3
IR00110	2
IR00101	0
IR00100	0
IR00011	2
IR00010	1
IR00001	1
IR00000	3
CR11111	0
CR11110	0
CR11101	1
CR11100	0
CR11011	1
CR11010	2
CR11001	1
CR11000	2
CR10111	0
CR10110	1
CR10101	0
CR10100	3
CR10011	4
CR10010	4

CR10001	2
CR10000	4
CR01111	0
CR01110	0
CR01101	0
CR01100	0
CR01011	0
CR01010	0
CR01001	1
CR01000	0
CR00111	0
CR00110	1
CR00101	0
CR00100	0
CR00011	2
CR00010	0
CR00001	1
CR00000	1

Results

GLM Results

GLM Results – Hypothesis One

The results from the GLM tests for Hypothesis One upon the datasets are listed in the following tables:

Table 93: Airlines/Aircraft Manufacturing GLM

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.02729	0.40184	-0.068	0.94585
CE	0.58027	0.37799	1.535	0.12475
CD0.10	-1.40344	0.54512	-2.575	0.01004
CD11.20	-1.75075	0.61525	-2.846	0.00443
CE0.10	-0.64010	0.44352	-1.443	0.14895
CE11.20	-0.42826	0.42585	-1.006	0.31457

Table 94: Data Communications/Telecommunications Manufacturing GLM

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.05657	0.29370	0.193	0.8473
CE	0.70087	0.28327	2.474	0.0134
CD0.10	-0.57581	0.31937	-1.803	0.0714
CD11.20	-1.91398	0.47362	-4.041	5.32e-05
CE0.10	0.05657	0.29370	0.193	0.8473
CE11.20	-0.35855	0.30794	-1.164	0.2443

Table 95: Electricity/Shipbuilding GLM

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.1204	0.3038	-0.396	0.69188
CE	1.2846	0.2809	4.573	4.80e-06
CD0.10	-2.8988	0.7236	-4.006	6.18e-05
CD11.20	-0.9091	0.3473	-2.618	0.00885
CE0.10	-0.1204	0.3038	-0.396	0.69188
CE11.20	-0.5515	0.3222	-1.712	0.08697

Table 96: Shipping Lines/Shipbuilding GLM

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.16175	0.27083	0.597	0.550
CE	1.13352	0.26195	4.327	1.51e-05
CD0.10	-1.56513	0.38328	-4.084	4.44e-05
CD11.20	-1.72446	0.40534	-4.254	2.10e-05
CE0.10	-0.09805	0.27597	-0.355	0.722
CE11.20	-0.09805	0.27598	-0.355	0.722

Table 97: Total Industry Pairs GLM

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.4000	0.1718	2.328	0.0199
CE	1.7578	0.1762	9.977	< 2e-16
CD0.10	-1.2573	0.2153	-5.840	5.2e-09
CD11.20	-1.2573	0.2153	-5.840	5.2e-09
CE0.10	0.1655	0.1718	0.964	0.3353
CE11.20	0.0011	0.1727	0.006	0.9949

Table 98: Paired Industries GLM

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.64436	0.17962	3.587	0.000334
CE	1.49901	0.18281	8.200	2.41e-16
CD0.10	-1.13884	0.21758	-5.234	1.66e-07
CD11.20	-1.34553	0.23105	-5.824	5.76e-09
CE0.10	0.12006	0.17894	0.671	0.502253
CE11.20	-0.02381	0.18014	-0.132	0.894865

Table 99: Total Increasing Returns/Total Constant Returns Industries GLM

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.91640	0.15542	5.896	3.72e-09
CE	1.18997	0.15718	7.571	3.71e-14
CD0.10	-0.80946	0.17144	-4.722	2.34e-06
CD11.20	-0.77890	0.17033	-4.573	4.81e-06
CE0.10	0.28241	0.15240	1.853	0.0639
CE11.20	0.07087	0.15315	0.463	0.6435

GLM Results – Hypothesis Two

The GLM results for Hypothesis Two are listed in the following tables:

Table 100: Airlines/Aircraft Manufacturing GLM – first extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-19.83786	3414.04933	-0.006	0.9954
CE	0.09407	0.68150	0.138	0.8902
CD0.10	-0.62344	0.80130	-0.778	0.4366
CD11.20	-1.55406	1.06445	-1.460	0.1443
CE0.10	-1.55406	1.06445	-1.460	0.1443
CE11.20	-1.55406	1.06445	-1.460	0.1443
Industry.CE	19.47982	3414.04935	0.006	0.9954
Industry.CD0.10	-0.76286	1.12565	-0.678	0.4980
Industry.CD11.20	0.16777	1.32592	0.127	0.8993
Industry.CE0.10	1.9595	1.24488	1.574	0.1155
Industry.CE.11.20	2.40136	1.26856	1.893	0.0584

Table 101: Data Communications/Telecommunications Manufacturing GLM – first extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-1.7248	0.7513	-2.296	0.0217
CE	0.6422	0.4442	1.446	0.1482
CD0.10	-0.5579	0.5270	-1.059	0.2898
CD11.20	-2.5444	1.0302	-2.470	0.0135
CE0.10	-0.2540	0.4991	-0.509	0.6108
CE11.20	-0.5579	0.5270	-1.059	0.2898
Industry.CE	1.0924	0.7677	1.423	0.1548
Industry.CD0.10	0.3572	0.6926	0.516	0.6060
Industry.CD11.20	1.1581	1.1721	0.988	0.3231
Industry.CE0.10	1.1013	0.6980	1.578	0.1146
Industry.CE.11.20	0.7586	0.6926	1.095	0.2734

