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Replication as a strategy in capital intensive industries

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Abstract

Researchers describing replication strategies have proposed theoretical constructs that are positively associated with successful replication. In a rigorous quantitative exploration of replication in capital intensive industries, this study is the first of its kind and seeks to prove the applicability of the theoretical frameworks.

Responses to questionnaires sent to petrochemical refining sites, coupled with an independent performance metric (the Solomon Associates Comparative Performance Assessment Index) were used to model the impact of replication practices on site performance. This model is used to show that firms attempting to centrally define an Arrow Core suffer a performance penalty. Furthermore, the model shows that a clear differentiation between the phases of ***exploration*** and ***exploitation*** is not a requirement for successful replication in capital intensive industries.

The model helps to explain why barriers exist preventing the conceptualisation of the core capabilities within capital intensive industries; why companies seeking to locally control deleterious practices are negatively impacted compared to those implementing centralised mechanisms; and why the effective use of a template yields a performance advantage even in the absence of a well defined Arrow Core.

The analysis also suggests appropriate practices for managers seeking to expand in capital intensive sectors.

Declaration

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University. I further declare that I have obtained the necessary authorisation and consent to carry out this research.

Melvin Jones

13 November 2008

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1. Introduction

1.1. Background

Despite the increasing prevalence of replication as a method for company expansion, the subject has not been popular amongst researchers (Winter & Szulanski, 2001). This is despite the fact that replication forms the basis of several successful expansion strategies, leading to the popularisation of the “MacDonald’s approach”.

Replication is also a common expansion method within the industrial and manufacturing sector, where companies role out technology and significant capital infrastructure across multiple sites. While replication of technology and tacit assets is relatively easily understood, the role of the intangible assets in successfully operating that technology is poorly understood (King, 2007).

There is significant evidence that the differences in the intangible assets between companies within the petrochemical sector significantly affect performance and profitability (Bloch & Hernu, 2007, King, 2007). This has been shown through the measurement of wide variations in profitability between sites with access to similar levels of modern technology. In addition, there exists a weak correlation between performance and the physical factors of size, age and geographic location of these operating sites (Bloch & Hernu, 2007).

Research has indicated that a firm's performance is strongly dependent on the build-up of knowledge within the firm (Spender & Grant, 1996). While considerable attention has been given to knowledge management and the ability or mechanism of the organisation to learn, few academics consider the implication that organisations therefore carry "knowledge" in their own right (Kogut & Zander, 1992). This introduces a differentiation between the codified or captured business processes surrounding the company's technology, and the tacit know-how which exists within a company and therefore allows for successful operation (Kogut & Zander, 1992).

While the usage of central organisational knowledge in the replication of standardised business processes has been postulated (Winter & Szulanski, 2001) and qualitatively shown (Szulanski & Jensen, 2004) to be a successful approach, variation in response to unique local conditions is inevitable (Jensen, 2007a). At the unit level, significant variations exist in the business processes of firms implementing a replication strategy. This implies that firms need to expressly manage the implications of variation within the model identified for exploitation (Jensen, 2007a).

Given that replication is more complex than apparent on face value (Rivkin, 2000), the benefit of variation on replicated processes that are underpinned by poorly understood interactions must be balanced against uniformity (Winter, Szulanski, Ringov and Jensen, 2007). Empirical evidence from the study of a United States franchising firm (in the service sector) indicates the superiority of precise replication strategy that seeks to minimise variation at a local unit level (Winter *et. al.,* 2007). When interactions are not well understood, or even recognised to be present, the potential benefits of prudent local adaptation and continuous improvement are negated by the negative impact of deviation from the recipe provided in a larger system (Jensen, 2007b).

This is supported by research into the penalties incurred by companies attempting to imitate competitor's superior performance, which shows that even small errors can lead to large performance penalties (Rivkin, 2000).

1.2. Problem statement

Companies active in the service and consumer industries are generally aware of the concepts of replication, and what elements of their business generate their unique differentiation. Evidence from companies like MacDonald's and Starbucks indicate how specific routines and human capital are successfully replicated across multiple sites (Winter & Szulanski, 2001). This shows a realisation that there is benefit from the replication of company knowledge that goes beyond the replication of products or technology, specifically given the strategic advantage gained from this difficult to imitate company asset (Szulanski & Jensen, 2004; Rivkin, 2000).

The benefit of the explicit re-utilisation of knowledge and successful business processes within capital intensive engineering industries has been explored (Hicks, Culley, Allen and Mullineux, 2002). However, the focus of these studies has tended to be around the design and replication of the capital intensive technology, rather than the replication of the business processes required to operate that technology (Hicks *et. al.,* 2002).

While this may be justified given the positive impact of technology adoption on refinery survival (Chen, 2002) and the evidence that large petrochemical sites are more responsive at adopting technology (Chen, 2005), recent benchmarking studies show strong evidence of non-technology related influences (Bloch & Hernu, 2007).

Wide variations in performance, measured as return on Investment (ROI), exist between refineries (Bloch & Hernu, 2007). This is true between sites within a company, between sites of similar physical description (size, age and geographic location), and between sites employing similar technologies (Bloch & Hernu, 2007). This indicates that site practices and business processes, as well as site culture, have a significant effect on site performance (Bloch & Hernu, 2007), over and above the impact of technology adoption (Chen, 2005).

In short, the benefits of a business process replication strategy within the capital intensive industry of petroleum refining have not been appreciated, exploited or adequately proven as a desirable and successful strategy.

1.3. Research aims

Until recently the research direction of company replication has been relatively poorly explored (Winter & Szulanski, 2001). Recent studies into the success of replicating organisational routines (Szulanski & Jensen, 2004) and the empirical evidence of uniformity of replication within the service sector (Winter *et. al., 2007;* Jensen, 2007a; Jensen, 2007b) show the success that controlled replication can achieve within the service sector.

This research aims to test the applicability of replication theory within capital intensive industries. The research will show the effect that formal replication has on the success of different manufacturing sites, specifically focusing on the replication of business processes and intangible knowledge assets. The research will make use of inter and intra company performance data, as well as information about company replication practices to arrive at a conclusion of the role of intangible asset replication.

1.4. Research relevance

Globally the demand for resources has been rapidly expanding, driven largely by high growth in the large emerging economies of Brazil, Russia, India and China (BRIC) (The Economist, 2008a).

The petroleum refining industry is an excellent proxy for capital intensive industries, as it exhibits many of the characteristics that are common in this sector. Capital investment for the past number of years has been sluggish (The Economist, 2008b), due to factors such as high capital requirements, mismatch between availability and market requirements and high demand for engineering skills. However, the balancing effect of supply and demand has created an increase in the spending within this sector, as well as having a dampening effect on demand (The Economist, 2008b).

With the South African context, the government has targeted an aggressive economic expansion plan, laid out in the Accelerated and Shared Growth Initiative for South Africa (AsgiSA) (The Presidency of RSA, 2006). AsgiSA targets the capital intensive industries such as chemicals and beneficiation for future growth.

In this climate of high demand for resources, companies in capital intensive industries like mining, manufacturing, beneficiation and refining are looking to expand. While speculation regarding global recession and economic turmoil following the financial crisis exist, demand from the developing BRIC economies will create a floor to falling commodity prices (The Economist, 2008c). This suggests that expanding capacity within capital intensive industries remains topical, both locally and internationally.

1.5. Scope and limitations

The research is focused on replication practices within the global capital intensive manufacturing industry. The petroleum refining sector is used as a proxy to study applicability of replication within capital intensive industry.

2. Literature review

The source of firms' competitive advantage, specifically as an input to strategic direction, has been intensively studied over the last three decades (Teece, Pisano & Shuen, 1997). During this time, various models have been proposed regarding how to identify relative advantage between firms. Teece *et. al.* (1997) suggest a clustering of these into three strategic paradigms. These clusters are used to introduce three main logical groupings of the source of competitive advantage. The first two concepts could be further grouped into a market based view of determining competitive position and profitability, versus the resource view assumed in the third cluster (Teece, *et. al.,* 1997).

2.1. Resources-based view

The cornerstone of a resource-based view on competitive advantage lies in a belief that the source of advantage lies in the tacit and difficult to imitate resources of the firm, rather than in the explicit technology (Teece, *et. al.,* 1997). This resource-based view is in line with Zander and Kogut's (1995) definition of the firm as "a repository of social knowledge, where competitive sets of capabilities are replicated over time while subjected to imitation".

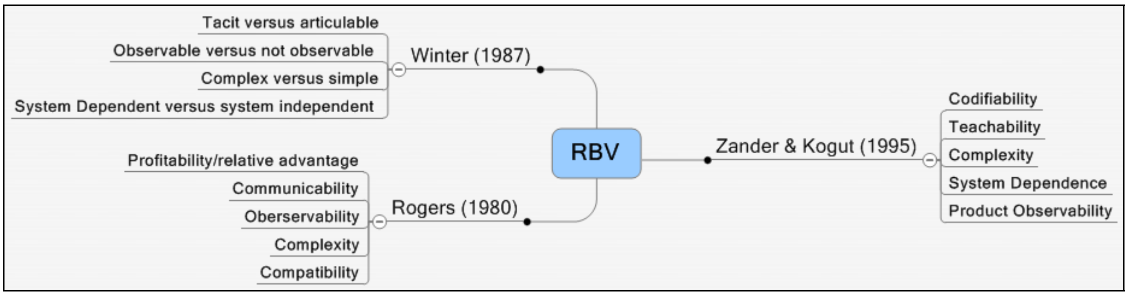
Studies find that the profitability differences between firms operating within an industry are larger than the differences that exist between industries (Rumelt, 1991). This evidence would suggest that the effect of capital outlay on new technology, as well as the effect of market forces, is generally smaller than the effect of firm-specific factors on profitability (Teece, *et. al.,* 1997). This has been shown to be true within petroleum refining, where large discrepancies in performance are evident between sites of similar physical description (Bloch & Hernu, 2007).

2.1.1. Characterising resources

Several different researchers have introduced concepts which can be used in different situations to characterise the resources which provide a firm its competitive capabilities (Rogers, 1980; Winter, 1987; Zander & Kogut, 1995).

Each of these researchers used a subtly different model to describe the aspects of the firm's resources, and then applied that model to characterise the ease of transfer and imitation of the firm's key resources. Figure 1-1 summarises the key concepts from each of these researchers.

Figure 1 - 1: Characterising capabilities using the RBV



2.1.2. Uncertainty within the firm

The elements within the frameworks presented in figure 1-1 explicitly allow for firm capabilities which cannot be easily characterised. Becker and Knudsen (2005) argue that all firms exist with several sources that introduce uncertainty:

- The environment in which the business operates (external)
- The effect of decisions on the firm (internal and external)
- The effect of the firms actions and responses (internal and external)

Understanding these uncertainties gives a basis with which they can potentially be managed and more fully understood (Becker & Knudsen, 2005). Uncertainly can be classified into 4 broad categories (Becker & Knudsen, 2005):

- **Certain:** The outcomes of any decision or set of circumstances can be fully understood, and the end result is known.
- **Probabilistic:** Outcomes can measured for risk and likelihood, and the possible outcomes are exactly known. This allows for a mathematical analysis of options.
- **Uncertain:** Outcomes are based on subjective judgement, ie not all probabilities are know. Decision making is improved by more analysis and investigation, as a more accurate characterisation of options is made.
- **Pervasive uncertainty:** Outcomes cannot be objectively or subjectively understood, and additional analysis of underlying data does not improve decision making. Given the finite nature of firm resources, additional effort

expended on analysing pervasively uncertain situations will decrease to total firm performance.

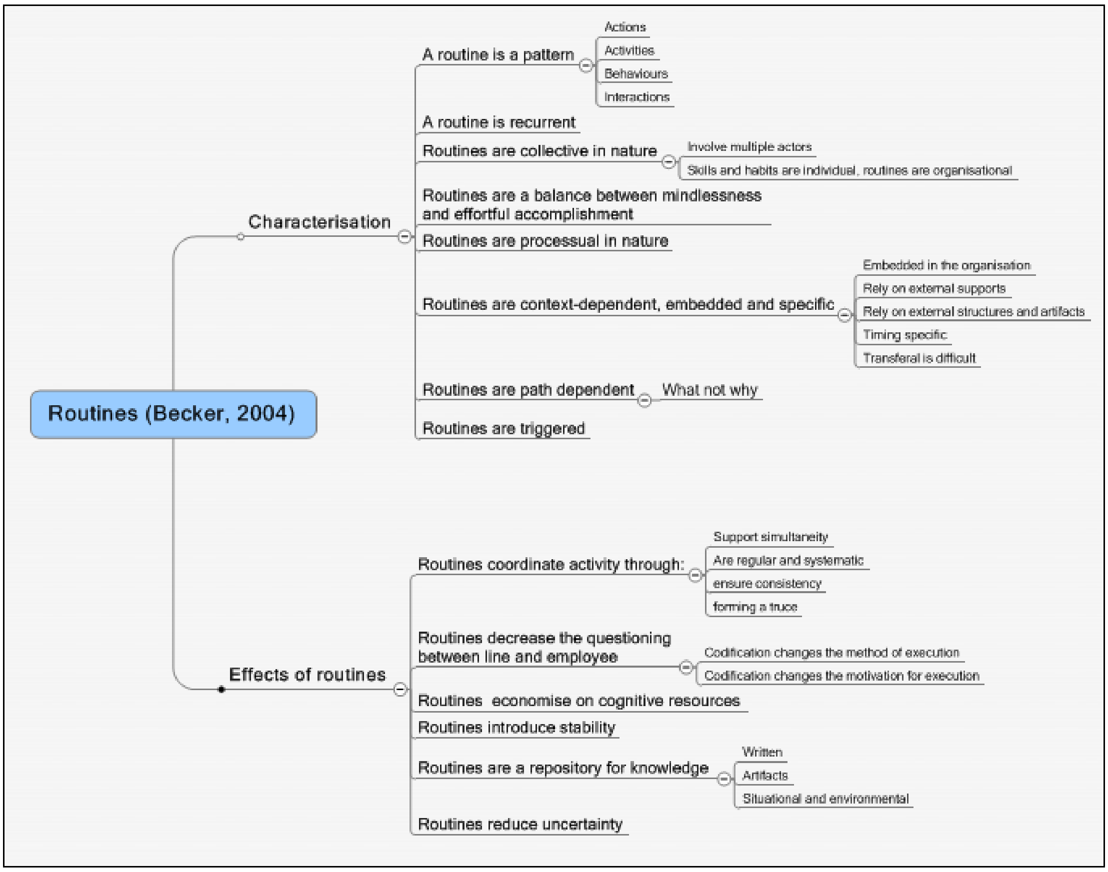
By economising on limited cognitive resources within the firm, routines preserve decision making and information processing capabilities. By formalising repetitive and frequent actions, these resources can be guided in the face of uncertainty (Becker, 2004).

2.1.3. Routines

Nelson and Winter (1982) first introduced the concept of using routines as a unit of analysis in the measurement of economic and organisational behaviour (Becker, 2004). Since then, this sub-field within the greater RBV subject matter has been actively researched (Becker, 2004).

Becker (2004) avoids attempting to define a routine, opting rather to utilise elements from other researchers to fully characterise what makes a routine. In addition, through an extensive review of the literature, Becker (2004) maps the effects routines have on organisations. Figure 1-2 shows the eight characteristics of routines, as well as the six main effects routines have on organisations.

Figure 1 - 2: Routines: their characterisation and organisational effects

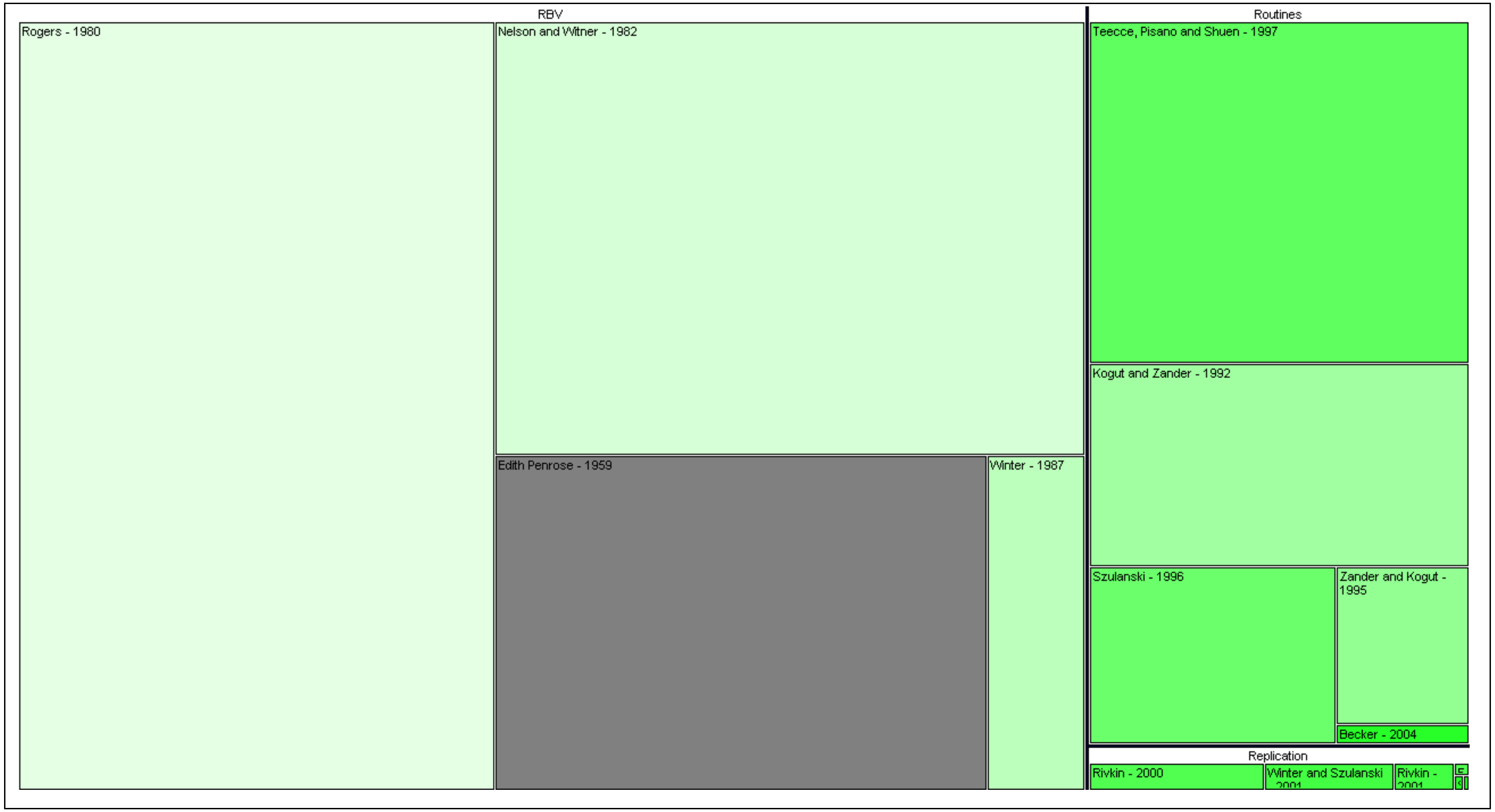


2.2. Replication

Replication as a theory base should be viewed as contributing to the resource-based view of organisational capabilities (Jensen, 2007b), specifically building on the research into routines as mechanism for describing the capabilities of the firm.

Figure 1-3 shows a schematic representation of the literature applicable to this research project. In the figure, the block is scaled by number of academic citations (an indication of its contribution to the RBV research field). The colour indicates the relative age of the research, with bright green being very recent gradually fading to grey as the date of publication recedes.

Figure 1 - 3: Treemap of the Resource Based View literature



The schematic is intended to show how relatively immature the research into replication is when compared and placed within the subfield of routines, within the larger field of RBV literature.

While the reliance on a relatively small number of primary researchers may seem excessive (Winter, Szulanski, Rivkin and Jensen), they are all affiliated to top universities, and have published in the pre-eminent business research journals (*Organisation Science*, *Strategic Management Journal* and *Harvard Business Review*).

2.2.1. Introduction

Replication is a phenomenon or process whereby organisations create and operate a large number of individual sites, producing products or performing similar services (Winter & Szulanski, 2001). It involves the redeployment and transfer of company resources from one economic setting to another (Teece, *et. al.,* 1997).

Replication has been occurring to the extent that this form of business is now one of the dominant organisational models (Winter & Szulanski, 2001). The ability for the parent company to re-utilise local success in a complex activity to capture profits on a larger scale is the main driver behind this approach (Szulanski & Winter, 2002).

Despite the appeal for grand scale replication, evidenced by whole industries attempting replication in some form, the majority of attempts to replicate local excellence fail (Szulanski & Winter, 2002). In the presence of such popularity, it is surprising that replication as an organisational model has been largely neglected by theorists (Winter & Szulanski, 2001).

Over the last decade, a combination of theory development and empirical evidence has started to shed light on the factors necessary for successful replication, as well as potential pitfalls (Jensen, 2007b; Winter *et. al.*, 2007; Szulanski & Winter, 2002; Winter & Szulanski, 2001; Rivkin, 2001; Rivkin, 2000).

One of the central tenants in business is to create a defensible position where the company can sustain and enhance its competitive advantage (Porter, 1980a). This allows the company to sustain returns above average market levels (Porter, 1980a). In defending such a position, replication can be a double edged sword.

Replication as a viable strategy arises largely due to the company's ability to exploit new opportunities faster than its competitors, due to the ability to transfer knowledge of individuals throughout the organisation (Kogut & Zander, 1992). This can be contrasted to the requirement for new companies to invent the knowledge and business processes, particularly in an environment where the key success factors may be poorly understood (King, 2007).

The success factors to exploit a replication strategy closely resemble the factors which lower the barriers to imitating that success (Zander & Kogut, 1995). Balancing the ability to successfully replicate with a defence against imitation in the presence of pressures to exploit a temporal opportunity increases the complexity of successful replication (Szulanski & Jensen, 2004; Rivkin, 2001).

Replication of company knowledge, tacit and explicit, is a key success factor in the replication of technology, i.e. the replication of the technology in the absence of the supporting processes does not automatically deliver value (Kogut & Zander, 1992). Given the evidence that companies lack the ability to develop new competencies quickly (Teece, *et. al.*, 1997), exploiting a strategic advantage in the short run requires that firms understand how to mobilise knowledge assets quickly.

Replication theory presents a basis for achieving this (Szulanski & Jensen, 2004), backed by empirical evidence that the absence of a formal replication strategy significantly decreases chances for success (Jensen, 2007b; Winter *et. al.*, 2007; Szulanski & Jensen, 2004).

While it may be tempting to think that replication is restricted to greenfield investments, this would show an appreciation of only a portion of the theoretical construct (Winter & Szulanski, 2001). Using replication theory to design the role-out of best practices into existing or acquired brownfield sites increases the probability of a successful implementation. Thus the application of replication theory is consistent between greenfield and brownfield sites (Szulanski & Jensen, 2004; Winter & Szulanski, 2001).

2.2.2. Phases of replication

Replication is argued to occur in two distinct phases, namely **exploration** and **exploitation** (Winter & Szulanski, 2001). Given that urgency in response to the threat of imitation is usually associated with a replication strategy, these two distinct phases may not be distinct in time (Winter & Szulanski, 2001).

During the exploration phase, companies are replicating their business model, but are learning more about what elements are key success factors for the business. After the first few replications, companies are able to compare between different sites. At this point, the expansion or replication strategy can move to phase two, where the company exploits a well defined and frozen model to replicate. In many cases, this freezing of the business may occur before the exploration has delivered the optimum solution (Winter & Szulanski, 2001).

Part of understanding the nature of this two phase approach is the understanding that replication is a dynamic and non-steady state process. Companies are continually adjusting the model with which they replicate their processes. It is also important to understand the key differences between true replication and a *faux replication* strategy. As opposed to developing the organisational traits, and ensuring a broad transferral of knowledge, best practices and technology, *faux* *replication* uses local adoption and adaptation processes to establish the new site (Winter & Szulanski, 2001).

There is therefore an always present tension in replication – on the one hand, it is important to allow for enough exploration to define the optimal mode to replicate. On the other hand, it is necessary to fix the model and not constantly introduce variation.

2.2.3. Key concepts

One of the core concepts in replication theory is the usage or existence of a template. The original definition of a template is: the existing routine or example that serves as a point of departure for replication (Winter & Szulanski, 2001).

Research has shown that replication is more likely to succeed when a template exists (Szulanski & Jensen, 2004). The template refers to the requirement for a working model of the desired business. Companies are able to replicate working examples by allowing observation of the practices in operation. It is possible to differentiate between physical examples, where the template is an actual site, and hybrid or mix and match templates where information and documentation from site(s) provide the guidance (Winter & Szulanski, 2001).

A similar concept, introduced by Barley and Tolbert, 1997, is the concept of a script. A script can be defined as a recurrent set of activities and patterns of interaction between actors in an institutional setting. These behaviours serve to maintain the structure within the organisation.

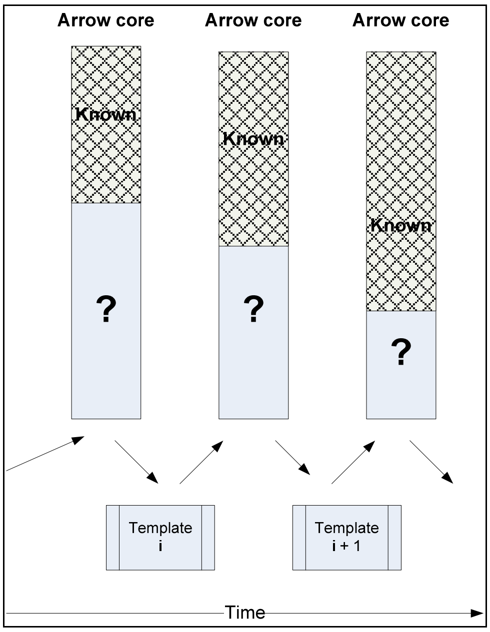
Existing within any organisation are positive contributors to success, but also non-value adding processes and activities. The degree to which the company understands the relationship between the results and actions taken to achieve those results determines the degree to which key contributors can be identified.

The ideal set of positive contributors is termed the Arrow Core. This is the composite of all knowledge and processes required for the replicator to successfully implement the particular business model (Winter & Szulanski, 2001). The very nature of business predicates that the Arrow Core can never be fully defined, and always remains partially untenable. However, through repeated replication, comparison between successive instances allows the template to be refined, and the Arrow Core to be more completely described. (Winter & Szulanski, 2001)

2.2.4. Model

Winter and Szulanski, 2001, introduce an iterative replication process. At the core of the process is the definition of the Arrow Core, from the observation of a predefined template. Figure 1-4 schematically represents the replication process.

Figure 1 - 4: Iterative arrow core and template procees (Winter & Szulanski, 2001)



An alternative to the above model is the concept of direct replication with no feedback or modification between successive replicas. The choice of model depends on the trade-off between precision/optimisation and speed of execution. This trade off is known as the *replication dilemma* (Winter & Szulanski, 2001).

By balancing between the lost opportunity from tweaking different elements within the business model and the ability to carefully control all elements within the business, one effectively sets the speed of execution. However, with exact replication, several negative or superfluous elements within the business get carried over between successive replicas.

2.3. Pre-determinants for replication success

2.3.1. Complexity

The complexity of a business strategy is largely dependent on the degree to which levels of unpredictability exist within the business process. This leads to causal ambiguity in the understanding of the drivers of business success (King, 2007). Complex business strategies are more difficult to copy, but also hamstring firms from being agile to changing external conditions.

Complex internal business models necessitate arriving at local rather than global optima. This internal tension between heuristics and optimisation provides the key to the barrier to external firms replicating the successful business model (Rivkin, 2000). High levels of complexity ensure that the solution of the global optimum is intractable.

These high levels of internal complexity and uncertainty inherently mean there are tacit success factors which cannot be codified. While it is exactly this complexity which protects a firm from external copying, it makes replication of the business model equally difficult. The idiosyncratic nature and scarcity of key resources, as well as a tendency to underplay or under appreciate the role of these key resources, further complicates replication (Winter & Szulanski, 2001). Further complexity is introduced when the companies are operating across borders, specifically when the unique relationship between headquarters and subsidiaries is a strong determinant of replication success (O'Donnell, 2000).

Firms should also realise that even relatively minor modifications in major replication generally encounter larger than expected difficulties. This is due to causal ambiguity and the skewed distribution of key knowledge. In circumventing this complexity firms need to take note of the stickiness of key knowledge transfer within the organisation. This stickiness can be significantly reduced through the existence and access to a template (Szulanski & Jansen, 2001). This free access to a template gives the replicator significant advantage over the competition (see previous section for description regarding the definition and usage of a template).

In a follow-up to the 2000 study, Rivkin (2001) shows that there is a complexity band within which the replicator enjoys maximum advantage over potential imitators. When the complexity is below a finite limit, imitation is trivial, and the threat of competitors is high. When the complexity exceeds a threshold, the complexity becomes so great that the replicator looes any advantage. There is thus a desirable level of moderate to high complexity which lowers internal barriers for replication and raises barriers to imitation.

2.3.2. Environmental changes

In many cases, internal business processes and manufacturing success are dependent on the way in which the business interfaces with suppliers and customers (O'Donnell, 2000). When these cannot be replicated or supplied in a new environment, it may be necessary to attempt importing or duplicating the original conditions in which success was achieved. In this case it can be argued that changing portions of the environment in order to ensure business success is key (Florida & Kenney, 2000: 291). Achieving success in new environments introduces complexity when considering the interaction between bureaucratic controls and local autonomy (O'Donnell, 2000).

Replicators may also be forced to change other ingrained environmental factors or work conditions, like labour relations and employee contracts. In order to successfully create elements of social culture and team based responses, unionisation and worker conditions are key variables in how effectively non-codified technology can be transferred (Florida & Kenney, 2000: 295). This duplication or importing of environmental conditions is created by the need for symmetry between inter and intra company work practices (Florida & Kenney, 2000: 295).

2.3.3. Technological drivers

Several macro economic trends have influenced the development and adoption of new refining technologies. Three of the most important trends are (Chen, 2005):

- Global changes in available crude oil quality, as many oil fields become depleted.
- Continuous adoption of more stringent environmental and quality specifications by regulators.
- Global changes in the demand for product mixes, with a significant swing towards middle distillate products (diesel).

While the above factors drive technology adoption and change across the industry, distinct differences exist in the adoption between individual refinery sites (both inter and intra firm) (Chen, 2005). These differences flow from the “least cost” strategy of operating multiple and geographically dispersed refineries, minimising outbound transportation costs by servicing local consumers. Factors such as inter-refinery competition and local market effects therefore have a large impact on relative technology adoption (Chen, 2005).

By using the technological complexity index developed by Nelson (1976) as an indication of how contemporary the technology within a site is, Chen (2005) is able to show that large scale technology adoption and modernisation is required to keep refineries in business. More detailed methods of analysing the effect of technology on the profitability of a refinery site are available (Liu, Yu, Fan & Bao, 2006). However, the findings from Chen (2005) indicate a gradual trend of mass technology modernisation across all operating sites, necessitated by micro and macro economic trends.

2.3.4. Knowledge management system drivers

Modern information and communication technology enables global manufacturing businesses to benefit through improved operations, by supporting knowledge sharing and knowledge management within those global enterprises (Liu & Young, 2006). Tools such as Product Lifecycle Management (PLM) and Enterprise Resource Planning (ERP) are examples of knowledge based systems which provide significant support to global decision making (Liu & Young, 2006).

These systems form the basis of the codified company knowledge (Zander & Kogut, 1995), and inter-company differences in the extent and success with which these systems are deployed affects the sustainability of their competitive advantage (Hicks, Culley, Allen & Mullineux, 2002). The successful deployment of these types of systems enables companies to rapidly role out previously captured procedures and company knowledge. This allows a better understanding of the structure and relationship between knowledge elements within the business, improving global decision making (Liu & Young, 2006).

3. Research hypotheses

Winter and Szulanski (2001) propose the usage of a template and the concept of the Arrow Core as central elements of successful replication. This is consistent with the concept that replication and continuous improvement is difficult in scenarios with high levels of tacit knowledge, which would indicate a poor understanding of the underlying processes (Teece, *et. al.,* 1997). In addition, the successive phases of exploration and exploitation can be used to characterise replication efforts (Winter & Szulanski, 2001).

More recently, studies by Winter *et. al.* (2007) and Jensen (2007b) have shown empirically that even small variations and local adaptations detract from the potential benefits of a replication strategy.

Given the evidence of the effects that both formal and tacit knowledge have on the performance of petroleum refineries (Bloch & Hernu, 2007), it is reasonable to postulate that replication theory is an appropriate strategy in this industry. The research will specifically test for the presence of Winter & Szulanski's (2001) central constructs in the petroleum refining industry. This will be used as a proxy to generalise findings for capital intensive industries.

Previous studies into the methods and applicability of replication have all been qualitative case studies or model-based simulations. While these give insight into the mechanisms of replication, they do not quantitatively test replication theories. This study directly measured the way in which replication was conducted, and shows the performance impact of replicating. In doing so, it is the first study of its kind.

The specific research hypotheses that are proposed are divided into a characterisation of the exploration (Hypothesis 1) and exploitation (Hypothesis 2) phases of replication. The hypotheses proposed are:

Hypothesis 1 *(Exploration)*: Successful replication is correlated with the development or conceptualisation of the Arrow core (Winter & Szulanski, 2001).

H1a: Successful replication is correlated with the definition of core capabilities at a centre or focal part of the organisation (Kogut & Zander, 1992).

H1b: Successful replication is correlated with the explicit definition of the valued features of the final product/service that are non-negotiable for each the organisation as a whole (Winter & Szulanski, 2001).

H1c: Successful replication is correlated with the identification of the procedures involved in the local production of the valued features (Winter & Szulanski, 2001).

H1d: Successful replication is correlated with the conscious identification and elimination of information and business processes that are deleterious (Winter & Szulanski, 2001).

Hypothesis 2 *(Exploitation)*: Successful replication is correlated with the effective use of a template (Winter & Szulanski, 2001).

H2a: Successful replication is correlated with accurate and exact implementation of a set of business processes (Winter *et. al.*, 2007; Winter & Szulanski, 2001).

H2b: Successful replication is correlated with the control of variation in the local adaptation of the template (Jensen, 2007b).

H2c: Successful replication is correlated with the controlled exploration and adaptation in sites where a close replica of the template is in place and operating.

4. Research methodology

4.1. Population of relevance

The research targeted capital intensive industries to extend the body of replication knowledge and test its applicability outside the retail and service sectors. Capital intensive industries are those that are characterised by a high investment in assets relative to sales or profits generated from those assets (Firer, Ross, Westerfield & Jordan, 2004: 93). As such, the target population can be defined as all capital intensive industries (Zikmund, 2003:373).

Given the current boom in demand for resources and industrial production capacity, the relevance of replication as a strategy in capital intensive industries is a contemporary problem (The Economist, 2008b).

4.2. Sample frame and sample

Solomon Associate provides independent global benchmarking and consulting services to energy industries. Through their independent Comparative Performance Analysis (CPA), they are able to gauge the relative performance of petroleum refineries (Solomon associates, 2008). The CPA is a consistent and uniformed benchmarking assessment, which minimises the effect of size, complexity and location on the performance index. This creates a multi-dimensional measure of comparative performance between refining sites (Solomon associates, 2008).

This independent objective measure allows for a correlation between performance and the elements of replication strategy to be determined. The sampling frame can be defined as the portion of the working population which can be practically dealt with (Zikmund, 2003: 373). Given the availability of an objective measurement, the petroleum refineries that participate in Solomon's Benchmarking (85% of global capacity) were selected (Solomon Associates, 2008). This formed the basis of the decision to use refining as the representative sample for capital intensive industry. Information was sampled particularly from the following global petroleum refinery companies.

- Sasol – 1 site
- Petronas – 3 sites
- Chevron – 12 sites
- Total – 27 sites
- BP – 17 sites
- Shell – 38 sites
- ExxonMobil – 58 sites
- ConnocoPhillips – 12 sites

4.3. Unit of analysis

The unit of analysis will be single production sites within each of the companies within the sample.

4.4. Data collection instrument - design

Two types of data were collected, both using the electronic survey software service of Survey Monkey. Firstly, data about the objective measurement, i.e. the Solomon's CPA, was collected to give an indication of the absolute performance of the various sites. The questionnaire asks participants to indicate the performance of their site based on the categories which Solomon define, namely pace-setter, first quartile, second quartile etc. Solomon Associates were also directly approached to contribute to the success of the study, but declined to participate.

In addition to the unbiased CPA measure, respondents were asked to indicate their perception regarding the performance of their site. This biased indicator of performance was used as a second dependent variable. This biased indicator captures managerial perceptions, over an above the objective measurement. This is necessary since these perceptions are often a significant driver in the decision making process (Seal, Garrison & Noreen, 2006).

Secondly, data regarding the replication practices within sites was gathered. As introduced in the literature survey, all previous studies into replication have been qualitative (Zander & Kogut, 1995, Szulanski & Jensen, 2004). This qualitative research has generated theories regarding replication, but these have never been tested. The questionnaire was designed based on the elements of previous research, and transitions from theory generation into theory testing.

Key concepts of simplicity, avoiding loaded questions, avoiding ambiguity and local layout were adhered to (Zikmund, 2003: 336). Questions were created to directly test the various aspects proposed by the hypotheses. The questionnaire is divided into three main sections, namely:

- Introduction of survey and demographic questions
- Questions regarding the definition, existence and general practices regarding the template site
- Testing implementation and control of the Arrow Core, as well as practices for controlled variations.

By dividing the questionnaire into distinct sections, it was possible to collect, analyse and include partially completed responses. This, coupled with the two dependent performance variables, improved the significance and rigour of the data analysis.

Once the questionnaire had been drafted and reviewed to the satisfaction of the primary researchers, it was sent for review to a leading contemporary in the field of replication (Dr. Robert Jensen received his PhD from Wharton, and has been widely published in top journals like Organisation Science and Strategic Management Journal). His response was used to improve the quality and coverage of the questionnaire, and specifically to remove some ambiguities regarding the underlying elements being tested.