Table 102: Electricity/Shipbuilding GLM- first extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-2.1425	1.0835	-1.977	0.048004
CE	1.2907	0.3863	3.341	0.000834
CD0.10	-20.1174	3479.8038	-0.006	0.995387
CD11.20	-1.1455	0.5592	-2.048	0.040531
CE0.10	-0.3133	0.4673	-0.671	0.502512
CE11.20	-0.5668	0.4874	-1.163	0.244805
Industry.CE	1.5425	1.0991	1.403	0.160497
Industry.CD0.10	18.0380	3479.8039	0.005	0.995864
Industry.CD11.20	0.6935	0.7393	0.938	0.348193
Industry.CE0.10	0.7653	0.6724	1.138	0.255042
Industry.CE.11.20	0.3437	0.6801	0.505	0.613314

Table 103: Shipping Lines/Shipbuilding GLM – first extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-1.3528	0.6991	-1.935	0.052974
CE	1.2907	0.3863	3.341	0.000834
CD0.10	-20.1174	3479.8038	-0.006	0.995387
CD11.20	-1.1455	0.5592	-2.048	0.040531
CE0.10	-0.3133	0.4673	-0.671	0.502512
CE11.20	-0.5668	0.4874	-1.163	0.244805
Industry.CE	0.7017	0.7266	0.966	0.334199
Industry.CD0.10	19.3636	3479.8038	0.006	0.995560
Industry.CD11.20	-0.8469	0.8316	-1.018	0.308461
Industry.CE0.10	0.7188	0.6205	1.158	0.246696
Industry.CE.11.20	1.1422	0.6412	1.781	0.074855

Table 104: Total Industry Pairs GLM- first extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.4918	0.4406	-1.116	0.26433
CE	1.9922	0.2567	7.760	8.52e-15
CD0.10	-1.8241	0.4366	-4.178	2.94e-05
CD11.20	-1.0735	0.3435	-3.125	0.00178
CE0.10	-0.1477	0.2924	-0.505	0.61342
CE11.20	-0.2412	0.2949	-0.818	0.41330
Industry.CE	0.2516	0.4732	0.532	0.59497
Industry.CD0.10	0.9174	0.5074	1.808	0.07059
Industry.CD11.20	-0.1969	0.4450	-0.442	0.65814
Industry.CE0.10	0.6805	0.3798	1.792	0.07317
Industry.CE.11.20	0.5449	0.3782	1.441	0.14961

GLM Results – Hypotheses Three to Six

The GLM results for Hypotheses Three to Six are listed in the following tables:

Table 105: Airlines/Aircraft Manufacturing GLM – second extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.3345	0.4456	0.751	0.453
CE	-0.4187	0.6177	-0.678	0.498
CD0.10	-18.3656	2894.1846	-0.006	0.995
CD11.20	-1.1495	1.0513	-1.093	0.274
CE0.10	-1.1495	1.0513	-1.093	0.274
CE11.20	-18.3656	2894.1846	-0.006	0.995
CE.CD0.10	17.5547	2894.1846	0.006	0.995
CE.CD11.20	-0.5552	1.3024	-0.426	0.670
CE.CE0.10	0.9954	1.1894	0.837	0.403
CE.CE11.20	18.8356	2894.1846	0.007	0.995

Table 106: Data Communications/Telecommunications Manufacturing GLM – second extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.3813	0.3292	1.158	0.2468
CE	-0.3045	0.4852	-0.628	0.5303
CD0.10	-1.8960	1.0430	-1.818	0.0691
CD11.20	-18.3116	2075.2566	-0.009	0.9930
CE0.10	-0.4402	0.6486	-0.679	0.4973
CE11.20	-0.4402	0.6486	-0.679	0.4973
CE.CD0.10	1.8960	1.1143	1.702	0.0888
CE.CD11.20	16.8765	2075.2566	0.008	0.9935
CE.CE0.10	1.0762	0.7685	1.400	0.1614
CE.CE11.20	0.4402	0.7579	0.581	0.5614

Table 107: Electricity/Shipbuilding GLM- second extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.0144	0.3232	0.045	0.9645
CE	0.9450	0.3743	2.525	0.0116
CD0.10	-18.0891	2144.3197	-0.008	0.9933
CD11.20	-0.6267	0.7742	-0.809	0.4182
CE0.10	-0.6267	0.7742	-0.809	0.4182
CE11.20	-1.5566	1.0518	-1.480	0.1389
CE.CD0.10	15.4500	2144.3198	0.007	0.9943
CE.CD11.20	-0.2206	0.8707	-0.253	0.8000
CE.CE0.10	0.7602	0.8563	0.888	0.3747
CE.CE11.20	1.2884	1.1145	1.156	0.2477

Table 108: Shipping Lines/Shipbuilding GLM – second extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.3842	0.2988	1.286	0.1984
CE	0.5741	0.3828	1.500	0.1337
CD0.10	-18.2712	2123.7260	-0.009	0.9931
CD11.20	-1.7958	1.0441	-1.720	0.0855
CE0.10	-0.9211	0.7682	-1.199	0.2305
CE11.20	-0.2937	0.6419	-0.458	0.6473
CE.CD0.10	17.0548	2123.7260	0.008	0.9936
CE.CD11.20	0.2202	1.1364	0.194	0.8463
CE.CE0.10	1.2088	0.8407	1.438	0.1505
CE.CE11.20	0.4655	0.7261	0.641	0.5214