The updated questionnaire was sent to a group of five industry managers as a pre-test. This pre-test ensured that the purpose of the study was being clearly communicated in the introduction, and that all questions were unambiguous and easily interpreted. Final adjustments to the questionnaire were made based on the feedback received from this group.

A copy of the questionnaire is included in Appendix 1.

4.5. Data collection

Data was collected via electronic questionnaires (Survey Monkey). As mentioned, the population sampled was refineries that participate in the Solomon Associates CPA. This represents 85% of total global refining capacity (Solomon Associates, 2008).

Within this total pool, two different solicitation techniques were used to collect the data. The researchers had direct access to senior management within a subset of the large, Western manufacturing companies. These companies were directly approached and asked to participate in the study. As such, questionnaires could be target to specific individuals within these companies.

In addition to these "solicited" questionnaires, "unsolicited" requests were sent to the other operating companies within the population. Since the responses were kept anonymous, the effect of respondent bias based on the differences in the manner of introduction cannot be eliminated. The effect from this bias was not anticipated to affect the results of the study.

In both instances, the site production manager was targeted to complete the survey, but responses from other senior managers were expected. This discrepancy between respondents was not expected to affect the quality of the results.

In the case of both the groups, an initial introduction and opportunity to opt out was given a few days before sending out the survey for completion. Three follow-up reminders were sent to each participant, in an attempt to maximise the opportunity and likelihood to receive a good response (Fowler, 2001). This method of repeated requests was also seen as a partial mitigation to the potential unavailability of the collection tool (Survey Monkey). This was only partially successful, and complaints about the survey being unavailable were received.

4.6. Data analysis

The data from the questionnaire was characterised into 12 independent variables representing the sub-elements within the main hypotheses. The responses gathered from the questions were transformed from the total of 28 questions into these 12 variables.

The composite variables are identified in table 4-1, with a cross reference to the questions in the questionnaire. The details of the transforms, creating these variables from the 28 questions, are presented in table 4-2.

Table 4 - 1: Description of variables

Variable #	Variable description	Questionnaire
x_1	Effective site age (as indication of technology)	*Q1.2, Q1.4*
x_2	Company size	*Q1.3,*
x_3	Existence of a template site	*Q2.2*
x_4	Degree of implementation of precise template practices	*Q2.4, Q2.5, Q2.6, Q2.7,*
x_5	Degree of local variation and adaptation of template practice	*Q2.8, Q2.9, Q2.10, Q3.7, Q3.3*
x_6	Active elimination of deleterious practices	*Q3.4*
x_7	Template practices replication methods	*Q2.3, Q3.5, Q3.6,*
x_8	Degree of controlled adaptation at template site	*Q3.9, Q3.10*
x_{8a}	Degree of controlled adaptation at template site	*Q3.11*
x_9	External introduction of replication strategy *(category variable)*	*Q2.11, Q2.12,*
x_{10}	Degree of variation control mechanisms	*Q3.1, Q3.2, Q3.12*
x_{11}	Geographic influences *(category variable)*	*Q1-1*
y_1	Site Performance Estimate (biased)	*Q2.1*
y_2	Solomon's Comparative Performance Analysis Ranking (unbiased)	*Q3.8*

Table 4 - 2: Composite variable transforms

Composite independent variables	Transform
X1	0.3 x Q1.2 + 0.7 x Q1.4
X2	Q1.3
X3	Q2.2
X4	0.25 x (Q2.4 + Q2.5 + Q2.6 + Q2.7)
X5	0.2 x (Q2.8 + Q2.9 + Q2.10 + Q3.7 + Q3.3)
X6	Q3.4
X7	(Q2.3 + Q3.5 + Q3.6) / 3
X8	0.5 x (Q3.9 + Q3.10)
X8a	Q3.11
X9	(Q2.11 +Q2.12)/2
X10	(Q3.1 + Q3.2 + Q3.12) / 3
X11	Q1.1
Dependent variables	**Transform**
Y1	Q2.1
Y2	Q3.8

Except in the case of composite variable x_1, all variables were created through the equal weight combination of the normalised responses from each question. The relative technology of the site was composed to give a higher weighting to the last major investment. This compensated for very old sites within the sample where recent modernisation improved technical competitiveness.

Through the analysis of variable x_8 (presented in section 5), it was clear that while the unit of measure was common, two clearly different aspects of controlled adaptation were being answered. In the case of x_8, adaptation of practices common across company sites is represented. In x_{8a}, the local adaptation of practices is measured.

In order to test the Hypotheses set forward, a model between the independent variables in table 4-2 and the dependent variables y_1 (biased estimate) and y_2 (CPA – unbiased estimate determined by Solomon Associates) was built. The variables greyed out in table 4-1 and table 4-2 were used as category variables, and were not included in the model.

Multiple regression was conducted to characterise the relationship between the independent variables and the dependent variables (Albright, Winston & Zappe, 2006: 564). Given the findings from Jensen (2007a) in a preliminary empirical classification of replication data in the services sector, there existed a reasonable expectation of the applicability of linearity between the inputs and outputs.

Due to the unknown extent of the application of replication and template practices within this industry, assumptions about the underlying population distributions could not be made. The possible non-fulfilment of normality assumptions requires the use of robust, distribution-free procedures (Kendall & Stewart, 1967: 465).

Since non-normal distributions can cause traditional least-squares approaches to incorrectly weight observations (especially if there are outliers), these approaches require extensive analysis of residuals and model results. Robust techniques dramatically reduce the level of effort required in this analysis, through the robust treatment of outliers (Kendall & Stewart, 1967: 465).

Given the uncertainty regarding the underlying population distribution, Huber's method of robust maximum likelihood estimation is widely used to perform the robust multi-variable regression, and hence is chosen for the regression analysis (Arslan, Edlund & Ekblom, 2001: 64)

4.7. Research limitations

Petroleum refining was chosen as a proxy for capital intensive industries. This was done due to the availability of the independent variable of the Solomon Associates refinery CPA (Solomon Associates, 2008).

While Solomon Associates do generate a CPA for a broader classification of manufacturing sites in the energy sector, other industries were excluded from this survey (Solomon Associates, 2008). This was done since:

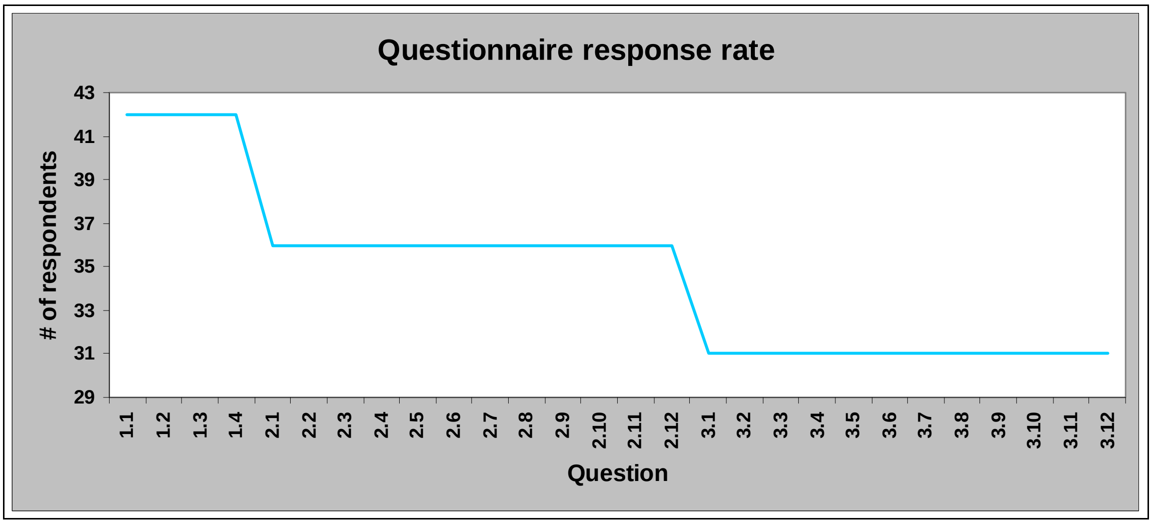
- The characterisation of chemical companies involves a more complex and varied mix of technologies and end products. This would increase the complexity of correcting for technology effects on company performance.
- The coverage of the CPA measure as a percentage of total chemical, power generation and pipeline industries is significantly smaller than in refining.

5. Results and discussion

5.1. Participant responses

The questionnaire (Appendix 1) was designed with three separate sections. This design ensured that if respondents were unable to complete a questionnaire (time constraint, willingness or ability), a partial response could be gathered. By placing two index or dependent variables in different places within the questionnaire, it was possible to complete a partial multiple regression with a larger sample set. The questionnaire response rate is shown in figure 5 - 1.

Figure 5 - 1: Questionnaire completion



42 out of 168 respondents returned a response. Although this is somewhat low in absolute terms, it represents an acceptable response rate of 25%. Response rates to survey questionnaires vary widely depending on the survey type, as well as the

setting (Dillman, 2007: 4). There is a general recognition that electronic surveys receive a lower response rate, with rates as low as 5% not being uncommon. Response rates of above 20% are considered relatively good when using an electronic medium (Couper, Baker, Bethlehem, Clark, Martin & O'Reilly, 1998: 401).

From figure 5 -1 it is clear that roughly 10% of participants declined to complete each subsequent portion of the total questionnaire. The dependent performance questions (y_1 and y_2) were positioned separated on page 2 and 3 of the questionnaire (Q2.1 and Q3.8).

The highly competitive nature of the petrochemical industry has led to organisations being sceptical about sharing information outside of their organisation. Despite the assurance of participant anonymity, it is reasonable to assume that participants may have been reluctant to share performance information (biased or unbiased) about their site or company.

Sampling error and uncertainty decrease as the size of the sample increases (Albright *et. al.*, 2006: 407). In determining an adequate sample, it is necessary to consider the degrees of freedom. When the total degrees of freedom is larger than 30, the sample is said to adequately approximated the population for the distribution of the population parameters to be considered normally distributed (Albright, *et. al.,* 2006: 425).

The degrees of freedom (*df.)* for a multivariable problem are given by equation 5-1:

$$\boxed{df = n - k - 1} \qquad \text{Equation 5 - 1}$$

where *n* is the number of data points and *k* is the number of variables in the multivariable regression problem. In table 4-1, 10 independent composite variables were constructed from the information in the questionnaire (for use in the model). Given that only 31 respondents completed the entire questionnaire, the *df*. is equal to 20, significantly less than the threshold of 30.

By using only a subsection of the total data (*ie.* data received up till end of section 2 of the questionnaire), it is possible to redefine a more selective set of composite variables. This would not allow for the testing of all Hypotheses set out in Section 3, but would meet the requirements of equation 5-1. This approach is more fully explored in the regression analysis.

5.2. Data coding and scaling

In order to statistically analyse the response captured by the questionnaires, a code was developed to translate the data into a numeric format. Figure 5-2 shows the overview of how each question was coded.

Figure 5 - 2: Question code tables

Question 1-1:	
	Country
1	North America
2	South America
3	Europe
4	Africa
5	Middle East
6	Asia
7	Australia

Question 1-2:	
	5 year period
1	Pre 1965
2	1965-1970
3	1970-1975
4	1975-1980
5	1980-1985
6	1985-1990
7	1990-1995
8	1995-2000
9	2000-2005
10	Post 2005

Question 1-3:	
	# of refineries
1	Less than 5
2	Less than 10
3	Less than 20
4	Less than 50
5	More than 50

Quesiton 1-4:	
	5 year period
0	Never
1	Pre 1965
2	1965-1970
3	1970-1975
4	1975-1980
5	1980-1985
6	1985-1990
7	1990-1995
8	1995-2000
9	2000-2005
10	Post 2005

Question 2-1:	
	Relative performance
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10

Question 2-2:	
	Yes/No
0	No
1	Yes - single
2	Yes - multiple

Question 2-3:	
	Categories
	Sum of # of choices

Question 2-4:	
	Degress of similarity
0	No template
1	Totally different
2	Dissimilar
3	Similar
4	Very Similar
5	Identical

Question 2-5:	
	Degress of similarity
0	No template
1	Totally different
2	Significantly different
3	Moderately different
4	Significantly Similar
5	Identical

Question 2-6:	
	Degress of similarity
0	No template
1	Totally different
2	Significantly different
3	Moderately different
4	Significantly Similar
5	Identical

Question 2-7:	
	Degress of similarity
0	No template
1	Totally different
2	Dissimilar
3	Similar
4	Very Similar
5	Identical

Question 2-8:	
	Level of local adaptation
0	None
1	0-25%
2	25-50%
3	50-75%
4	75-100%
5	All

Question 2-9:	
	Level of local adaptation
0	None
1	0-25%
2	25-50%
3	50-75%
4	75-100%
5	All

Question 2-10:	
	Level of local adaptation
0	No template
1	Totally different
2	Significantly different
3	Moderately different
4	Significantly Similar
5	Identical

Question 2-11:	
	Yes/No
0	No
1	Yes

Question 2-12:	
	Yes/No
0	Not al all
2	Not significantly
3	Moderately
4	Significantly
5	Extensively

Question 3-1:	
	Local category
0	No site adaptation
1	Some adaptation
2	Moderate adaptation
3	High adaptation
4	Extensive adaptation

Question 3-2:	
	Local category
0	Never
1	< every 4 years
2	Every 4 years
3	Every 3 years
4	Every 2 years
5	Annually
6	Quarterly
7	Monthly
8	Continuous

Question 3-3:	
	Level of local adaptation
0	Not al all
1	To some extent
2	Moderately
3	Large extent
4	Very dependent

Question 3-4:	
	Yes/No
0	No
1	Yes - locally
2	Yes - headquarters

Question 3-5:	
	Categories
1	Non-production
2	Production
3	Once off
4	Itterative

Question 3-6:	
	Categories
0	No ERP
1	Within sites
2	Per site
3	Per region
4	Per BU
5	Single

Question 3-7:	
	Level of local adaptation
0	No ERP
1	None locally
2	Some locally
3	Most locally
4	All locally

Question 3-8:	
	Relative Perfornace
1	4th Quartile
2	3rd Quartile
3	2nd Quartile
4	1st Quartile
5	Pacesetter

Question 3-9:	
	Degree of improvement
0	No Template
1	Not at all
2	Not significant
3	Moderate
4	Significant
5	Very significnat

Question 3-10:	
	Degree of improvement
0	No Template
1	None
2	Few improvements
3	Some improvements
4	Most improvements
5	All improvements

Question 3-11:	
	Degree of improvement
1	Very low
2	Low
3	Moderate
4	High
5	Extremely high

Question 3-12:	
	Local category
1	Very unsuccessful
2	Unsuccessful
3	Moderately successful
4	Very successful
5	Exteremely successful

Elements which are important to note within the coding table:

- Where a practice was found to be totally lacking, and should thus have no influence on the statistical and regression analysis, that variable was coded to zero.
- Within the variables captured within the tables in figure 5-2, the second line indicates the units of the variable. Composite variables (e.g. x_1 = Q1.2 & Q1.4) have identical units of measure, ensuring consistency within the regression analysis.
- The scale was applied to the range of question responses, and used to generate a unitary scale for each question.

By dividing the individual response by the maximum value within the scale, the response set was normalised to a unitary scale. The descriptive statistics for each question are shown in table 5-1.

Table 5 - 1: Descriptive statistics of question responses

	Mean	Std. Error	Median	Mode	Std. Dev.	Variance	Kurtosis	Skewness	Minimum	Maximum	Sum	Count
1.1	0.30	0.03	0.14	0.14	0.22	0.05	1.56	1.33	0.14	1.00	12.71	42.00
1.2	0.25	0.04	0.10	0.10	0.25	0.06	3.67	2.05	0.10	1.00	10.40	42.00
1.3	0.63	0.03	0.60	0.60	0.20	0.04	0.25	-0.15	0.20	1.00	26.40	42.00
1.4	0.83	0.05	1.00	1.00	0.32	0.10	2.84	-2.06	0.00	1.00	34.90	42.00
2.1	0.70	0.03	0.70	0.80	0.18	0.03	-0.59	-0.26	0.30	1.00	25.30	36.00
2.2	0.46	0.08	0.25	0.00	0.48	0.23	-1.98	0.17	0.00	1.00	16.50	36.00
2.3	0.32	0.06	0.20	0.00	0.34	0.12	-0.79	0.75	0.00	1.00	11.40	36.00
2.4	0.47	0.06	0.75	0.75	0.38	0.14	-1.64	-0.33	0.00	1.00	17.00	36.00
2.5	0.51	0.07	0.75	0.75	0.42	0.18	-1.77	-0.31	0.00	1.00	18.25	36.00
2.6	0.47	0.07	0.50	0.00	0.41	0.17	-1.71	-0.01	0.00	1.00	16.75	36.00
2.7	0.41	0.06	0.50	0.50	0.34	0.12	-1.11	0.15	0.00	1.00	14.75	36.00
2.8	0.68	0.05	0.80	0.80	0.27	0.07	0.95	-1.35	0.00	1.00	24.40	36.00
2.9	0.64	0.04	0.60	0.80	0.25	0.06	0.09	-0.75	0.00	1.00	23.00	36.00
2.10	0.71	0.03	0.70	0.60	0.17	0.03	-0.51	0.12	0.40	1.00	25.60	36.00
2.11	0.62	0.08	1.00	1.00	0.49	0.24	-1.86	-0.51	0.00	1.00	21.00	34.00
2.12	0.40	0.06	0.60	0.60	0.33	0.11	-1.33	0.00	0.00	1.00	13.60	34.00
3.1	0.56	0.04	0.50	0.75	0.23	0.05	-1.03	-0.03	0.25	1.00	17.50	31.00
3.2	0.49	0.05	0.50	0.50	0.27	0.07	-0.53	0.09	0.00	1.00	15.25	31.00
3.3	0.48	0.04	0.50	0.25	0.24	0.06	-0.86	0.14	0.00	1.00	15.00	31.00
3.4	0.32	0.05	0.50	0.50	0.28	0.08	-0.79	0.01	0.00	1.00	10.00	31.00
3.5	0.80	0.05	1.00	1.00	0.31	0.09	-0.56	-1.10	0.25	1.00	24.75	31.00
3.6	0.75	0.04	0.80	1.00	0.24	0.06	-1.50	-0.31	0.40	1.00	23.20	31.00
3.7	0.50	0.04	0.50	0.50	0.24	0.06	-0.33	0.71	0.25	1.00	15.50	31.00
3.8	0.60	0.03	0.60	0.60	0.19	0.03	0.04	-0.26	0.20	1.00	18.60	31.00
3.9	0.40	0.06	0.60	0.60	0.31	0.10	-1.63	-0.39	0.00	0.80	12.40	31.00
3.1	0.41	0.06	0.60	0.60	0.31	0.09	-1.47	-0.35	0.00	0.80	12.60	31.00
3.11	0.63	0.03	0.60	0.60	0.14	0.02	2.71	-0.20	0.20	1.00	19.40	31.00
3.12	0.59	0.03	0.60	0.60	0.15	0.02	0.27	-0.45	0.20	0.80	18.40	31.00