Table 109: Paired Industries GLM – second extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.80923	0.20071	4.032	5.54e-05
CE	1.12824	0.25542	4.417	1.00e-05
CD0.10	-2.60266	1.02441	-2.541	0.0111
CD11.20	-1.34370	0.62196	-2.160	0.0307
CE0.10	-0.06894	0.44459	-0.155	0.8768
CE11.20	-0.34826	0.47241	-0.737	0.4610
CE.CD0.10	1.68637	1.05037	1.606	0.1084
CE.CD11.20	0.07675	0.67150	0.114	0.9090
CE.CE0.10	0.35662	0.49248	0.724	0.4690
CE.CE11.20	0.50241	0.51710	0.972	0.3312

Table 110: Total Increasing Returns/Total Constant Returns Industries GLM – second extended matrix

	Estimate	Std Error	z value	Pr(>|z|)
Industry	1.07781	0.17682	6.096	1.09e-09
CE	0.79015	0.24311	3.250	0.00115
CD0.10	-1.57265	0.47955	-3.279	0.00104
CD11.20	-0.64695	0.36607	-1.767	0.07718
CE0.10	0.20020	0.31594	0.634	0.52629
CE11.20	-0.21369	0.33646	-0.635	0.52536
CE.CD0.10	0.99283	0.51683	1.921	0.05473
CE.CD11.20	-0.08491	0.41591	-0.204	0.83822
CE.CE0.10	0.23384	0.36830	0.635	0.52549
CE.CE11.20	0.47151	0.38466	1.226	0.22028

GLM Results – Hypothesis One Sensitivity Tests

Table 111: Airlines/Aircraft Manufacturing GLM (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.01439	0.40482	0.036	0.97165
CE	0.63966	0.38096	1.679	0.09314
CD0.8	-1.37733	0.54639	-2.521	0.01171
CD9.16	-2.18926	0.73794	-2.967	0.00301
CE0.8	-1.08904	0.50077	-2.175	0.02965
CE9.16	-0.18760	0.41503	-0.452	0.65126

Table 112: Airlines/Aircraft Manufacturing GLM (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.04905	0.40041	-0.122	0.90250
CE	0.54968	0.37662	1.460	0.14443
CD0.11	-1.41723	0.54449	-2.603	0.00924
CD12.22	-1.41723	0.54448	-2.603	0.00924
CE0.11	-0.44650	0.42469	-1.051	0.29309
CE12.22	-0.65698	0.44250	-1.485	0.13763

Table 113: Data Communications/Telecommunications Manufacturing GLM (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.08642	0.29517	0.293	0.769684
CE	0.74492	0.28474	2.616	0.008893
CD0.8	-0.91061	0.34591	-2.632	0.008476
CD9.16	-1.68467	0.43817	-3.845	0.000121
CE0.8	-0.12242	0.30096	-0.407	0.684176
CE9.16	-0.12242	0.30096	-0.407	0.684176

Table 114: Data Communications/Telecommunications Manufacturing GLM (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.05588	0.29373	0.190	0.849108
CE	0.69986	0.28337	2.470	0.013520
CD0.11	-0.68979	0.32661	-2.112	0.034686
CD12.22	-1.70211	0.43768	-3.889	0.000101
CE0.11	0.15900	0.29145	0.546	0.585382
CE12.22	-0.46637	0.31321	-1.489	0.136491

Table 115: Electricity/Shipbuilding GLM (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.0833	0.3064	-0.272	0.785685
CE	1.3778	0.2824	4.878	1.07e-06
CD0.8	-2.8782	0.7240	-3.975	7.03e-05
CD9.16	-1.4739	0.4127	-3.571	0.000355
CE0.8	-0.2984	0.3136	-0.952	0.341245
CE9.16	-0.2984	0.3136	-0.952	0.341245

Table 116: Electricity/Shipbuilding GLM (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.1653	0.3011	-0.549	0.5829
CE	1.1781	0.2797	4.212	2.53e-05
CD0.11	-2.1758	0.5235	-4.156	3.23e-05
CD12.22	-1.0728	0.3576	-3.000	0.0027
CE0.11	0.1411	0.2936	0.481	0.6308
CE12.22	-0.5892	0.3203	-1.840	0.0658

Table 117: Shipping Lines/Shipbuilding GLM (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.22981	0.27507	0.835	0.403
CE	1.26613	0.26540	4.771	1.84e-06
CD0.8	-1.68818	0.40647	-4.153	3.28e-05
CD9.16	-2.07612	0.47056	-4.412	1.02e-05
CE0.8	-0.40053	0.29112	-1.376	0.169
CE9.16	-0.03866	0.27948	-0.138	0.890

Table 118: Shipping Lines/Shipbuilding GLM (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.08812	0.26698	0.330	0.741350
CE	0.99880	0.25888	3.858	0.000114
CD0.11	-1.46355	0.36403	-4.020	5.81e-05
CD12.22	-1.94332	0.43223	-4.496	6.92e-06
CE0.11	0.08812	0.26698	0.330	0.741350
CE12.22	0.08812	0.26698	0.330	0.741350

Table 119: Total Industry Pairs GLM (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	1.0135	0.1593	6.363	1.98e-10
CE	1.3102	0.1611	8.131	4.25e-16
CD0.8	-0.9645	0.1802	-5.353	8.63e-08
CD9.16	-1.1037	0.1867	-5.912	3.38e-09
CE0.8	0.0463	0.1557	0.297	0.766
CE9.16	0.2086	0.1550	1.346	0.178

Table 120: Total Industry Pairs GLM (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.35622	0.16973	2.099	0.0358
CE	1.64251	0.17490	9.391	< 2e-16
CD0.11	-1.14341	0.20651	-5.537	3.08e-08
CD12.22	-1.32813	0.21781	-6.098	1.08e-09
CE0.11	0.42315	0.16991	2.490	0.0128
CE12.22	-0.03422	0.17122	-0.200	0.8416

GLM Results – Hypothesis Two Sensitivity Tests

Table 121: Airlines/Aircraft Manufacturing GLM – first extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-20.31938	5150.65507	-0.004	0.997
CE	0.06568	0.68409	0.096	0.924
CD0.8	-0.64430	0.80134	-0.804	0.421
CD9.16	-1.57055	1.06415	-1.476	0.140
CE0.8	-20.10010	5827.37100	-0.003	0.997
CE9.16	-0.64430	0.80134	-0.804	0.421
Industry.CE	20.33067	5150.65509	0.004	0.997
Industry.CD0.8	-0.74199	1.12567	-0.659	0.510
Industry.CD9.16	-0.62667	1.49784	-0.418	0.676
Industry.CE0.8	20.10010	5827.37104	0.003	0.997
Industry.CE.9.16	1.49160	1.05751	1.410	0.158

Table 122: Airlines/Aircraft Manufacturing GLM – first extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-19.84053	3418.60966	-0.006	0.9954
CE	-0.04536	0.68099	-0.067	0.9469
CD0.11	-0.72736	0.79585	-0.914	0.3607
CD12.22	-0.72736	0.79585	-0.914	0.3607
CE0.11	-1.63690	1.06037	-1.544	0.1227
CE12.22	-1.63690	1.06037	-1.544	0.1227
Industry.CE	19.62193	3418.60968	0.006	0.9954
Industry.CD0.11	-0.65893	1.12177	-0.587	0.5569
Industry.CD12.22	-0.65893	1.12177	-0.587	0.5569
Industry.CE0.11	2.48420	1.26514	1.964	0.0496
Industry.CE.12.22	2.04237	1.24139	1.645	0.0999

Table 123: Data Communications/Telecommunications Manufacturing GLM – first extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-1.5214	0.7352	-2.069	0.0385
CE	0.6582	0.4436	1.484	0.1378
CD0.8	-0.8817	0.5688	-1.550	0.1211
CD9.16	-1.7630	0.7518	-2.345	0.0190
CE0.8	-0.5493	0.5274	-1.042	0.2976
CE9.16	-0.2442	0.4995	-0.489	0.6248
Industry.CE	1.0764	0.7674	1.403	0.1607
Industry.CD0.8	0.2627	0.7371	0.356	0.7216
Industry.CD9.16	0.3767	0.9368	0.402	0.6876
Industry.CE0.8	1.1683	0.7056	1.656	0.0978
Industry.CE.9.16	0.6497	0.6766	0.960	0.3369

Table 124: Data Communications/Telecommunications Manufacturing GLM – first extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-1.7793	0.7638	-2.330	0.0198
CE	0.6422	0.4442	1.446	0.1482
CD0.11	-0.5579	0.5270	-1.059	0.2898
CD12.22	-2.5444	1.0302	-2.470	0.0135
CE0.11	-0.2540	0.4991	-0.509	0.6108
CE12.22	-0.5579	0.5270	-1.059	0.2898
Industry.CE	1.0924	0.7677	1.423	0.1548
Industry.CD0.11	0.1524	0.6972	0.219	0.8269
Industry.CD12.22	1.4457	1.1523	1.255	0.2096
Industry.CE0.11	1.3526	0.7182	1.883	0.0596
Industry.CE.12.22	0.5579	0.6912	0.807	0.4196

Table 125: Electricity/Shipbuilding GLM- first extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-2.0808	1.0822	-1.923	0.054511
CE	1.4783	0.3818	3.872	0.000108
CD0.8	-19.8866	3159.3441	-0.006	0.994978
CD9.16	-1.9434	0.7480	-2.598	0.009375
CE0.8	-0.7852	0.5211	-1.507	0.131875
CE9.16	-0.2473	0.4744	-0.521	0.602089
Industry.CE	1.3549	1.0975	1.235	0.217006
Industry.CD0.8	17.8072	3159.3442	0.006	0.995503
Industry.CD9.16	0.9878	0.9146	1.080	0.280085
Industry.CE0.8	1.2372	0.7109	1.740	0.081791
Industry.CE.9.16	0.2473	0.6688	0.370	0.711497

Table 126: Electricity/Shipbuilding GLM- first extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-2.44821	1.10737	-2.211	0.02705
CE	1.15429	0.38962	2.963	0.00305
CD0.11	-2.77874	1.02526	-2.710	0.00672
CD12.22	-1.54747	0.62448	-2.478	0.01321
CE0.11	-0.12868	0.44787	-0.287	0.77387
CE12.22	-0.36649	0.46263	-0.792	0.42825
Industry.CE	1.67892	1.10029	1.526	0.12704
Industry.CD0.11	1.16930	1.20464	0.971	0.33172
Industry.CD12.22	1.09548	0.78977	1.387	0.16541
Industry.CE0.11	1.08420	0.69102	1.569	0.11666
Industry.CE.12.22	-0.08549	0.66917	-0.128	0.89834