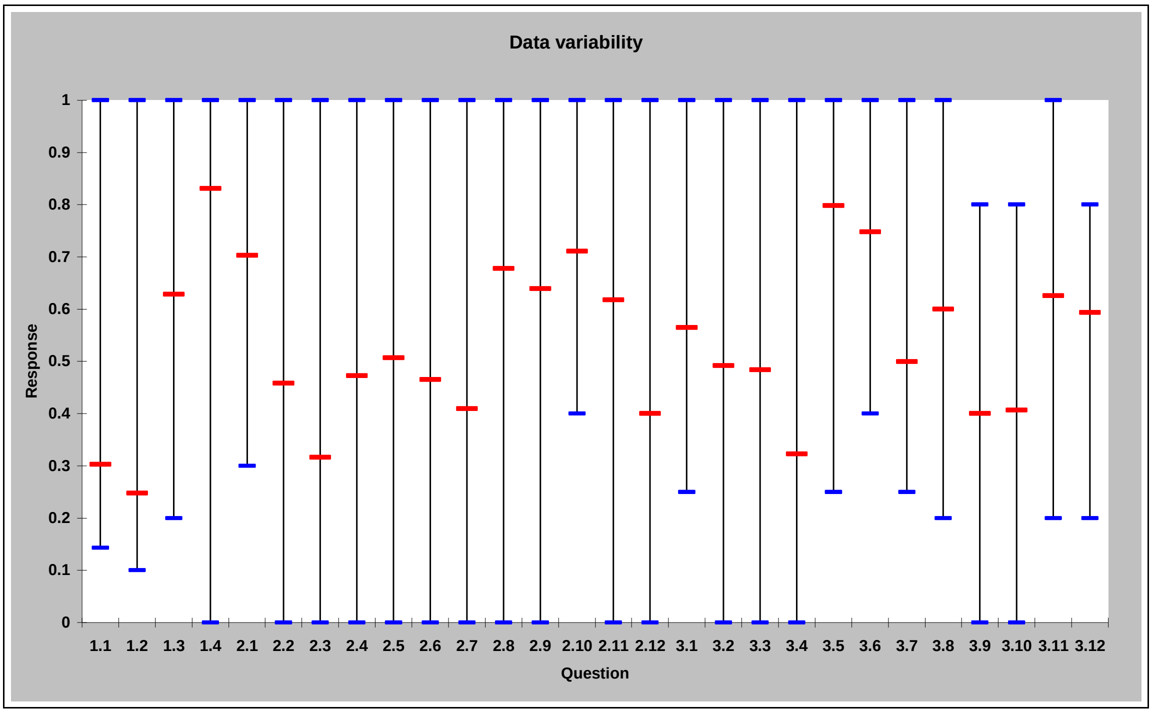
Rigorous tests for the normality of each variable, as well as the statistical confidence intervals for the population descriptors, will be shown and discussed under the section on regression. The elements which are important to note from table 5-1 are:

- The data is rich, with substantial variability in the mean and median (see figure .5–3).
- The standard errors are low, which is to be expected given the relative adequacy of the sample size (for the estimation of the population descriptors).

- The data appears relatively non-normal, with significant differences between the mean and the median. In addition, the measures of Kurtosis and Skewness indicate that the variables are not normally distributed.

Figure 5-3 shows the mean, maximum and minimum information from table 5-1. In this figure, the mean is indicated by the red dot, and the extremities of the lines indicate the minimum and maximum respectively.

Figure 5 - 3: Variability within the data set



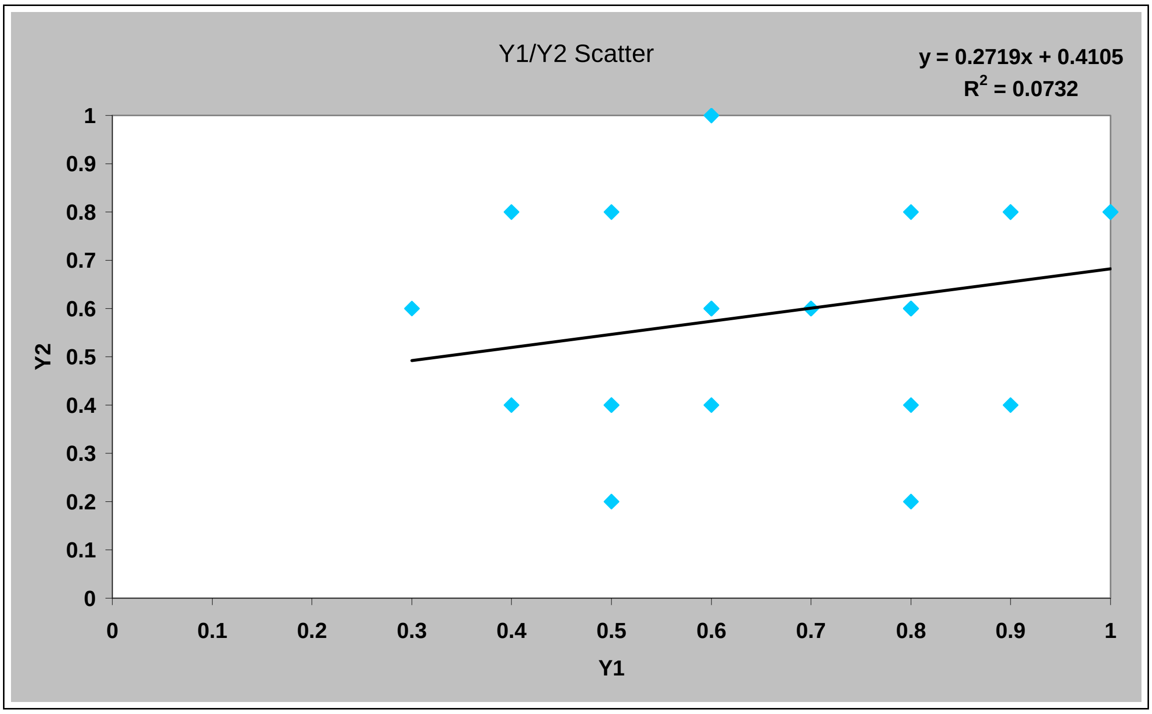
5.3. Correlation of dependent variables

In Section 4, two dependent performance variables were defined, namely:

- ***y_1***: Perceived level of site performance (biased dependent variable)
- ***y_2***: Solomon Comparative Performance Assessment Index (unbiased dependent variable)

By evaluating the co-linearity of these two variables, it is possible to determine whether the two variables are identically describing the same measure and underlying trend (Albright, *et. al.*, 2006: 639). Figure 5-4 shows a scatter diagram of ***y_1*** versus ***y_2***, with an indication of the low level of co-linearity.

Figure 5 - 4: Scatter plot and linear regression result



Since the variables have been normalised, perfectly co-linear variables would be expected to have a high R^2 (indication of goodness of fit).

The test for co-linearity indicates that significantly divergent or different site performance elements are captured by the two different variables. Possible reasons for these differences could be:

- ***Respondent bias:*** respondents may be inclined to overstate the performance of their own sites. This is partially confirmed by evaluating the distribution of respondents to Q2.1 (y_1), shown below in figure 5-5. The response shows that 92% of sites within the sample perform above an average performance level, and that the sample has a mean of 70% (table 5-1). This is clearly highly improbable.

  When compared to the distribution of y_2, shown in figure 5-6, the average lies close to the expected value, falling within the second quartile measure. The distribution still fails to meet the expected uniform distribution indicated by the red line. A possible explanation of this is offered under the section evaluating the effects of geographic location.

- ***Relative normalisation*** of y_1 versus y_2: Solomon Associates use measures of refinery size, technology and age to normalise the site performance index to reflect only elements of performance which are affected by the manner in which the site is operated. It is unlikely that respondents would be either able or inclined to attempt to apply such normalisation to their estimate of relative site performance.

- ***Objective nature*** of $\boldsymbol{y_{2}}$: Given the objectivity of an external measurement, from a body like Solomon Associates, it is reasonable to assume that as an absolute measure of performance it is more likely to capture true site performance.

Figure 5 - 5: Distribution of responses to Q2.1 (“biased” site performance

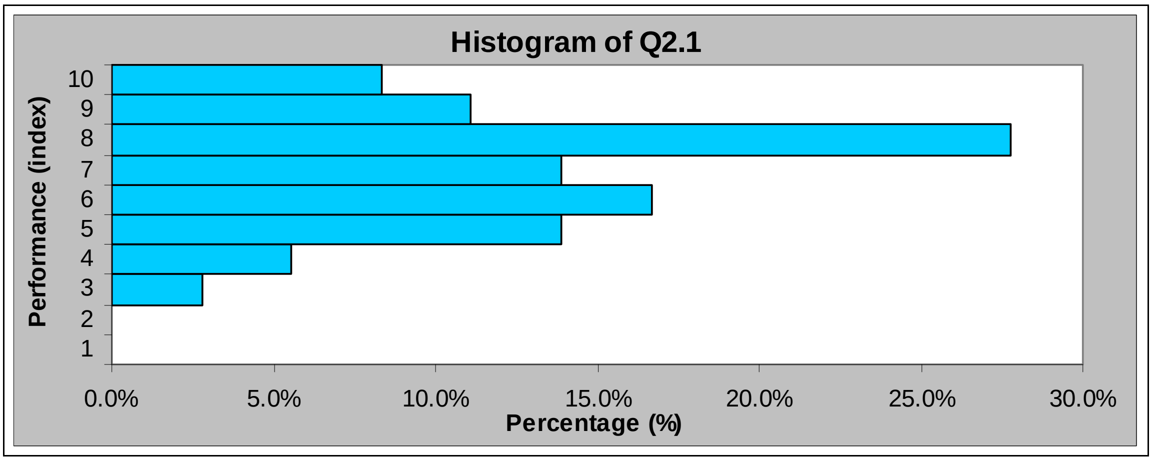


Figure 5-5 shows the upwardly shifted average, potentially an indication of respondent bias.

Figure 5 - 6: Distribution of responses to Q3.8 (“unbiased” site performance)

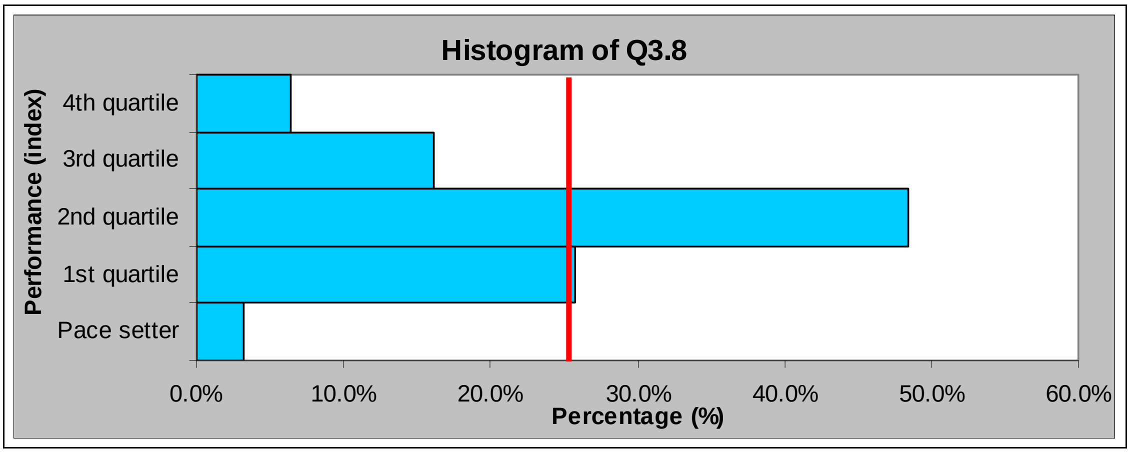


Figure 5-6 shows the unexpected non-uniform distribution of the Solomon CPA, with the mean located close to the expected value, potentially enforcing the value of the independent “unbiased” performance indicator.

5.4. Category variables

Within the questionnaire (Appendix 1) two clearly distinctive categorisation variables were included. These were the geographic location (variable x_{11}) and the site ownership change (variable x_9 questions. The purpose of these two variables was to:

- test for clear geographic influences or differences
- test for the external implementation of replication strategies on existing sites

5.4.1. Geographic location (variable x_{11})

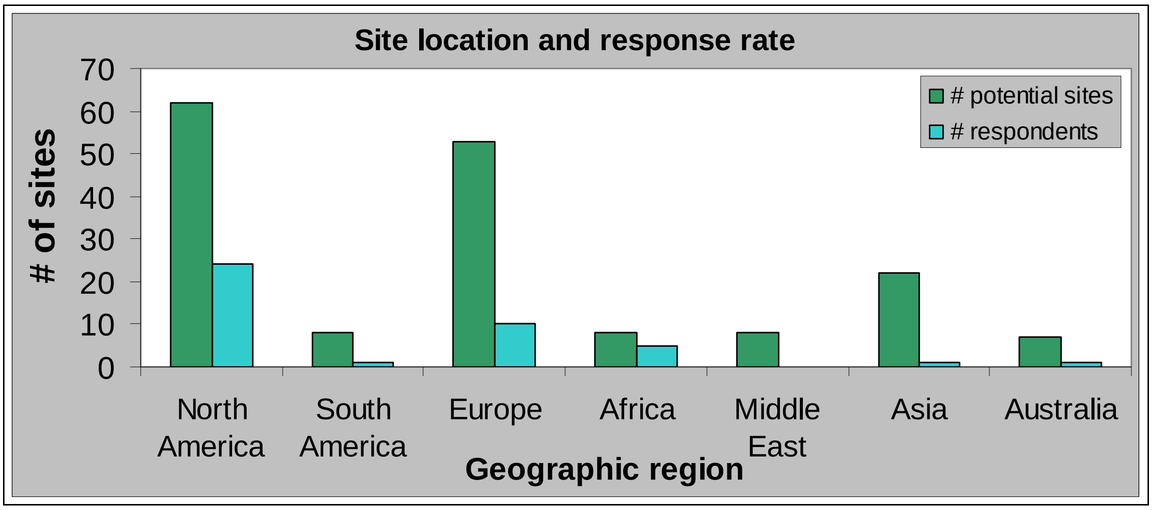
Table 5-2 shows the location of the sites that participated in the data collection.

Table 5 - 2: Actual versus potential number of respondents

	# potential sites	# respondents	% coverage	% of total
North America	62	24	39%	57%
South America	8	1	13%	2%
Europe	53	10	19%	24%
Africa	8	5	63%	12%
Middle East	8	0	0%	0%
Asia	22	1	5%	2%
Australia	7	1	14%	2%
Total	168	42	25%	

From table 5-2, as well as figure 5-7 below, it is clear that the majority of responses were received from North America and Europe. While these areas do represent the majority of the world's refining capacity (55%), they represent a combined total of 81% of the total sample population.

Figure 5 – 7: Graphic representation of geographic response



The high concentration of North American and European respondents skews the results. This may affect the global generalisability of the findings and conclusions. One way to control for this skewness within the data would be to group the data into separate categories.

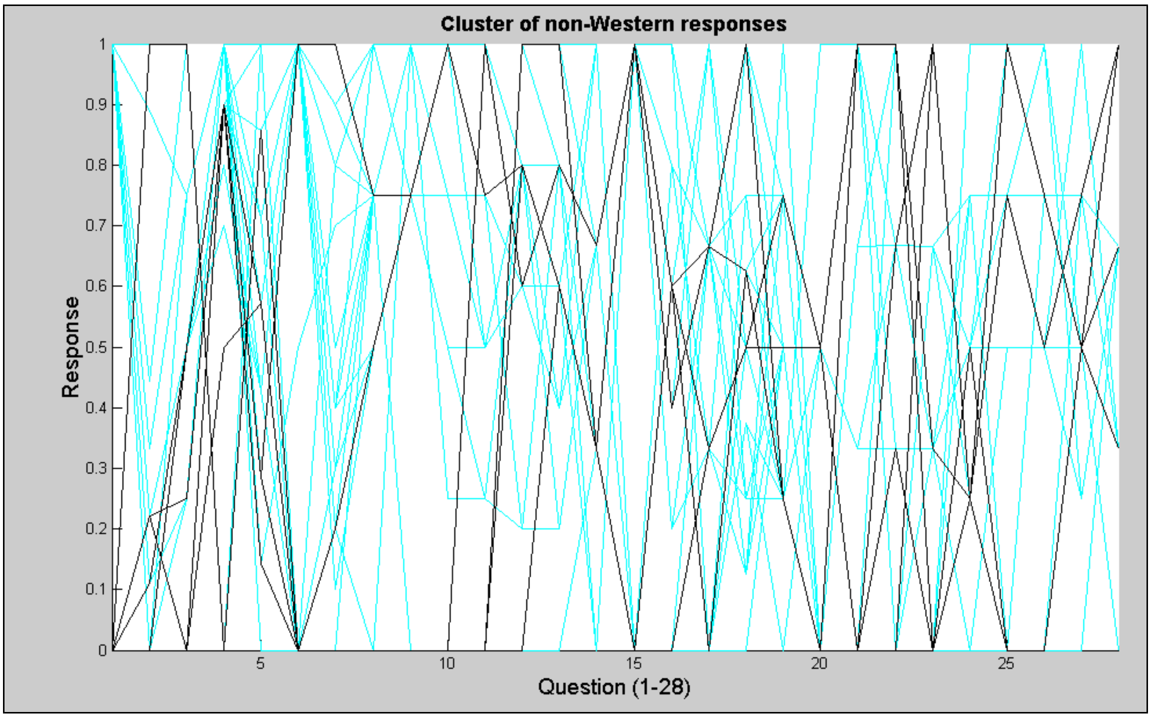
There are several elements which contributed to the low response rate outside North America and Europe:

- The method used to responses to the questionnaires differed between the two groupings defined in the methodology section. The multinational refining companies were approached directly, and requested to participate in the survey. In contrast, the penetration into sites not directly owned by these companies was much lower.
- Researchers have found Asia (the region with the third most refineries) as having the largest concentration of "outer-circle" (people who speak a language as a foreign rather than a second language) English speakers in the world (Bolton, 2008). This relatively low level of English proficiency serves as a natural barrier to completing the English questionnaire.
- The lower response rates from developing countries has been extensively studied, and as such the result is not unexpected (Hoskisson, Eden, Lau & Wright, 2000).

Given the low response rate outside North America and Europe, the controls for geographic region are removed. In order to illustrate the effect of removing this control, the clustering of Western versus non-Western responses are shown in the parallel plot in figure 5-8.

Each line represents a single sites response across each of the questions. The lines in black show the non-Western cluster, with question 1 coded as Western = 1, non Western = 0. The lines in cyan represent the remainder of the sample.

Figure 5 - 8: Variability of Western versus Non-Western responses



From figure 5-8 several conclusions can be reached:

- There is no systematic pattern evident in the non-Western respondents
- The behaviour of the non-Western respondents does not appear more or less variable than the larger sample.

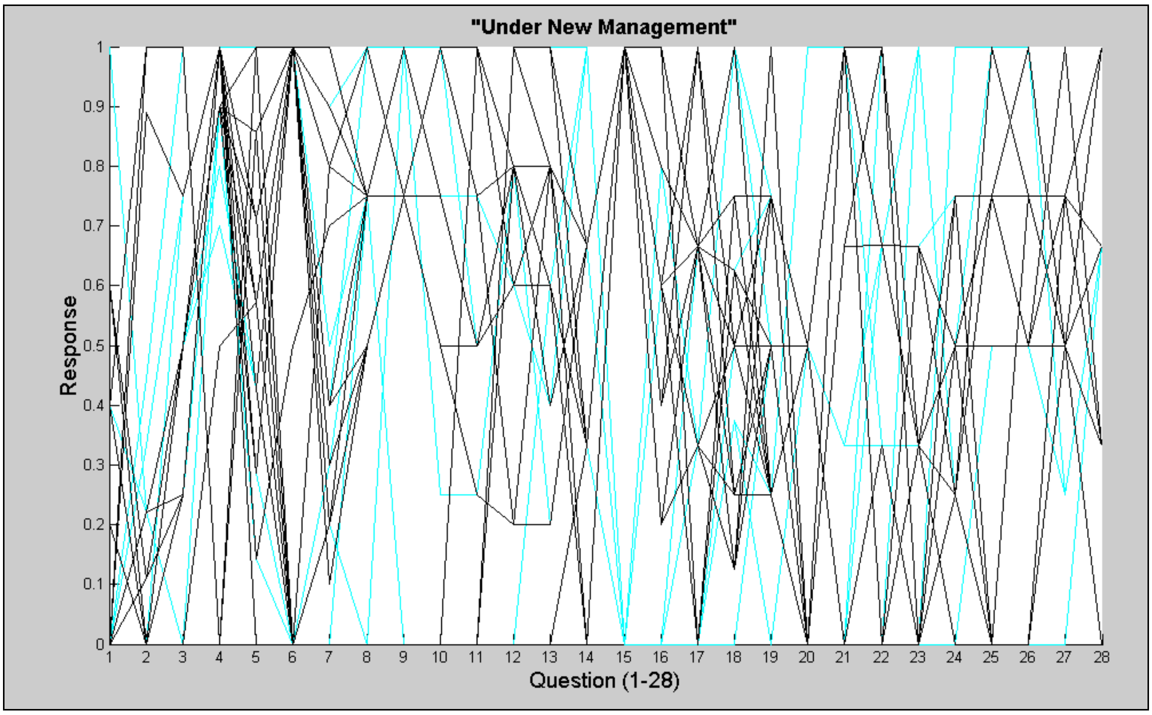
Given the limited total sample size, coupled with the lack of clear clustering of data according to the geographic location, it is not possible to draw any conclusions regarding the effect of location on replication practices.

5.4.2. Change of ownership (variable x_9)

59% of the sites within the sample have undergone a change in the main operating company for that site at some point in the last 10 years. Ideally one would want to test for differences in the operational success of these "under new management" sites.

Figure 5-9 shows the cluster analysis of the sites which have undergone a change in management. As in figure 5-8, each line represents a single sites response across each of the questions. The lines in black show the cluster of sites which are "under new management". The lines in cyan represent the remainder of the sample.

Figure 5 - 9: Sites which have undergone a change in management in the last 10 years



There are three trends that visually emerge which differentiate the responses of the one cluster from the other:

- Question 16 (Q2.12): This is directly related to the impact of the change which was implemented by the new company. This would obviously not be applicable to sites which have not undergone a change, thereby polarising the responses to Question 16.
- Questions 8 & 9 (Q2.4 & Q2.5): Both these questions belong to the analysis variable (defined in table 4-1) x_4. This variable is capturing the implementation of template practices. The lack of intermediary responses within this cluster would warrant further analysis.

- Question 23 & 24 (Q3.6 & Q3.7): These questions belong to two separate analysis variables, namely x_5 and x_7. The first deals with the template site practices, and the second with replication methods. Both concepts are central to what is being tested, specifically in trying to determine how new management may affect the operating practices of the site. The differences within these variables would need to be further analysed for the implications and statistical relevance.

The above analysis indicates that there ***may*** be value in attempting to statistically describe and model the two categories separately. This would enable the comparison of the application of replication theory in sites "under new management". Given the small total sample, which would be further compromised by splitting the data into two separate clusters, the independent analysis of these categories was not done.

5.5. Variable correlation analysis and clustering

In table 4-1 the mapping of the questions to the analysis variables was presented. This mapping was necessary to show which questions were attempting to capture the different facets of the same underlying phenomenon.

In table 5-3 the correlation matrix of all the question responses is shown. The original mapping from table 4-1 has been shown in parallel to the question numbers. Within the body of the matrix, clusters with a correlation coefficient of higher than 0.5 were highlighted in cyan.

The highlighted blocks form an informal cluster analysis, giving indication of a significant correlation between the responses to the questions highlighted. The purpose of this test is two-fold:

- To test for the expected correlation between questions belonging to the same analysis variable.
- To test for any unexpected correlation between questions and analysis variables.

Table 5 - 3: Correlation matrix of question responses individual

Variable		X11	X1	X2	X1	Y1	X3	X7	X4	X4	X4	X4	X5	X5	X5	X9	X9	X10	X10	X5	X6	X7	X7	X5	Y2	X8	X8	X8	X10
Question #		1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11	3.12
X11	1.1	1																											
X1	1.2	0.38	1																										
X2	1.3	-0.12	0.35	1																									
X1	1.4	-0.34	**-0.53**	**-0.50**	1																								
Y1	2.1	0.05	0.19	0.42	-0.44	1																							
X3	2.2	-0.20	0.00	0.31	0.06	0.18	1																						
X7	2.3	-0.16	0.20	0.35	-0.01	-0.14	**0.64**	1																					
X4	2.4	-0.10	0.25	**0.58**	-0.32	0.13	**0.60**	**0.73**	1																				
X4	2.5	-0.11	0.25	**0.56**	-0.16	0.10	**0.74**	**0.70**	**0.76**	1																			
X4	2.6	0.01	0.33	**0.55**	-0.27	0.14	**0.65**	**0.68**	**0.71**	**0.90**	1																		
X4	2.7	0.02	0.36	**0.52**	-0.29	0.14	**0.51**	0.49	**0.50**	**0.61**	**0.70**	1																	
X5	2.8	0.06	0.10	-0.06	0.05	0.14	-0.02	-0.02	-0.10	0.00	-0.04	0.02	1																
X5	2.9	0.14	0.00	-0.25	0.10	-0.04	-0.24	-0.15	-0.23	-0.22	-0.29	-0.17	**0.59**	1															
X5	2.10	-0.18	0.16	0.45	-0.25	0.23	0.09	0.11	0.30	0.23	0.30	0.33	-0.02	-0.13	1														
X9	2.11	0.14	0.18	-0.12	0.07	0.09	-0.11	-0.02	-0.21	-0.12	-0.04	0.09	0.00	0.14	-0.41	1													
X9	2.12	0.05	0.01	-0.23	0.22	-0.02	-0.11	0.04	-0.25	-0.23	-0.22	0.01	0.00	0.25	-0.38	**0.71**	1												
X10	3.1	0.03	0.25	0.23	-0.03	0.28	-0.11	0.04	0.01	-0.17	-0.19	-0.19	-0.11	-0.08	-0.14	0.37	0.18	1											
X10	3.2	0.29	0.27	0.22	-0.28	0.21	0.06	0.28	0.14	0.06	0.03	0.22	0.18	0.09	0.23	-0.18	0.10	-0.01	1										
X5	3.3	0.07	0.08	-0.17	0.15	-0.13	0.14	0.15	0.15	-0.10	-0.26	-0.31	-0.03	0.27	-0.21	0.02	0.15	0.28	-0.05	1									
X6	3.4	-0.02	0.16	0.35	-0.16	-0.11	0.18	0.40	0.39	0.29	0.26	0.21	0.03	-0.03	0.42	**-0.52**	-0.31	-0.14	0.31	-0.11	1								
X7	3.5	**-0.51**	-0.08	0.43	0.16	0.08	0.46	0.40	0.41	0.38	0.30	0.42	-0.06	-0.14	0.37	0.18	0.22	0.19	-0.05	-0.05	0.15	1							
X7	3.6	-0.17	0.08	-0.10	0.11	0.10	0.03	-0.04	-0.12	-0.13	-0.05	0.17	-0.04	-0.12	-0.30	**0.55**	**0.50**	0.15	-0.32	0.07	-0.49	0.22	1						
X5	3.7	0.23	-0.14	-0.17	0.08	-0.20	-0.03	-0.21	-0.04	-0.10	-0.15	-0.34	-0.18	0.11	0.00	-0.35	-0.32	0.11	-0.24	0.32	0.31	-0.17	-0.48	1					
Y2	3.8	-0.47	0.11	0.32	-0.15	0.27	0.32	0.37	0.33	0.30	0.32	0.33	0.00	-0.29	0.40	0.07	-0.02	0.08	0.18	-0.15	0.20	0.47	0.06	-0.26	1				
X8	3.9	-0.23	0.23	**0.49**	-0.16	0.00	**0.66**	**0.76**	**0.72**	**0.81**	**0.79**	0.48	0.03	-0.26	0.24	-0.21	-0.25	-0.23	0.22	-0.07	0.23	0.31	-0.09	-0.26	0.41	1			
X8	3.10	-0.38	0.25	**0.52**	-0.02	-0.06	**0.63**	**0.72**	**0.60**	**0.73**	**0.67**	**0.51**	0.02	-0.22	0.33	-0.16	-0.08	-0.24	0.24	-0.11	0.33	0.39	-0.05	-0.27	0.44	**0.87**	1		
X8	3.11	0.04	0.25	0.03	-0.20	0.25	0.19	0.06	-0.04	0.11	0.02	0.10	0.03	0.04	-0.46	0.43	0.31	0.30	-0.08	0.30	-0.39	-0.03	0.23	-0.14	0.05	0.06	0.03	1	
X10	3.12	0.32	0.11	0.27	-0.41	0.14	0.09	0.22	0.23	0.13	0.24	0.37	0.22	0.30	0.19	-0.12	-0.03	-0.32	0.49	-0.28	0.29	-0.07	-0.23	-0.28	0.05	0.23	0.15	-0.24	1

By evaluating the results presented in table 5-3, several patterns emerge within the data.

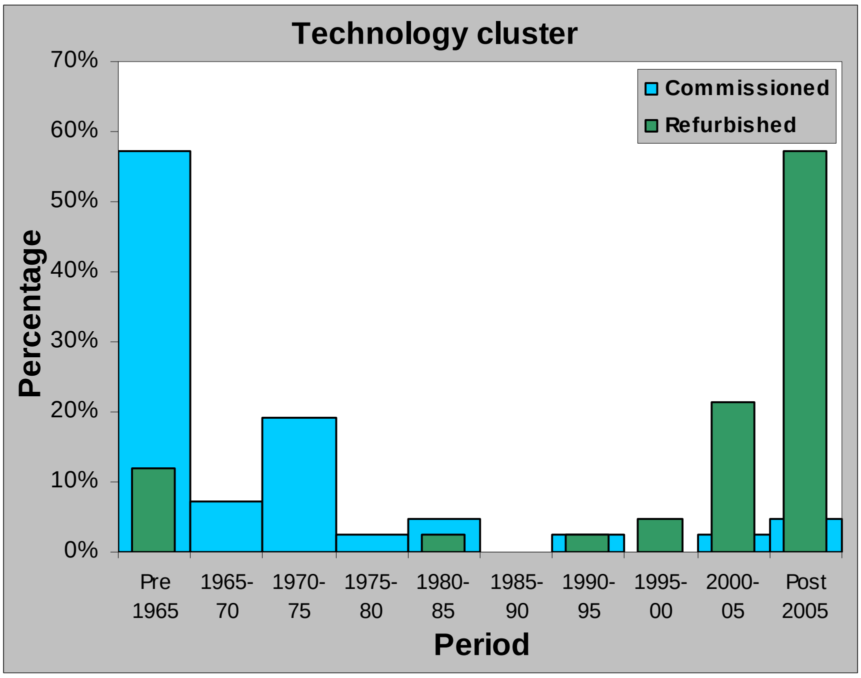
5.5.1. Technology cluster (x_1 cluster)

One of the main research questions being analysed regards the source of performance advantage between different refining sites. One of the largest potential sources of performance advantage would come from differences in the technology deployed within these sites.

Liu, Yu, Xu, Fan and Bao (2007) showed that while the specific type of technology deployed within the industry is relatively generic, there have been significant advances since the early 1900's. This would suggest that the age of the site, as well as when the site last under went a major technology investment, would serve as a good proxy for that sites technology.

The significant negative correlation between the age of the site and when last it under went a major turnaround (Q1-2 & Q1-4), highlighted in the correlation analysis, is shown visually in figure 5-10.

Figure 5 - 10: Commissioning date compared to last major refurbishement

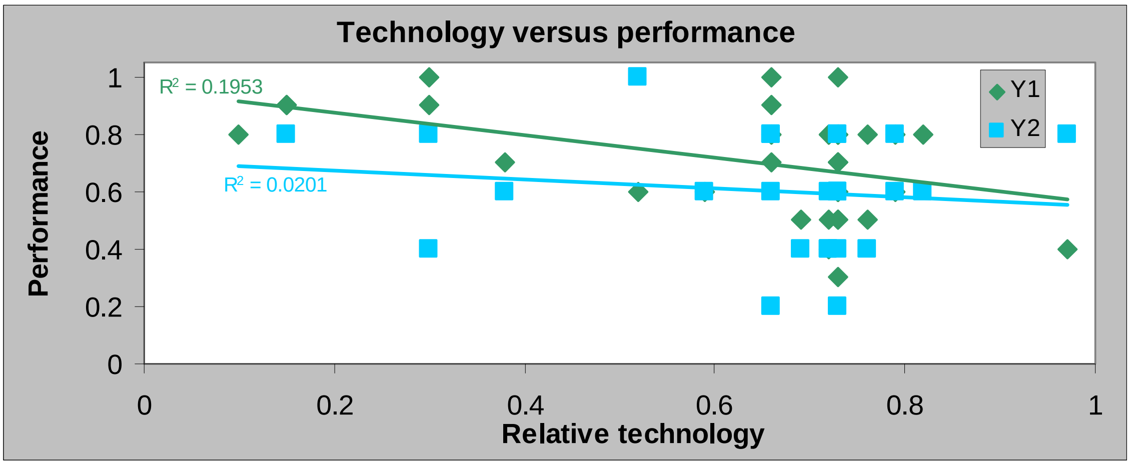


This significant inverse relationship should be expected. As the site ages, management will invest increasing sums of money to ensure the site remains competitive. Chen (2005) shows the positive correlation between refinery investment and demand-side factors, which would support the expectation of high investment over the last 10 years (The Economist, 2008b).

In section 5-3, the possibility of site age and relative technology influencing the respondent's view of relative site performance was introduced. This concept is tested in figure 5-11. In order to create a vector describing the site's relative technology, the composite variable x_1 was created from the combination of Q1.2

and Q1.4 (in a 30/70 ratio), weighting the effect of recent investment more heavily than the original site age.

Figure 5 - 11: Effect of technology on performance vectors



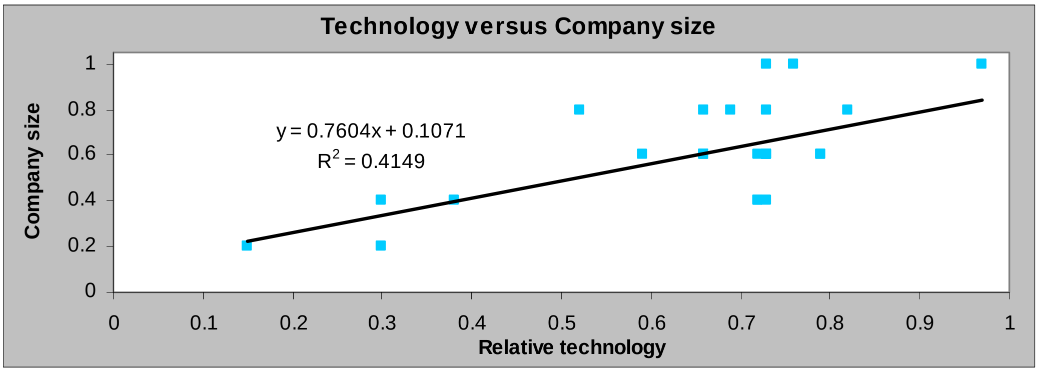
The concern raised in the section 5-3 about the objectivity of respondents in the face of relative technology differences can be rejected. Figure 5-11 shows a negligible relationship between the technology variable x_1 and both performance variables (though the “unbiased” CPA metric is more influenced).

5.5.2. Company size (x_2):

Chen (2005) highlights the different opinions amongst researchers regarding the size of the company on the performance of individual sites. The x_2 cluster from table 5-3, shows three strong relationships:

- A relationship between company size and technology (x_1). By performing the transform introduced in section 5.5.1, a strong positive relationship between company size and relative technology is found. This is shown in figure 5-12.

Figure 5 - 12: Investment trend by large companies



- A strong and consistently positive relationship across the entire x_4 cluster. This cluster is an indication of the template practices which are employed by a company. The positive correlation would suggest that larger companies have more sophisticated practices, consistent with those of template deployment.
- A relationship with cluster x_8, which also indicate elements of template practices. The positive correlation would suggest that larger companies have more sophisticated practices, consistent with those of template deployment.

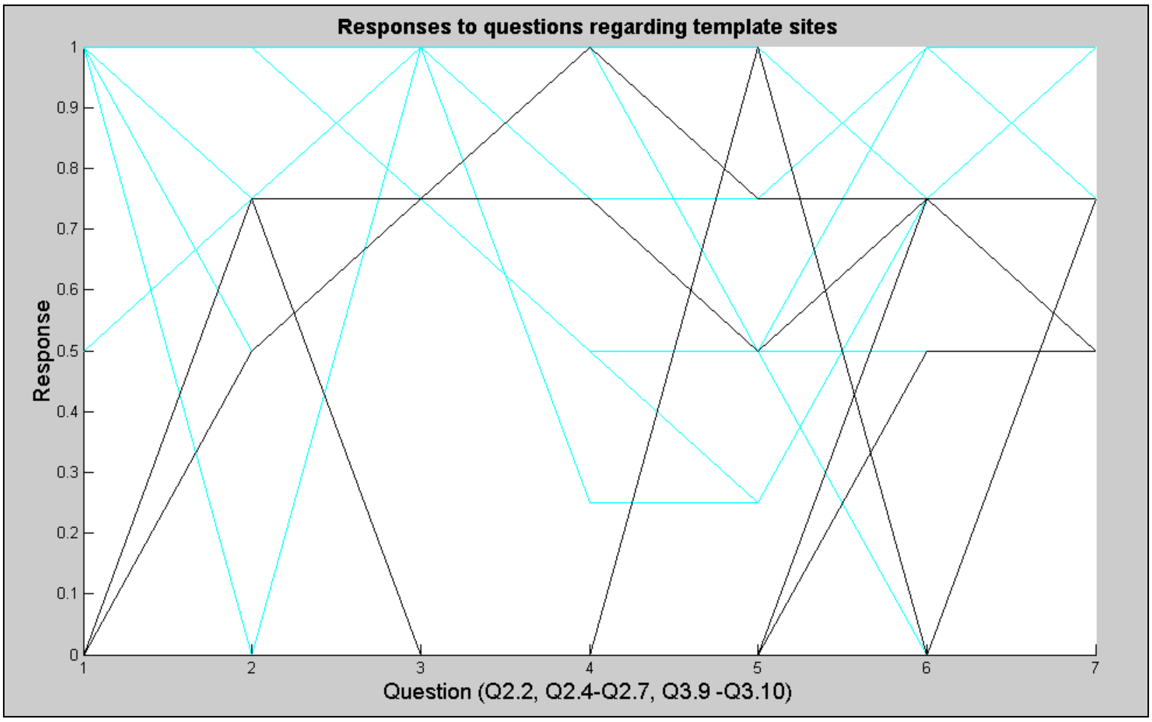
From the strong relationship shown in this section, one would expect that the x_2 cluster will feature as a rich variable in the regression analysis.