Table 127: Shipping Lines/Shipbuilding GLM – first extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-1.00799	0.67652	-1.490	0.136235
CE	1.47829	0.38176	3.872	0.000108
CD0.8	-18.88660	1916.23906	-0.010	0.992136
CD9.16	-1.94336	0.74800	-2.598	0.009375
CE0.8	-0.78521	0.52113	-1.507	0.131875
CE9.16	-0.24735	0.47439	-0.521	0.602089
Industry.CE	0.51414	0.72424	0.710	0.477764
Industry.CD0.8	17.94214	1916.23911	0.009	0.992529
Industry.CD9.16	-0.04907	0.96866	-0.051	0.959599
Industry.CE0.8	0.86525	0.65714	1.317	0.187940
Industry.CE.9.16	0.65281	0.62587	1.043	0.296926

Table 128: Shipping Lines/Shipbuilding GLM – first extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-1.8273	0.7386	-2.474	0.01336
CE	1.1543	0.3896	2.963	0.00305
CD0.11	-2.7787	1.0253	-2.710	0.00672
CD12.22	-1.5475	0.6245	-2.478	0.01321
CE0.11	-0.1287	0.4479	-0.287	0.77387
CE12.22	-0.3665	0.4626	-0.792	0.42825
Industry.CE	0.8381	0.7284	1.151	0.24989
Industry.CD0.11	2.0250	1.1113	1.822	0.06843
Industry.CD12.22	-0.4450	0.8768	-0.507	0.61181
Industry.CE0.11	0.8825	0.6200	1.423	0.15465
Industry.CE.12.22	1.3110	0.6422	2.041	0.04122

Table 129: Total Industry Pairs GLM- first extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.19033	0.31026	0.613	0.53958
CE	1.72776	0.30160	5.729	1.01e-08
CD0.8	-1.58687	0.48493	-3.272	0.00107
CD9.16	-1.36277	0.45063	-3.024	0.00249
CE0.8	-0.82037	0.38962	-2.106	0.03524
CE9.16	0.03790	0.34559	0.110	0.91266
Industry.CE	-0.03918	0.40081	-0.098	0.92213
Industry.CD0.8	0.87993	0.52596	1.673	0.09433
Industry.CD9.16	0.44005	0.49814	0.883	0.37703
Industry.CE0.8	1.28739	0.43651	2.949	0.00319
Industry.CE.9.16	0.42912	0.39770	1.079	0.28059

Table 130: Total Industry Pairs GLM- first extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.72907	0.45169	-1.614	0.106502
CE	1.83704	0.26032	7.057	1.70e-12
CD0.11	-1.35964	0.36871	-3.688	0.000226
CD12.22	-1.35964	0.36871	-3.688	0.000226
CE0.11	0.08845	0.28416	0.311	0.755591
CE12.22	-0.18453	0.28937	-0.638	0.523686
Industry.CE	0.40671	0.47516	0.856	0.392027
Industry.CD0.11	0.45291	0.45033	1.006	0.314543
Industry.CD12.22	0.16750	0.46112	0.363	0.716424
Industry.CE0.11	0.81827	0.38418	2.130	0.033181
Industry.CE.12.22	0.43236	0.37333	1.158	0.246817

GLM Results – Hypotheses Three to Six Sensitivity Tests

Table 131: Airlines/Aircraft Manufacturing GLM – second extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.3345	0.4456	0.751	0.453
CE	-0.1982	0.5968	-0.332	0.740
CD0.8	-18.3607	2887.0327	-0.006	0.995
CD9.16	-1.1495	1.0513	-1.093	0.274
CE0.8	-18.3607	2887.0327	-0.006	0.995
CE9.16	-1.1495	1.0513	-1.093	0.274
CE.CD0.8	17.5498	2887.0327	0.006	0.995
CE.CD9.16	-1.3354	1.4794	-0.903	0.367
CE.CE0.8	17.8907	2887.0327	0.006	0.995
CE.CE9.16	1.6195	1.1959	1.354	0.176

Table 132: Airlines/Aircraft Manufacturing GLM – second extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.33453	0.44562	0.751	0.453
CE	-0.48586	0.61736	-0.787	0.431
CD0.11	-18.38534	2922.83469	-0.006	0.995
CD12.22	-1.14953	1.05132	-1.093	0.274
CE0.11	-1.14953	1.05132	-1.093	0.274
CE12.22	-18.38534	2922.83469	-0.006	0.995
CE.CD0.11	17.57441	2922.83475	0.006	0.995
CE.CD12.22	-0.05444	1.24040	-0.044	0.965
CE.CE0.11	1.30368	1.18945	1.096	0.273
CE.CE12.22	18.53949	2922.83474	0.006	0.995

Table 133: Data Communications/Telecommunications Manufacturing GLM – second extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.3813	0.3292	1.158	0.2468
CE	-0.1278	0.4680	-0.273	0.7848
CD0.8	-18.3355	2100.2216	-0.009	0.9930
CD9.16	-1.8960	1.0430	-1.818	0.0691
CE0.8	-0.4402	0.6486	-0.679	0.4973
CE9.16	-0.4402	0.6486	-0.679	0.4973
CE.CD0.8	18.0253	2100.2216	0.009	0.9932
CE.CD9.16	0.4609	1.1556	0.399	0.6900
CE.CE0.8	0.7504	0.7604	0.987	0.3237
CE.CE9.16	0.7504	0.7604	0.987	0.3237

Table 134: Data Communications/Telecommunications Manufacturing GLM – second extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.3813	0.3292	1.158	0.2468
CE	-0.3229	0.4907	-0.658	0.5105
CD0.11	-1.8960	1.0430	-1.818	0.0691
CD12.22	-18.2966	2059.7775	-0.009	0.9929
CE0.11	-0.4402	0.6486	-0.679	0.4973
CE12.22	-0.4402	0.6486	-0.679	0.4973
CE.CD0.11	1.7418	1.1147	1.563	0.1181
CE.CD12.22	17.0926	2059.7775	0.008	0.9934
CE.CE0.11	1.2512	0.7754	1.614	0.1066
CE.CE12.22	0.2861	0.7586	0.377	0.7061

Table 135: Electricity/Shipbuilding GLM- second extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.0144	0.3232	0.045	0.96447
CE	1.1278	0.3624	3.111	0.00186
CD0.8	-18.0886	2143.8056	-0.008	0.99327
CD9.16	-0.6267	0.7742	-0.809	0.41825
CE0.8	-0.6267	0.7742	-0.809	0.41825
CE9.16	-1.5566	1.0518	-1.480	0.13889
CE.CD0.8	15.4496	2143.8057	0.007	0.99425
CE.CD9.16	-0.9828	0.9162	-1.073	0.28340
CE.CE0.8	0.4931	0.8563	0.576	0.56470
CE.CE9.16	1.5566	1.1134	1.398	0.16209

Table 136: Electricity/Shipbuilding GLM- second extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.01021	0.32109	-0.032	0.9746
CE	0.73698	0.39577	1.862	0.0626
CD0.11	-1.64571	1.04940	-1.568	0.1168
CD12.22	-1.64571	1.04940	-1.568	0.1168
CE0.11	-0.73829	0.77350	-0.954	0.3398
CE12.22	-0.73829	0.77350	-0.954	0.3398
CE.CD0.11	-0.55151	1.21310	-0.455	0.6494
CE.CD12.22	0.79841	1.12248	0.711	0.4769
CE.CE0.11	1.28483	0.86130	1.492	0.1358
CE.CE12.22	0.33282	0.85860	0.388	0.6983

Table 137: Shipping Lines/Shipbuilding GLM – second extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.4234	0.3015	1.404	0.1602
CE	0.8255	0.3671	2.249	0.0245
CD0.8	-18.1411	2089.6785	-0.009	0.9931
CD9.16	-1.6808	1.0448	-1.609	0.1077
CE0.8	-0.7816	0.7656	-1.021	0.3073
CE9.16	-0.7816	0.7656	-1.021	0.3073
CE.CD0.8	16.7548	2089.6786	0.008	0.9936
CE.CD9.16	-0.3669	1.1722	-0.313	0.7543
CE.CE0.8	0.6097	0.8374	0.728	0.4665
CE.CE9.16	1.0693	0.8383	1.276	0.2021

Table 138: Shipping Lines/Shipbuilding GLM – second extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.34344	0.29611	1.160	0.2461
CE	0.24151	0.41301	0.585	0.5587
CD0.11	-1.90705	1.04313	-1.828	0.0675
CD12.22	-18.28361	2036.61183	-0.009	0.9928
CE0.11	-1.05312	0.76884	-1.370	0.1708
CE12.22	0.06903	0.56690	0.122	0.9031
CE.CD0.11	0.69065	1.11810	0.618	0.5368
CE.CD12.22	16.70807	2036.61188	0.008	0.9935
CE.CE0.11	1.70371	0.84730	2.011	0.0444
CE.CE12.22	0.33643	0.66365	0.507	0.6122

Table 139: Paired Industries GLM – second extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.8241	0.2016	4.087	4.37e-05
CE	1.3221	0.2488	5.313	1.08e-07
CD0.8	-18.9636	2125.0034	-0.009	0.993
CD9.16	-0.9184	0.5533	-1.660	0.097
CE0.8	-0.2903	0.4725	-0.615	0.539
CE9.16	-0.2903	0.4725	-0.615	0.539
CE.CD0.8	17.8796	2125.0034	0.008	0.993
CE.CD9.16	-0.7043	0.6213	-1.134	0.257
CE.CE0.8	0.2684	0.5169	0.519	0.604
CE.CE9.16	0.5780	0.5178	1.116	0.264

Table 140: Paired Industries GLM – second extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.7936	0.1998	3.973	7.1e-05
CE	0.9263	0.2662	3.480	0.000502
CD0.11	-1.8726	0.7419	-2.524	0.011600
CD12.22	-1.8726	0.7419	-2.524	0.011603
CE0.11	-0.1348	0.4452	-0.303	0.762053
CE12.22	-0.1348	0.4452	-0.303	0.762054
CE.CD0.11	1.0095	0.7766	1.300	0.193597
CE.CD12.22	0.6686	0.7825	0.854	0.392865
CE.CE0.11	0.7952	0.4972	1.599	0.109721
CE.CE12.22	0.2008	0.4922	0.408	0.683334

Table 141: Total Increasing Returns/Total Constant Returns Industries GLM – second extended matrix (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	1.12023	0.17920	6.251	4.07e-10
CE	1.05872	0.23537	4.498	6.86e-06
CD0.8	-2.10235	0.60264	-3.489	0.000486
CD9.16	-0.56282	0.36835	-1.528	0.126525
CE0.8	0.03221	0.33092	0.097	0.922458
CE9.16	-0.11307	0.33863	-0.334	0.738455
CE.CD0.8	1.37049	0.63416	2.161	0.030686
CE.CD9.16	-0.64115	0.42876	-1.495	0.134817
CE.CE0.8	0.08759	0.37924	0.231	0.817344
CE.CE9.16	0.47597	0.38730	1.229	0.219082