5.5.3. Template existence and practices (x_3, x_4 cluster)

The x_3 (existence of a template site) variable could potentially have been classified within the data analysis as another category variable. The presence of one or more template sites within the company of the respondent, could be used to exclude sites without a template from a portion of the analysis. 50% of respondents indicated no best practice sites within their organisations, which would halve the available sample for portions of the analysis.

Figure 5-13 shows the way respondents interpreted the questions regarding the template sites.

Figure 5 - 13: Respondent interpretation



The coding of Q2.2 is given in figure 5-2, and shows that a response of 0 indicates no template site. Through all the subsequent questions the respondents were asked to indicate the way in which best practices where shared from this template site. In these questions, an appropriate response given a negative response to Q2.2 would be “No template site”, coded as 0 for all subsequent questions.

Figure 5-13 shows that respondents chose options other than “No template site”, despite the initial indication. This could be interpreted in several ways, but for this analysis this has taken to mean the respondents have recognised that there are appropriate sharing mechanisms for site best practices within their organisations. As such, $\boldsymbol{x_3}$ is not used as a category variable.

The strong correlation between all the elements of $\boldsymbol{x_4}$ (precision of template implementation) indicates that the cluster is testing a common underlying phenomenon. All four questions grouped within this cluster attempt to measure the precision or sophistication of how the template sites practices are implemented and communicated. An equal weighting transform is applied to Q2.4-Q2.7 to create the composite variable $\boldsymbol{x_4}$.

5.5.4. Best practices and ERP (x_7, x_8 cluster)

The variables $\boldsymbol{x_7}$ and $\boldsymbol{x_8}$ are indicative of how the company best practices were captured, as well as how thoroughly this was codified in an ERP (enterprise resource planning) system.

Question Q2.3 was formulated to capture what practices are utilised by companies to share best practices with their sites (Jensen, 2008). This portion of x_7 (replication methods) has a very high positive correlation with the combination variables x_4 and x_8.. The position within the questionnaire, as well as the low correlation with other elements of x_7, indicates that this variable may be combined with the remainder of x_4. However, based on the combination of correlations with the remainder of x_7, as well as the other inter-correlations within this variable, there is evidence that there is unique variability captured by this variable.

Within x_8 two substantially different pieces of information have been captured. Q3.9 and Q3.10 indicate elements of template implementation, where as Q3.11 highlights the positive aspects of local adaptation. The differences in the information that is captured by the different variables can be seen from the different behaviour in the correlation matrix, figure 5-3. The very low correlation of Q3.11 to the remainder of x_8 (and indeed the whole x_4) indicates that this variable is capturing unique elements of site behaviour not included in the other data. As such, whereas Q3.9 and Q3.10 are uniformly weighted to form the suggested (table 4-1) combination variable x_8, Q3.11 will be analysed separately as variable x_{8a}.

5.5.5. "Under new management" cluster (x_9)

A detailed discussion regarding this cluster was made in section 5.4.2. This combination variable was removed from the regression analysis.

5.5.6. Remainder of combination variables

Due to the lack of strong correlation with any of the other variables, the set of combination variables x_5, x_6, and x_{10} have not yet been covered in the discussion.

Within combination variable x_5 (local adaptation) the correlations between the different components are moderate. This would indicate that each question brings a portion of the underlying data to the picture, but is not totally unrelated to the larger combination variable. This, combined with the limited sample size, motivates for a uniformed combination of the questions into this variable.

Combination variable x_6 (deleterious practice elimination) has moderate correlation with several of the other variables, often just below the 0.5 threshold. The elimination of deleterious practices has been established as a key part of successful replication, and as such is retained for further analysis.

Within combination variable x_{10} (control mechanisms) the correlations between the different components are moderate. This would indicate that each question brings a portion of the underlying data to the picture, but is not totally unrelated to the larger combination variable. This, combined with the limited sample size, motivates for a uniformed combination of the questions into this variable.

5.6. Regression variables

In section 5.5, analysis was shown which motivates the selection of transformed variables for inclusion in the regression analysis. In table 5-5 the transforms are presented.

Table 5 - 4: Definition of regression variables

Composite independent variables	Transform
X1	0.3 x Q1.2 + 0.7 x Q1.4
X2	Q1.3
X3	Q1.4
X4	0.25 x (Q2.4 + Q2.5 + Q2.6 + Q2.7)
X5	0.2 x (Q2.8 + Q2.9 + Q2.10 + Q3.7 + Q3.3)
X6	Q3.4
X7	(Q2.3 + Q3.5 + Q3.6) / 3
X8	0.5 x (Q3.9 + Q3.10)
X8a	Q3.11
X10	(Q3.1 + Q3.2 + Q3.12) / 3
Dependent variables	**Transform**
Y1	Q2.1
Y2	Q3.8

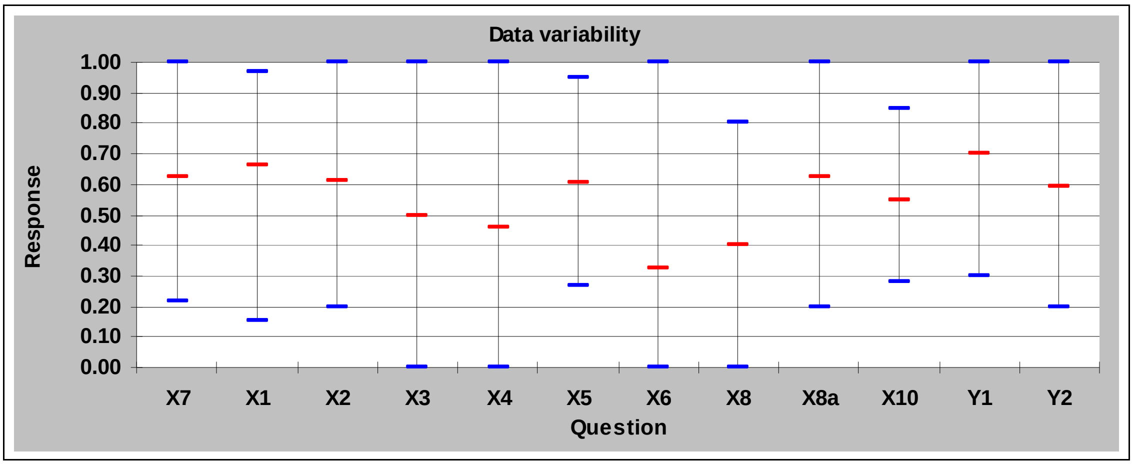
Since the variables have been transformed, the main descriptive statistics from table 5-1 are given again.

Table 5 - 5: Descriptive statistics of regression variables

Descriptive Statistics Section					
Variable	Count	Mean	Standard Deviation	Min	Max
X7	31	0.62	0.21	0.22	1.00
X1	31	0.66	0.17	0.15	0.97
X2	31	0.61	0.20	0.20	1.00
X3	31	0.50	0.50	0.00	1.00
X4	31	0.46	0.35	0.00	1.00
X5	31	0.61	0.12	0.27	0.95
X6	31	0.32	0.27	0.00	1.00
X8	31	0.40	0.30	0.00	0.80
X8a	31	0.63	0.14	0.20	1.00
X10	31	0.55	0.14	0.28	0.85
Y1	***31***	***0.70***	***0.18***	***0.30***	***1.00***
Y2	***31***	***0.59***	***0.17***	***0.20***	***1.00***

The analysis of these values, coupled with the visualisation of the variability (shown in figure 5-14), shows that the total variability and randomness of the transformed variables remains high.

Figure 5 - 14: Variability of combination variables



The correlation analysis is repeated for the combination variables in table 5-6. The conclusions reached in the detailed analysis in section 5-5 remain largely unchanged. The presence of multicolinearity between the independent variables is not unexpected, given the natural relationship between the different replication and template practices.

In addition to the correlation coefficients, the variance inflation factor (VIF) factor is given. This gives an indication of the increase in the standard error due to the introduction of that variable, and shows the effect of correlation within the variable set on the accuracy of the model. For large samples, a VIF of smaller than 10 is required, and for small sample a VIF smaller than 5 (Maindonald & Braun, 2007: 206). Based on the VIF's, no variable is disqualified from the regression.

Table 5 - 6: Correlation analysis of regression variables

	X1	X2	X3	X4	X5	X6	X7	X8	X8a	X10	Y1	Y2	Inflation of variation
X1	1.00												4.59
X2	**0.64**	1.00											4.32
X3	0.38	0.43	1.00										3.51
X4	**0.54**	**0.70**	**0.76**	1.00									5.53
X5	-0.19	-0.12	-0.09	-0.22	1.00								1.25
X6	-0.15	0.35	0.18	0.33	0.20	1.00							2.83
X7	**0.52**	0.43	**0.60**	**0.60**	-0.23	0.11	1.00						2.65
X8	**0.50**	**0.52**	**0.67**	**0.78**	-0.15	0.29	**0.58**	1.00					3.14
X8a	0.10	0.03	0.19	0.06	-0.03	-0.39	0.11	0.04	1.00				1.44
X10	0.22	0.38	0.01	0.09	0.08	0.24	0.11	0.09	0.03	1.00			1.42
Y1	-0.42	-0.32	-0.25	-0.20	0.05	0.22	0.01	-0.28	-0.32	-0.05	1.00		
Y2	-0.14	-0.18	-0.29	-0.07	-0.07	-0.07	0.04	-0.06	-0.20	0.14	0.27	1.00	

5.7. Regression analysis

In section 5-3, the validity of the relative performance variable y_1 (biased estimator) was investigated. The conclusion reached was that the skewed distribution, as well as the negligible correlation with the objective performance measure y_2 (unbiased estimator), introduced concerns regarding the usefulness of y_1 as a performance index for the site. Several potential reasons for this lack of uniform distribution and correlated response were offered in that discussion.

Before finally rejecting y_1 as a useful dependent index for the testing of the hypotheses, the results of the multivariable analysis are presented and discussed.

5.7.1. Regression analysis of y_1

The transformed composite variables shown in table 5-4 were used as inputs to model the variability in y_1. The summary results from the robust regression of y_1 are shown in table 5-7.

Table 5 - 7: Multivariable linear regression results for y_1

Regression Summary Section					
Parameter	**Value**				
Dependent Variable	Y1				
Number Ind. Variables	10				
Weight Variable	None				
R 2	0.45				
Adj R2	0.18				
Coefficient of Variation	0.24				
Mean Square Error	0.03				
Square Root of MSE	0.17				
Ave Abs Pct Error	18.21				
F-Ratio (Prob. Level)	1.66 (0.16)				
Regression Equation Section					
Independent Variable	**Regression Coef.**	**Stnd. Error**	**T-Value (H0:B(i)=0)**	**Prob. Level**	**Reject H0 at 5%?**
Intercept	**0.99**	**0.28**	**3.52**	**0.00**	**Yes**
X1	-0.39	0.32	-1.19	0.25	No
X2	-0.30	0.29	-1.05	0.31	No
X3	-0.12	0.10	-1.13	0.27	No
X4	0.21	0.21	1.01	0.32	No
X5	0.04	0.27	0.14	0.89	No
X6	0.09	0.18	0.51	0.62	No
X7	**0.44**	**0.21**	**2.10**	**0.05**	**Yes**
X8	-0.21	0.17	-1.19	0.25	No
X8a	-0.29	0.25	-1.17	0.26	No
X10	0.09	0.26	0.36	0.72	No

From table 5-7 the questionable usability of y_1 as a dependent performance variable becomes clear:

- The coefficient of determination (R^2) shows that the independent variables can explain 45% of the total variation in y_1. However, when taken in conjunction with the adjusted coefficient, which accounts for the small total sample size, this value decreases to 18%. This low goodness of fit is shown visually in figure 5-15.
- The relatively small result from the partial F-test (smaller than 3), coupled with the poor probability level (greater than 5%), indicate a poor regression result (Albright, *et. al.*, 2006).
- Only 1 of the independent variables is shown to have any statistically significantly descriptive power (x_7 – template replication methods***)***. This

corroborates the finding noted from the difference between the R^2 and the adjusted R^2, which indicates that the additional independent variables addition to the accuracy of the prediction is close to random.

Figure 5 - 15: Reconstruction of Y1

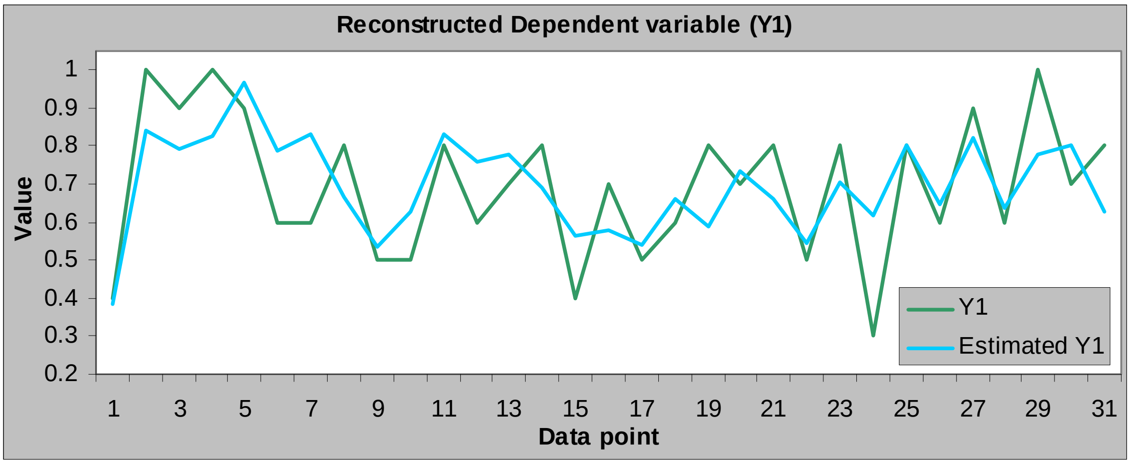


Figure 5-15 shows how the estimate closely approximates the mean of y_1 with minimal variability around this mean. The estimate fails to correctly capture several of the peaks in the data.

Appendix 2 shows the full results of the regression analysis. Specific note should be taken of the normality of all the residuals. In all cases, using the robust regression, the residuals of y_1 were found to be non-normal.

The attempt to use y_1 with the larger partial sample, in order to generate a higher confidence regression result, was attempted. Given that variable x_1 to x_4 are composed exclusively from questions in the first two questionnaire sections, 36 respondents could be used to generate a partial regression result. The results from this regression were poorer than that achieved with a larger variable set (but smaller sample), with an R^2 of 0.35.

Based on this analysis $\boldsymbol{y_1}$ was not used to test the hypotheses defined in section 3.

5.7.2. Regression analysis of y_2

The theoretical superiority of $\boldsymbol{y_2}$ as a "non-biased" indicator of the performance of the site are due to:

- Independent nature of the performance analysis removes respondent and site bias from the CPA index.
- The CPA index has been corrected for the influences of age, geographic location and technology.
- While respondents may be inclined to overstate their Solomon index, this effect was partially discounted through insurances of respondent anonymity. In addition, the analysis in section 5-3 show that this variable is statistically well behaved.

As with $\boldsymbol{y_1}$, the transformed composite variables shown defined table 5-4 were used as independent regression variables. Table 5-8 shows the summary results from the regression analysis.

Table 5 - 8: Multivariable linear regression results for y_2

Regression Summary Section	
Parameter	**Value**
Dependent Variable	Y2
Number Ind. Variables	10
Weight Variable	None
R 2	0.64
Adj R2	0.45
Coefficient of Variation	0.21
Mean Square Error	0.02
Square Root of MSE	0.13
Ave Abs Pct Error	19.15
F-Ratio (Prob. Level)	3.50 (0.008)

Regression Equation Section					
Independent Variable	**Regression Coef.**	**Stnd. Error**	**T-Value (H0:B(i)=0)**	**Prob. Level**	**Reject H0 at 5%?**
Intercept	**0.62**	**0.22**	**2.79**	**0.01**	**Yes**
X1	-0.39	0.27	-1.42	0.17	No
X2	-0.38	0.24	-1.59	0.13	No
X3	**-0.33**	**0.09**	**-3.75**	**0.00**	**Yes**
X4	**0.55**	**0.16**	**3.36**	**0.00**	**Yes**
X5	0.22	0.22	1.00	0.33	No
X6	**-0.35**	**0.14**	**-2.44**	**0.02**	**Yes**
X7	**0.48**	**0.18**	**2.64**	**0.02**	**Yes**
X8	-0.13	0.14	-0.92	0.37	No
X8a	-0.35	0.19	-1.84	0.08	No
X10	**0.62**	**0.20**	**3.03**	**0.01**	**Yes**

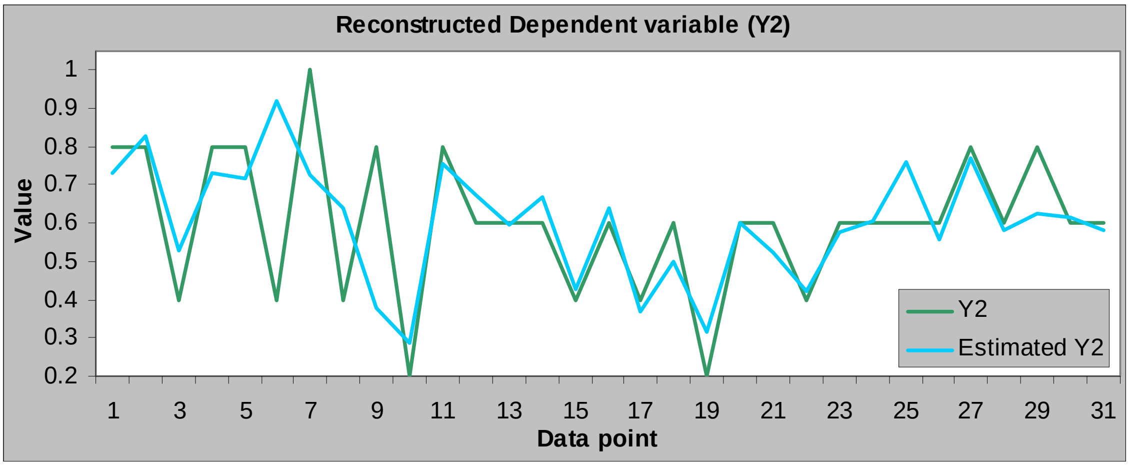
The aspects which brought the validity of $\boldsymbol{y_1}$ into question are not applicable to the regression results of $\boldsymbol{y_2}$. Rather, from table 5-8 the following is clear:

- The coefficient of determination shows that the independent variables account for 64% of the variation within $\boldsymbol{y_2}$. When this is adjusted to account for the small sample size, a significant portion of the variability is still described (45%).
- The results of the partial F-test show an acceptably high (greater than 3) value, with a probability smaller than 5% (Albright, *et. al.*, 2006). This indicates that variables within the model add significantly to the improved regression result.