Table 142: Total Increasing Returns/Total Constant Returns Industries GLM – second extended matrix (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	1.04746	0.17510	5.982	2.21e-09
CE	0.58258	0.25216	2.310	0.02087
CD0.11	-1.39625	0.44307	-3.151	0.00163
CD12.22	-0.70509	0.36436	-1.935	0.05298
CE0.11	0.11652	0.31480	0.370	0.71128
CE12.22	-0.01589	0.32082	-0.050	0.96050
CE.CD0.11	0.85339	0.48279	1.768	0.07712
CE.CD12.22	0.05016	0.41322	0.121	0.90338
CE.CE0.11	0.61534	0.37158	1.656	0.09772
CE.CE12.22	0.27372	0.37106	0.738	0.46071

GLM Results – Hypothesis Five Sensitivity Tests - Truncated

Table 143: Airlines/Aircraft Manufacturing GLM – second extended matrix, truncated (10/20 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.07297	0.41176	0.177	0.8593
CE	0.27890	0.46318	0.602	0.5471
CD0.10	-1.34132	0.54894	-2.443	0.0145
CD11.20	-1.69233	0.61832	-2.737	0.0062
CE0.10	-1.66701	1.03521	-1.610	0.1073
CE11.20	-0.34503	0.43333	-0.796	0.4259
CE.CE0.10	1.51286	1.17524	1.287	0.1980

Table 144: Airlines/Aircraft Manufacturing GLM – second extended matrix, truncated (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.12617	0.41326	0.305	0.76014
CE	0.31906	0.44603	0.715	0.47440
CD0.8	-1.30932	0.54991	-2.381	0.01727
CD9.16	-2.12910	0.74010	-2.877	0.00402
CE0.8	-17.78669	1831.97814	-0.010	0.99225
CE9.16	-0.08665	0.42260	-0.205	0.83753
CE.CE0.8	17.31668	1831.97823	0.009	0.99246

Table 145: Airlines/Aircraft Manufacturing GLM – second extended matrix, truncated (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.08063	0.41214	0.196	0.8449
CE	0.13823	0.48776	0.283	0.7769
CD0.11	-1.33667	0.54912	-2.434	0.0149
CD12.22	-1.33667	0.54911	-2.434	0.0149
CE0.11	-1.65353	1.03501	-1.598	0.1101
CE12.22	-0.55760	0.45023	-1.238	0.2155
CE.CE0.11	1.80768	1.17506	1.538	0.1240

Table 146: Data Communications/Telecommunications Manufacturing GLM – second extended matrix, truncated (10/20 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.1961	0.3054	0.642	0.520794
CE	0.1906	0.3998	0.477	0.633570
CD0.10	-0.4717	0.3265	-1.445	0.148468
CD11.20	-1.8386	0.4765	-3.859	0.000114
CE0.10	-0.9080	0.6181	-1.469	0.141802
CE11.20	-0.2448	0.3163	-0.774	0.438970
CE.CE0.10	1.5440	0.7429	2.078	0.037686

Table 147: Data Communications/Telecommunications Manufacturing GLM – second extended matrix, truncated (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.19329	0.30529	0.633	0.526646
CE	0.38501	0.37393	1.030	0.303179
CD0.8	-0.84019	0.35049	-2.397	0.016522
CD9.16	-1.62547	0.44087	-3.687	0.000227
CE0.8	-0.91427	0.61826	-1.479	0.139201
CE9.16	-0.02658	0.30946	-0.086	0.931554
CE.CE0.8	1.22442	0.73473	1.667	0.095614

Table 148: Data Communications/Telecommunications Manufacturing GLM – second extended matrix, truncated (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.2133	0.3067	0.696	0.486741
CE	0.1111	0.4168	0.267	0.789785
CD0.11	-0.5774	0.3338	-1.730	0.083647
CD12.22	-1.6147	0.4412	-3.659	0.000253
CE0.11	-0.8697	0.6181	-1.407	0.159422
CE12.22	-0.3440	0.3217	-1.069	0.284991
CE.CE0.11	1.6806	0.7501	2.241	0.025053

Table 149: Electricity/Shipbuilding GLM- second extended matrix, truncated (10/20 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.04203	0.31327	-0.134	0.89327
CE	1.07615	0.33999	3.165	0.00155
CD0.10	-2.85569	0.72501	-3.939	8.19e-05
CD11.20	-0.85142	0.35219	-2.417	0.01563
CE0.10	-0.86976	0.73768	-1.179	0.23838
CE11.20	-0.48650	0.32875	-1.480	0.13891
CE.CE0.10	1.00329	0.82347	1.218	0.22308

Table 150: Electricity/Shipbuilding GLM- second extended matrix, truncated (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.03162	0.31435	-0.101	0.919874
CE	1.25127	0.32702	3.826	0.000130
CD0.8	-2.85008	0.72517	-3.930	8.49e-05
CD9.16	-1.44113	0.41533	-3.470	0.000521
CE0.8	-0.82818	0.73786	-1.122	0.261693
CE9.16	-0.25165	0.32013	-0.786	0.431821
CE.CE0.8	0.69464	0.82363	0.843	0.399010

Table 151: Electricity/Shipbuilding GLM- second extended matrix, truncated (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	-0.0463	0.3128	-0.148	0.88235
CE	0.8183	0.3673	2.228	0.02588
CD0.11	-2.1058	0.5262	-4.002	6.29e-05
CD12.22	-0.9878	0.3632	-2.719	0.00654
CE0.11	-0.8864	0.7376	-1.202	0.22942
CE12.22	-0.4900	0.3285	-1.492	0.13572
CE.CE0.11	1.4330	0.8292	1.728	0.08395