- The descriptive power within the estimate of y_2, shown in figure 5-16, while still not fully accounting for all the variability, is visibly better than y_1 (figure 5-15).
- Five of the ten independent variables are found to have a statistically significant contribution to the estimate of y_2.

Figure 5-16 shows that the estimate of y_2 has significant descriptive power, closely following the original value away from the mean.

Figure 5 - 16: Reconstruction of Y1



Based on this analysis and the descriptive power within the estimate, the maximum likelihood estimate of y_2 is found to be an appropriate tool for testing the hypotheses presented in Section 3.

Appendix 3 shows the full results of the regression analysis. Specific note should be taken of the normality of all the residuals. In all cases, using the robust regression, the residuals of $\boldsymbol{y_2}$ were found to be normal.

Equation 5-2 shows the form of the final estimate ($\hat{y}_2$) of $\boldsymbol{y_2}$.

$$\hat{y}_2 = 0.62 - 0.39x_1 - 0.38x_2 - 0.33x_3 + 0.55x_4 + 0.22x_5 - 0.35x_6 + 0.48x_7 - 0.13x_8 - 0.35x_{8a} + 0.62x_{10}$$

Equation 5 - 2

5.8. Hypothesis testing

In section 3, two hypotheses were proposed.

5.8.1. Hypothesis 1 (Exploration)

Hypothesis 1 contends that successful replication is correlated with the development or conceptualisation of the Arrow Core (Winter & Szulanski, 2001). For the purpose of the analysis, the measure of success was defined by the Solomon Comparative Performance Assessment, CPA, captured in variable $\boldsymbol{y_2}$.

In order to determine the validity of this hypothesis, four sub-hypotheses were proposed. Each sub-hypothesis was directly tested through one of the composite variables defined in table 5-4. The null sub-hypotheses are defined in table 5-9.

Table 5 - 9: Results of the test for hypothesis 1

Main hypothesis						
Hypothesis 1 *(Exploration)*: Successful replication is correlated with the development or conceptualisation of the Arrow core.						
Sub hypotheses		**Null Hypothesis**	**Test variable**	**Reject H0 at 5%?**	**Probability**
H1a	Successful replication is correlated with the definition of core capabilities at a centre or focal part of the organisation.	H0: H1a=0	x3	Yes	0.00
H1b	Successful replication is correlated with the explicit definition of the valued features of the final product/service that are non-negotiable for each individual site.	H0: H1b=0	x4	Yes	0.00
H1c	Successful replication is correlated with the identification of the procedures involved in the local production of the valued features.	H0: H1c=0	x5	No	0.33
H1d	Successful replication is correlated with the conscious identification and elimination of information and business processes that are deleterious.	H0: H1d=0	x6	Yes	0.02

From table 5-9, the null hypothesis for the sub-hypotheses H1a, H1b and H1d can be rejected. Sub-hypothesis H1c was not rejected. This partial result for hypothesis 1 shows that while there are significant relationships, the hypothesis regarding exploration cannot be accepted in its entirety.

In addition to the rejection of the sub-hypotheses, the sign of the regression coefficient is also important in determining the validity of the hypothesis. This is because the hypothesis was stated for the non-zero case, rather than for the strictly positive case. From table 5-8, it can be seen that the coefficients x_3 and x_6 are negative, while x_4 and x_5 are positive. Therefore, in addition to H1c, the null hypotheses for H1a and H1d can not be rejected.

From this analysis, the following statements can be made regarding the development of the arrow core within the Petrochemical Refining Industry:

- The ***definition*** of a ***template*** or focal site has a significantly negative effect on the individual site performances (evidenced from the negative regression coefficient, as well as the high confidence determined for the regression coefficient).
- The ***definition*** of a ***common*** set of ***practices*** that are non-negotiable for all sites has a strongly positive effect on individual site performances (evidenced from the significantly positive regression coefficient, as well as the high confidence determined for the regression coefficient)..
- No conclusion can be reached regarding the importance of the identification of unique ***local practices*** to the success of individual sites (evidenced from low confidence determined for the regression coefficient).
- The conscious identification and ***removal*** of ***deleterious*** practices has a significantly negative effect on the individual sites performance (evidenced from the negative regression coefficient, as well as the high confidence determined for the regression coefficient).

While the lack of conclusion regarding H1c is unfortunate, the counter-intuitive conclusions regarding H1a and H1d require further analysis and exploration. Potential explanations that could be investigated include:

- The relative immaturity of the concept of a template site within this industry. This may result in a temporary negative performance effect which will reverse over time.
- Inappropriate weightings, translations or apportionment within the various transformations. This was tested through applying different codes and transforms to x_3 and x_6. These trials did not change the sign of the coefficients, or affect the conclusions which were reached from the regression analysis.
- Only a single respondent indicated the usage of a single template site, where the rest indicated either no template or multiple template sites, which is noteworthy to the result of H1a. This lack of this practice within the industry is highly significant.
- The majority (58%) of respondents to Q3.4, which is the sole independent input into determining the result for testing H1d, indicated that local rather than central processes were responsible for the removal of negative practices. This would result in those sites deviating further from the defined template practices, especially when the reason behind practices defined as part of the template are not understood. This effect was not adequately captured in the questionnaire.

The acceptance of only H1c within the greater definition of Hypothesis 1 can be interpreted in several ways. For the purpose of this study, it is assumed that the conclusions regarding the company specific definition of an arrow core, template site and the associate practices do not affect the tests regarding the implementation of those company best practices.

5.8.2. Hypothesis 2 (Exploitation)

Hypothesis 2 contends that successful replication is correlated with the effective use of a template (Winter & Szulanski, 2001). For the purpose of the analysis, the measure of success was defined by the Solomon Comparative Performance Assessment, CPA, captured in variable y_2.

In order to determine the validity of this hypothesis, three sub-hypotheses were proposed. Each sub-hypothesis was directly tested through one of the composite variables defined in table 5-4. The null sub-hypotheses are defined in table 5-10.

From table 5-10, the null hypotheses for sub-hypotheses H2a and H2b can be rejected. Sub-hypothesis H2c was not rejected. This partial result for hypothesis 2 shows that while there are significant relationships, but that the hypothesis regarding exploitation cannot be accepted in its entirety.

Table 5 - 10: Results of the test for hypothesis 2

Main hypothesis					
Hypothesis 2 *(Explitation)*: Successful replication is correlated with the effective use of a template					
Sub hypotheses		**Null Hypothesis**	**Test variable**	**Reject H0 at 5%?**	**Probability**
H2a	Successful replication is correlated with accurate and exact implementation of a set of business processes.	H0: H2a=0	x7	Yes	0.02
H2b	Successful replication is correlated with the control of variation in the local adaptation of the template.	H0: H2b=0	x10	Yes	0.01
H2c	Successful replication is correlated with the controlled exploration and adaptation in sites where a close replica of the template is in place and operating.	H0: H2c=0	x8, x8a	No	0.37, 0.08

In addition to the rejection of the sub-hypotheses, the sign of the regression coefficient is also important in determining the validity of the hypothesis. This is because the hypothesis was stated for the non-zero case, rather than for the strictly positive case. From table 5-8, it can be seen that the coefficients x_8 and x_{8a} are negative, while x_7 and x_{10} are positive. This does not affect the rejection of H2a and H2b, and does not change the result for H2c.

From this analysis, the following statements can be made regarding the exploitation of template practices within the Petrochemical Refining Industry:

- The ***accurate*** and exact ***implementation*** of a defined set of business processes has a strongly positively effect on the performance of individual sites (evidenced from the significantly positive regression coefficient, as well as the high confidence determined for the regression coefficient).
- The control of ***local adaptation*** and ***variation*** of the template practices has a strongly positive effect on the performance of individual sites (evidenced from the significantly positive regression coefficient, as well as the high confidence determined for the regression coefficient).
- No conclusion can be reached regarding the importance of ***controlling exploration*** and ***adaptation*** at either the template site, or at a close replica (evidenced from the low confidence determined for the regression coefficient).

Within the construct of hypothesis 2, the concepts captured in H2a and H2b regarding the effective exploitation of template site practices strongly correlate with positive site performance. While no conclusion could be reached regarding H2c, it is reasonable to accept hypothesis 2.

6. Conclusions

Despite the recent change in the world's economic climate, many of the large emerging economies are in a position where their growth and continued demand will place a floor under commodity prices (Economist, 2008c). Coupled with aggressive infrastructure investment plans in South Africa (The Presidency, 2006), methodologies for successful expansion in capital intensive industries will remain topical both locally and internationally.

Given the increased prevalence of replication in global expansion strategies (Winter & Szulanski, 2001), the applicability of this path to achieving growth within capital intensive companies needs to be evaluated.

While the replication of technology and tacit assets are relatively common in capital intensive businesses, the role of the intangible assets in successfully operating that technology has been neglected (King, 2007). This is despite significant evidence that the differences in the tacit knowledge assets between companies within the petrochemical sector significantly affect performance and profitability (Bloch & Hernu, 2007, King, 2007).

The re-use of central organisational knowledge through the replication of standardised business processes has been postulated (Winter & Szulanski, 2001) and qualitatively shown (Szulanski & Jensen, 2004) to be a successful approach. However, no quantitative studies have been published to prove the value of replication above a more *lassez faire* expansion strategy.

The lack of academic evidence has not stopped global companies realising the benefit to be gained from the replication of company knowledge, and taking strategic advantage from difficult to imitate tacit company asset (Szulanski & Jensen, 2004; Rivkin, 2000).

In order to show the benefits of a business process replication strategy within the capital intensive industry of petroleum refining, two theoretical constructs were tested:

- ***Exploration***: evaluating whether successful companies have developed and conceptualised the Arrow Core, as defined by Winter and Szulanski (2001).
- ***Exploitation***: evaluating whether successful companies have used the concept of a template in order to replicate aspects of the Arrow Core (Winter & Szulanski, 2001).

Inter and intra company data from the petroleum refining sector was used to model the presence of the above constructs, and formally test the hypotheses proposed regarding replication. While several sub-hypotheses were shown to be valid, the main hypotheses regarding the prevalence and applicability of replication in capital intensive industries were rejected.

6.1. Exploration

In their theoretical treatment of replication, Winter and Szulanski (2001) propose that the definition of an Arrow Core forms a key element in successful replication within a company. The Arrow Core represents the ideal set of positive contributors which a company uses to produce its product.

The test for the presence of the Arrow Core was formulated as a composite of four sub hypotheses, each testing for an element of the Arrow Core. This analysis clearly showed that successful replication was only correlated with aspects of the Arrow Core, and not with the entire theoretical construct. Two of the four characteristics of the Arrow Core were found to have a negative impact on the success of replication.

H1a: *Successful replication is correlated with the definition of core capabilities at a centre or focal part of the organisation.* In the regression analysis the aspects of central definition of the positive contributors was found to have a negative impact on the success of replication. This would suggest that companies actively attempting to create or define the Arrow Core at a focal part of the organisation perform less well than companies allowing the development of best practices at local sites.

While the source of this negative impact could be temporary, pointing to the immaturity of replication theory within this industry, this seems unlikely. A more acceptable conclusion is that the impact of operating complex technology currently requires high levels of local autonomy and expertise. Companies attempting to centrally define all the positive contributors are simply unable to do so.

This conclusion is in line with Rivkin's (2001) findings, showing that under very complex conditions the effort required to define the Arrow Core are so high that it negates the advantages from doing so.

H1b: *Successful replication is correlated with the explicit definition of the valued features of the final product/service that re non-negotiable for each site.* This was shown to be valid for capital intensive industries. A clear performance advantage was found within sites where a common set of practices regarding the final product was deployed and non-negotiable across the entire organisation.

This shows that while the definition of a complete set of positively contributing capabilities at the focal point of the organisation has a negative impact on performance, the deployment of a set of common practices across all sites does positively impact performance. This would indicate that the company wide definition and roll-out of best practices, originating at multiple sites and not concentrated at a focal point, positively impacts performance.

H1c: *Successful replication is correlated with the identification of the procedures involved in the local production of the valued features.* Winter and Szulanski (2001) postulate that successful replication involves actively identifying unique local processes that have positive interactions with the Arrow Core. No conclusion was reached from the analysis regarding the validity of this statement.

H1d: *Successful replication is correlated with the conscious identification and elimination of information and business processes that are deleterious.* The analysis conducted found that there was a significant negative performance impact at sites using this practice. In the discussion regarding this phenomenon, it was noted that across the entire sample, all examples of deleterious process identification and removal were locally driven and controlled by the individual sites.

By definition, high levels of causal ambiguity (like those present in complex manufacturing companies) make understanding the interactions between the consequences and the initiating causes. Given the efforts to centrally define and roll-out best practices and the local attempts to remove deleterious practices, the opportunity for local agents to be acting under conditions of incomplete information or imperfect understanding are real. This could lead to the two parties acting at cross purposes, and to the removal of potentially positive interactions.

The lack of evidence of the complete implementation of the Arrow Core could suggest that the requirement for a formal and central definition of the Arrow Core is not a pre-requisite for successful replication within capital intensive industries. However, the recognition and definition of the valued product features which are non-negotiable within the entire organisation are a pre-requisite. Undue effort to centrally define all aspects of the Arrow Core has been shown to have a negative impact on performance within Capital Intensive industries.

6.2. Exploitation

Once companies are comfortable with the extent of the definition of the Arrow Core, a single site with the most complete deployment of the Arrow Core is used as the template for replication. This freezing of the template marks the end of the exploration phase, and signals recognition that the effort spent in defining and partially perfecting the Arrow Core should now be exploited. The decision to freeze the template is determined by the trade off between speed and precision.

The use of a template to replicate the positive elements captured in the Arrow Core was proposed to be a key element in successful replication strategies (Winter & Szulanski, 2001). In order to test this, three sub hypotheses were used to determine the applicability of templates in capital intensive industries. Within this composite hypothesis, two of the three hypotheses were found to be true, and no conclusion could be reached regarding the third.

H2a: *Successful replication is correlated with accurate and exact implementation of a set of business processes*. While the central definition of a complete set of complimentary practices was found to be absent (*hypotheses H1a)*, the exact implementation of a set of business processes was found to have a strongly positive performance impact.

This is in no way contradictory, giving indication of the use of replication in the absence of a complete definition of the Arrow Core. Sites which attempted to exactly implement practices which had been shown to be successful at other sites within the organisation were more successful.

This would indicate that while the replicators access to the template in a complex industry does not allow the definition or formalisation of the Arrow Core, this access does bring advantage to sites attempting to exactly replicate a successful practice.

H2b: *Successful replication is correlated with the control of variation in the local adaptation of the template*. This was shown to be valid in the regression model and subsequent analysis. In contrast to hypothesis H1a, this result showed that a system initiated across the organisation to control local variation and adaptation of template site practices was a successful strategy.

This conclusion is in line with the findings regarding H1d, which showed that local attempts to remove deleterious practices were unsuccessful. This would suggest that certain practices and positive interactions are only clear on the organisational level, and cannot be controlled for locally.

H2c: *Successful replication is correlated with the controlled exploration and adaptation in sites where a close replica of the template is in place and operating.* No conclusion could be reached regarding this sub hypothesis. Exploitation is the phase where best practices and knowledge gained at the expense of the organisation, are leveraged for greater profits.

The intention of testing for H2c was to determine how continuous feedback and improvement is accounted for by the entire organisation. Controlled exploration at the template site was postulated to be a mechanism for capturing this learning. A lack of clear conclusion indicates that this may not be the dominant form for continuous improvement across organisations, and that a level of local autonomy may have a stronger role to play. However, no conclusion, positive or negative, could be reached.

From the modelling and analysis of the effective use of a template site, the two central sub hypotheses were found to hold. The lack of conclusion regarding H2c does not detract from the findings that the usage of a template in replicating business practices yields a clear performance advantage to sites using this practice.

6.3. Recommendations

This analysis of replication practices within petroleum refining has yielded several useful conclusions generalisable to capital intensive industry as a whole. As the first quantitative study of replication, it was possible to test the validity of the theoretical constructs presented in the literature. While aspects of the theory are not applicable in this industry, the framework presented an excellent platform from which to reach strong conclusions and make recommendations. The following recommendations could be presented to decision makers and managers in capital intensive industries.

Companies seeking to expand through a replication strategy should be wary of attempting to completely centralise a definition of all positive interactions (an Arrow Core). Indications are that the complexity in capital intensive industries could hamstring this effort, leading to a situation where the effort required in the exploration and definition of the interaction exceeds the gains to be had during the exploitation of those practices.

While the attempt to centrally define all positive contributors is not advisable, this does not preclude the requirement to share best practices between sites. The evidence from the study shows that local repositories of best practices are advantageous to the performance of the individual sites. Coupled with the use of these sites as templates and opportunities for experiential learning, companies can leverage best practices across the organisation.

The best practices gathered from these sites need to be treated as non-negotiable within the individual sites. By enforcing adherence to certain practices, and explicitly controlling for deviation or variation from the template sites practices, companies gain a performance advantage. Managers are advised to implement a central programme to define best practices across the individual sites. Those sites should then be used as templates for the roll-out of that practice across the whole organisation, while ensuring that variations or deviations are minimised.

While local autonomy may be important to allow for the development of best practices, certain company initiatives need to be centrally administered and controlled. By allowing sites to locally control for deleterious practices, the opportunity to remove potentially positive interactions arises – especially where those practices may have been identified across the whole organisation. This was shown to be true in the analysis. Managers are advised to carefully consider which practices are non-negotiable for sites, thereby preventing decision making in the presence of local causal ambiguity.

6.4. Future research

As the first quantitative study or replication, this report has found many of the central arguments within the theoretical constructs regarding replication to be of questionable applicability to capital intensive industries. However, since a single industry was used as a proxy, and the total sample size was relatively small, these findings need to be verified.

Throughout the analysis, the effect of company size (x_2) was used as an input into the analysis. However, no conclusions were reached regarding the impact of company size on the applicability of replication theory. It seems reasonable to postulate that there exists some threshold below which companies are too small to gain significant advantage from replication. This effect should be investigated.

Capital intensive industries are characterised by relatively slow expansions, with lead times for equipment, as well as capital requirements, often necessitating five to ten year periods between successive iterations. Under these conditions, perfection would have a stronger weight than speed of replication. This could skew analysis into replication in this industry, and should be explored.