Table 152: Shipping Lines/Shipbuilding GLM – second extended matrix, truncated (10/20 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.284411	0.282270	1.008	0.313654
CE	0.789446	0.332638	2.373	0.017631
CD0.10	-1.498826	0.386262	-3.880	0.000104
CD11.20	-1.659899	0.408034	-4.068	4.74e-05
CE0.10	-1.225457	0.737539	-1.662	0.096603
CE11.20	0.008608	0.285083	0.030	0.975913
CE.CE0.10	1.513139	0.812790	1.862	0.062651

Table 153: Shipping Lines/Shipbuilding GLM – second extended matrix, truncated (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.30474	0.28413	1.073	0.28349
CE	1.08302	0.31160	3.476	0.00051
CD0.8	-1.64956	0.40846	-4.039	5.38e-05
CD9.16	-2.03948	0.47212	-4.320	1.56e-05
CE0.8	-1.16827	0.73786	-1.583	0.11335
CE9.16	0.02612	0.28655	0.091	0.92738
CE.CE0.8	0.99642	0.81214	1.227	0.21986

Table 154: Shipping Lines/Shipbuilding GLM – second extended matrix, truncated (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.2469	0.2794	0.884	0.376824
CE	0.4660	0.3574	1.304	0.192270
CD0.11	-1.3732	0.3678	-3.733	0.000189
CD12.22	-1.8597	0.4350	-4.275	1.91e-05
CE0.11	-1.3258	0.7378	-1.797	0.072354
CE12.22	0.2469	0.2794	0.884	0.376824
CE.CE0.11	1.9764	0.8193	2.412	0.015849

Table 155: Paired Industries GLM – second extended matrix, truncated (10/20 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.72152	0.18906	3.816	0.000135
CE	1.31418	0.22517	5.836	5.33e-09
CD0.10	-1.10451	0.21942	-5.034	4.81e-07
CD11.20	-1.31278	0.23264	-5.643	1.67e-08
CE0.10	-0.40347	0.40978	-0.985	0.324817
CE11.20	0.02804	0.18488	0.152	0.879434
CE.CE0.10	0.69115	0.46129	1.498	0.134055

Table 156: Paired Industries GLM – second extended matrix, truncated (8/16 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.7504	0.1904	3.940	8.14e-05
CE	1.4803	0.2178	6.797	1.07e-11
CD0.8	-1.3009	0.2329	-5.586	2.33e-08
CD9.16	-1.5382	0.2509	-6.131	8.75e-10
CE0.8	-0.5566	0.4386	-1.269	0.204
CE9.16	0.1591	0.1853	0.859	0.390
CE.CE0.8	0.5346	0.4861	1.100	0.271

Table 157: Paired Industries GLM – second extended matrix, truncated (11/22 years)

	Estimate	Std Error	z value	Pr(>|z|)
Industry	0.720137	0.188939	3.811	0.000138
CE	1.079944	0.239246	4.514	6.36e-06
CD0.11	-1.008814	0.214079	-4.712	2.45e-06
CD12.22	-1.313350	0.232613	-5.646	1.64e-08
CE0.11	-0.408133	0.409678	-0.996	0.319139
CE12.22	-0.009731	0.185062	-0.053	0.958064
CE.CE0.11	1.068490	0.465575	2.295	0.021734

Table 158: Total Increasing Returns/Total Constant Returns Industries GLM – second extended matrix, truncated (10/20 years)

	Estimate	Std. Error	z value	Pr(>|z|)
Industry	0.98496	0.16474	5.979	2.25e-09
CE	1.01283	0.20592	4.919	8.72e-07
CD0.10	-0.78173	0.17313	-4.515	6.33e-06
CD11.20	-0.75089	0.17207	-4.364	1.28e-05
CE0.10	-0.04322	0.28838	-0.150	0.881
CE11.20	0.11091	0.15688	0.707	0.480
CE.CE0.10	0.47726	0.34494	1.384	0.166

Table 159: Total Increasing Returns/Total Constant Returns Industries GLM – second extended matrix, truncated (8/16 years)

	Estimate	Std. Error	z value	Pr(>|z|)
Industry	1.0501	0.1678	6.259	3.87e-10
CE	1.2261	0.1992	6.156	7.45e-10
CD0.8	-0.9512	0.1813	-5.246	1.55e-07
CD9.16	-1.0908	0.1877	-5.811	6.21e-09
CE0.8	-0.1422	0.3048	-0.466	0.641
CE9.16	0.2302	0.1583	1.454	0.146
CE.CE0.8	0.2620	0.3567	0.735	0.463

Table 160: Total Increasing Returns/Total Constant Returns Industries GLM – second extended matrix, truncated (11/22 years)

	Estimate	Std. Error	z value	Pr(>|z|)
Industry	0.96663	0.16358	5.909	3.44e-09
CE	0.77769	0.21619	3.597	0.000322
CD0.11	-0.72784	0.17080	-4.261	2.03e-05
CD12.22	-0.69773	0.16982	-4.109	3.98e-05
CE0.11	-0.08731	0.28796	-0.303	0.761748
CE12.22	0.15370	0.15625	0.984	0.325260
CE.CE0.11	0.81917	0.34913	2.346	0.018962

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For the thesis main body only. The references for the case studies are located in the Case Study Bibliography section after this section.

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