Another element which was continuously included, but which yielded no conclusions, regards the effect of technology and site age (x_1) on performance. Previous studies (Bloch & Hernu, 2007) have shown that significant performance differences can be found over and above those introduced by technology. Since the dependent variable (y_2) that formed the basis of most conclusions has been corrected for technology, no conclusions regarding this aspect could be reached. Given the large impact of technology on performance (Chen, 2005), further analysis on this aspect is warranted.

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Further investigate the impact of local procedures on the positive performance of individual sites within the organisation needs to be done. While care was taken in this study to control for multi co linearity, there may be commonalities between locally and centrally defined practices. Future research could be conducted to further investigate this aspect, and tease out the unique performance differences.

One aspect of the theoretical construct which is only partially defined and could be more completely stated and investigated regards the differences between local and central controls. In the examination of H1a and H1d, the opportunity for the removal of potentially positive interactions was identified. Since local agents act to remove deleterious practices which the focal part of the organisation may either have introduced or assumed to be in play, introduced the opportunity for counter productive interventions.

This incomplete control over the implementation of the Arrow Core between local and central agents could skew conclusions regarding the necessity of the Arrow Core in replication strategies. By specifically measuring only eliminations that form part of the Arrow Core definition, it may be possible to more completely test the applicability of the Arrow Core in capital intensive industries.

While this study yielded rich conclusions, more study in this field is needed.

7. Consistency matrix

Table 7-1 shows the consistency matrix for the research project.

Title: Replication as a strategy in capital intensive industries.

Table 7 - 1: Consistency matrix

Hypotheses	Literature review	Instrument	Analysis
Hypothesis 1 *(Exploration)*: Successful replication is correlated with the development or conceptualisation of the Arrow core	Winter & Szulanski (2001)	x_3, x_4, x_5 & x_6	Multiple linear regression between questionnaire variables and y_1 & y_2.
H1a: Successful replication is correlated with the definition of core capabilities at a centre or focal part of the organisation	Kogut & Zander (1992)	x_3	Multiple linear regression between questionnaire variables and y_1 & y_2.
H1b: Successful replication is correlated with the explicit definition of the valued features of the final product/service that are non-negotiable for each individual site.	Winter & Szulanski (2001)	x_4	Multiple linear regression between questionnaire variables and y_1 & y_2.
H1c: Successful replication is correlated with the identification of the procedures involved in the local production of the valued features.	Winter & Szulanski (2001)	x_5	Multiple linear regression between questionnaire variables and y_1 & y_2.
H1d: Successful replication is correlated with the conscious identification and elimination of information and business processes that are deleterious.	Winter & Szulanski, 2001	x_6	Multiple linear regression between questionnaire variables and y_1 & y_2.

Hypothesis 2 *(Exploitation)*: Successful replication is correlated with the effective use of a template.	Winter & Szulanski (2001)	x_7, x_{10}, x_8 & x_{8a}	Multiple linear regression between questionnaire variables and y_1 & y_2.
H2a: Successful replication is correlated with accurate and exact implementation of a set of business processes.	Winter *et. al.* (2007) Winter & Szulanski (2001)	x_7	Multiple linear regression between questionnaire variables and y_1 & y_2.
H2b: Successful replication is correlated with the control of variation in the local adaptation of the template.	Jensen, 2007b	x_{10}	Multiple linear regression between questionnaire variables and y_1 & y_2.
H2c: Successful replication is correlated with the controlled exploration and adaptation in sites where a close replica of the template is in place and operating.	Winter & Szulanski (2001)	x_8 & x_{8a}	Multiple linear regression between questionnaire variables and y_1 & y_2.

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Appendix 1: Questionnaire

Replication survey: Sur

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1. Replication as a Strategy in Capital Intensive Industries

Given the current global demand for resources and energy, many operating companies are pursuing rapid expansion. Refining companies are no exception, and the question about how to successfully expand is thus particularly relevant.

In order to extract maximum value from it's operating expertise, companies can seek to operate multiple similar sites. Duplicating knowledge and best practices between different locations is known as replication.

While replication has been shown to be applicable in retail and service sectors, there is no evidence for it's applicability to technology industries (like refining).

This research intends to test the success of replication where technology choice and capital infrastructure have a significant impact on success.

The information collected is entirely anonymous. Your name, company or site will not be collected or stored. By completing this survey you indicate voluntary participation in this research, and grant permission for the response to be used in future research.

If you have any concerns, please contact me.

Melvin Jones
Email: jonesmk@gmail.com
Phone: +27 83 399 7670

The survey should take no longer than 10 - 15 minutes to complete, and is only 3 pages in length.

INTRODUCTORY QUESTIONS

* 1. Where is your site located?

- North America
- South America
- Europe
- Africa
- Middle East
- Asia
- Australia

* 2. In which five year period was the site first commissioned?

- Pre 1965
- 1965-70
- 1970-75
- 1975-80
- 1980-85
- 1985-90
- 1990-95
- 1995-00
- 2000-05
- Post 2005

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* 3. How many refining sites does your company operate?

- ◯ Less than 5
- ◯ Less than 10
- ◯ Less than 20
- ◯ Less than 50
- ◯ More than 50

* 4. When last did your site undergo a major refurbishment (greater than $500k)?

- ◯ Pre 1965
- ◯ 1965-70
- ◯ 1970-75
- ◯ 1975-80
- ◯ 1980-85
- ◯ 1985-90
- ◯ 1990-95
- ◯ 1995-00
- ◯ 2000-05
- ◯ Post 2005
- ◯ Never

2. Company practices

* 1. With 1 being poorly and 10 being the best, how would you compare your sites production performance against others within the industry?

* 2. Does your organisation have a template site on which organisational structure and operating practices for all other sites are based?

- ◯ Yes - single best practice template site
- ◯ Yes - multiple best practice sites
- ◯ No

* 3. How do the best practices from this template site get shared with your site? (please check all applicable options)

- ☐ No template site
- ☐ Experiential exposure of site personnel at COE
- ☐ Training/implementation by COE personnel at my site
- ☐ Documented procedures
- ☐ Updated business processes
- ☐ Newsletters, presentations, videos and reports
- ☐ Adhoc communication (email etc)
- ☐ Workshops and central training efforts
- ☐ Project and start-up teams deployed from COE
- ☐ Conferences
- ☐ Informal networks and site visits

* 4. To what extent is your site's orgnisational structure identical to the template site?

- ◯ Identical/Is the template site
- ◯ Very similar
- ◯ Similar
- ◯ Dissimilar
- ◯ Totally different
- ◯ Not applicable - no template site

* 5. To what extent do you believe the local operating practices differ from those of the template site?

- Not applicable - no template site
- Totally different
- Signifcantly different
- Moderately different
- Significantly similar
- Identical/Is the template site

* 6. To what extent do you believe the local culture differs from that at the template site?

- Not applicable - no tempate site
- Totally different
- Significantly different
- Moderately different
- Significantly similar
- Identical/Is the template site

* 7. To what extent are the physical layouts of the productive work spaces similar to that of the template site (eg, workshops, control rooms, laboratories etc)?

- Identical/Is the template site
- Very similar
- Similar
- Dissimilar
- Totally different
- Not applicable - no template site

* 8. What percentage of your sites operating procedures were designed or significantly adapted by local site personnel?

- None
- 0 - 25%
- 25% - 50%
- 50% - 75%
- 75% - 100%
- All

* 9. What percentage of your site's Process and Occupational Safety practices were designed or significantly adapted by local site personnel?

- None
- 0 - 25%
- 25% - 50%
- 50% - 75%
- 75% - 100%
- All

* 10. To what extent do you believe your sites operation is different from others within your organisation (due to issues like local work force and location)?

- Unique/single site company
- Totally different
- Significantly different
- Moderately different
- Significantly similar
- Identical

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* 11. Has the main operating company of the site changed in the last 10 years?

- ◯ Yes
- ◯ No

12. To what extent did the current operating company change existing business processes (eg Production Procedures, Saftey Processes, Planning etc)?

- ◯ Extensively
- ◯ Significantly
- ◯ Moderately
- ◯ Not significantly
- ◯ Not at all

3. Site practices

This is the final page of questions.

* 1. How tightly is adherence to corporate business processes and procedures controlled by headquarters?

- ◯ No site adaptation allowed
- ◯ Some site adaptation allowed
- ◯ Moderate site adaptation allowed
- ◯ High level of site adaptation allowed
- ◯ Extensive site adaptation allowed

* 2. How frequently are checks for variations in corporate work processes performed?

- ◯ Continuously
- ◯ Monthly
- ◯ Quarter or six monthly
- ◯ Annually
- ◯ Every 2 years
- ◯ Every 3 years
- ◯ Every 4 years
- ◯ Less than every 4 years
- ◯ Never

* 3. To what extent do you utilise site specific metrics (as opposed to company specified metrics) to determine performance?

- ◯ Not at all
- ◯ To some extent
- ◯ To a moderate extent
- ◯ To a large extent
- ◯ Very dependent on site speciific metrics

* 4. Does your company have a formal process for identifying and removing procedures that are obsolete or suboptimum?

- ◯ Yes - controlled by headquarters
- ◯ Yes - controlled locally
- ◯ No

* 5. How were the company best practices and business process captured?

- ◯ Developed at a non-production Centre of Excellence
- ◯ Developed at a production Centre of Excellence (site)
- ◯ Once-off collaborative effort between sites
- ◯ Itterative collaborative effort between sites, ie sharing of best practices

* 6. Which of the following best describes your organisations deployment of Enterprise Resource Planning (ERP-eg. SAP)?

- ◯ Single global instance
- ◯ Multiple instances on business unit level
- ◯ Multiple instances per geographical region
- ◯ Multiple instances on per site level
- ◯ Multiple instances within sites
- ◯ We do not use an ERP system

* 7. To what extent does your site control the business processes in your ERP system independently from headquarters?

- ◯ All changes controlled locally
- ◯ Most changes controlled locally
- ◯ Some changes controlled locally
- ◯ No changes controlled locally
- ◯ We do not use an ERP system

* 8. Please indicate your site's relative position in the latest Solomon Associates Comparative Performance Analysis, CPA (index).

- ◯ Pace setter
- ◯ 1st quartile
- ◯ 2nd quartile
- ◯ 3rd quartile
- ◯ 4th quartile

* 9. To what extent do you believe the application of the template site practices has resulted in improved site performance?

- ◯ Very significantly
- ◯ Significantly
- ◯ Moderately
- ◯ Not significantly
- ◯ Not at all
- ◯ Not applicable - no template site

* 10. How many of your company's improvements are piloted at a template site before being implemented at local sites?

- ◯ All improvements
- ◯ Most improvments
- ◯ Some improvements
- ◯ Few improvements
- ◯ None
- ◯ Not applicable - no template site

* 11. To what extent do you believe the practices unique to your site positively affect operational performance?

- ◯ Extremely high
- ◯ High
- ◯ Moderate
- ◯ Low
- ◯ Very low

* 12. How would you rate the success of your companies ability to roll out best practices?

- ◯ Extremely successful
- ◯ Very successful
- ◯ Moderately successful
- ◯ Unsuccessful
- ◯ Very unsuccessful

4. Contact details

Thank you for taking the time to complete this survey. Should you wish to receive a copy of the final report, please enter your email address below.

The contents of the survey will only be distributed in an aggregate and interpreted format, and the contents of the preceeding questions will not be stored with your contact details.

1. Email details

[ ]

You have completed the survey.

Appendix 2 – Complete regression results for y_1

Robust Multiple Regression Using Huber's Method (C=1.345)

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Run Summary Section

Parameter	Value	Parameter	Value
Dependent Variable	Y1	Rows Processed	31
Number Ind. Variables	10	Rows Filtered Out	0
Weight Variable	None	Rows with X's Missing	0
R2	0.4533	Rows with Weight Missing	0
Adj R2	0.1800	Rows with Y Missing	0
Coefficient of Variation	0.2384	Rows Used in Estimation	31
Mean Square Error	2.770068E-02	Sum of Weights	30.897
Square Root of MSE	0.1664352	Completion Status	Normal Completion
Ave Abs Pct Error	18.211		

Descriptive Statistics Section

Variable	Count	Mean	Standard Deviation	Minimum	Maximum
Q7	31	0.6217273	0.2058281	0.2166667	1
X1	31	0.664945	0.1690108	0.15	0.97
X10	31	0.5500556	0.1361983	0.2833333	0.85
X2	31	0.6129463	0.199568	0.2	1
X3	31	0.498332	0.4991375	0	1
X4	31	0.4593344	0.346263	0	1
X5	31	0.6071205	0.1232117	0.27	0.95
X6	31	0.3236568	0.2746775	0	1
X8	31	0.4025694	0.300315	0	0.8
X8a	31	0.6258925	0.1436763	0.2	1
Y1	31	0.6980978	0.1837931	0.3	1

R r's Method (C=1.345)

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Regression Equation Section

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	T-Value to test H0:B(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	0.9935	0.2827	3.515	0.0022	Yes	0.9164
Q7	0.4396	0.2092	2.102	0.0485	Yes	0.5161
X1	-0.3854	0.3230	-1.193	0.2467	No	0.2061
X10	0.0920	0.2575	0.357	0.7245	No	0.0634
X2	-0.3031	0.2886	-1.050	0.3061	No	0.1702
X3	-0.1176	0.1042	-1.128	0.2728	No	0.1890
X4	0.2107	0.2086	1.010	0.3246	No	0.1609
X5	0.0377	0.2738	0.138	0.8918	No	0.0520
X6	0.0907	0.1788	0.507	0.6176	No	0.0771
X8	-0.2079	0.1746	-1.191	0.2477	No	0.2054
X8a	-0.2942	0.2510	-1.172	0.2550	No	0.2005

Estimated Model

.993539152999632+ .439595027779099*Q7-.385385159044152*X1+ 9.20292205037931E-02*X10-.303068225525569*X2-.117554694755018*X3+ .210677562730758*X4+ 3.77211212019242E-02*X5+ .090687093002767*X6-.207871228638699*X8-.294150561429137*X8a

Regression Coefficient Section

Independent Variable	Regression Coefficient	Standard Error	Lower 95% C.L.	Upper 95% C.L.	Standardized Coefficient
Intercept	0.9935	0.2827	0.4039	1.5832	0.0000
Q7	0.4396	0.2092	0.0033	0.8759	0.4923
X1	-0.3854	0.3230	-1.0591	0.2883	-0.3544
X10	0.0920	0.2575	-0.4451	0.6292	0.0682
X2	-0.3031	0.2886	-0.9050	0.2989	-0.3291
X3	-0.1176	0.1042	-0.3350	0.0999	-0.3193
X4	0.2107	0.2086	-0.2245	0.6458	0.3969
X5	0.0377	0.2738	-0.5335	0.6090	0.0253
X6	0.0907	0.1788	-0.2824	0.4637	0.1355
X8	-0.2079	0.1746	-0.5720	0.1563	-0.3397
X8a	-0.2942	0.2510	-0.8177	0.2294	-0.2299

Note: The T-Value used to calculate these confidence limits was 2.086.

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R r's Method (C=1.345)

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Robust Regression Coefficients Section

Robust Iteration	Max % Change in any Beta	Robust B(0)	Robust B(1)	Robust B(2)	Robust B(3)
0	100.000	0.9859	0.4393	-0.3767	0.0883
1	13.408	0.9947	0.4396	-0.3867	0.0926
2	1.995	0.9935	0.4396	-0.3853	0.0920
3	0.064	0.9935	0.4396	-0.3854	0.0920
4	0.002	0.9935	0.4396	-0.3854	0.0920
5	0.000	0.9935	0.4396	-0.3854	0.0920
6	0.000	0.9935	0.4396	-0.3854	0.0920
7	0.000	0.9935	0.4396	-0.3854	0.0920
8	0.000	0.9935	0.4396	-0.3854	0.0920
9	0.000	0.9935	0.4396	-0.3854	0.0920
10	0.000	0.9935	0.4396	-0.3854	0.0920

Robust Percentiles of Residuals Section

Iter. No.	Max % Change in any Beta	---------------------- Percentiles of Absolute Residuals ---------------------- 25th	50th	75th	100th
0	100.000	0.044	0.107	0.165	0.310
1	13.408	0.045	0.108	0.167	0.318
2	1.995	0.045	0.108	0.167	0.317
3	0.064	0.045	0.108	0.167	0.317
4	0.002	0.045	0.108	0.167	0.317
5	0.000	0.045	0.108	0.167	0.317
6	0.000	0.045	0.108	0.167	0.317
7	0.000	0.045	0.108	0.167	0.317
8	0.000	0.045	0.108	0.167	0.317
9	0.000	0.045	0.108	0.167	0.317
10	0.000	0.045	0.108	0.167	0.317

Analysis of Variance Section

Source	DF	R2	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (5%)
Intercept	1		15.05733	15.05733			
Model	10	0.4533	0.459383	0.0459383	1.658	0.1610	0.5979
Error	20	0.5467	0.5540136	2.770068E-02			
Total(Adjusted)	30	1.0000	1.013397	3.377989E-02			

R… r's Method (C=1.345)

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Analysis of Variance Detail Section

Model Term	DF	R2	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (5%)
Intercept	1		15.05733	15.05733			
Model	10	0.4533	0.459383	0.0459383	1.658	0.1610	0.5979
Q7	1	0.1207	0.1223558	0.1223558	4.417	0.0485	0.5161
X1	1	0.0389	3.944362E-02	3.944362E-02	1.424	0.2467	0.2061
X10	1	0.0035	3.538159E-03	3.538159E-03	0.128	0.7245	0.0634
X2	1	0.0302	3.055535E-02	3.055535E-02	1.103	0.3061	0.1702
X3	1	0.0348	3.522337E-02	3.522337E-02	1.272	0.2728	0.1890
X4	1	0.0279	0.0282535	0.0282535	1.020	0.3246	0.1609
X5	1	0.0005	5.255807E-04	5.255807E-04	0.019	0.8918	0.0520
X6	1	0.0070	7.122589E-03	7.122589E-03	0.257	0.6176	0.0771
X8	1	0.0388	0.039276	0.039276	1.418	0.2477	0.2054
X8a	1	0.0375	0.0380478	0.0380478	1.374	0.2550	0.2005
Error	20	0.5467	0.5540136	2.770068E-02			
Total(Adjusted)	30	1.0000	1.013397	3.377989E-02			

Bootstrap Section

------------ Estimation Results ------------		| ------------ Bootstrap Confidence Limits ----------------		
Parameter	**Estimate**	**| Conf. Level**	**Lower**	**Upper**
Intercept				
Original Value	0.9935	| 0.9000	0.2712	1.8448
Bootstrap Mean	0.9997	| 0.9500	0.1438	2.0753
Bias (BM - OV)	0.0062	| 0.9900	-0.3072	2.7250
Bias Corrected	0.9874			
Standard Error	0.4964			
B(Q7)				
Original Value	0.4396	| 0.9000	-0.2139	0.9182
Bootstrap Mean	0.5211	| 0.9500	-0.3945	1.0268
Bias (BM - OV)	0.0815	| 0.9900	-0.8055	1.2831
Bias Corrected	0.3581			
Standard Error	0.3595			
B(X1)				
Original Value	-0.3854	| 0.9000	-1.3037	0.9550
Bootstrap Mean	-0.4824	| 0.9500	-1.4993	1.2257
Bias (BM - OV)	-0.0970	| 0.9900	-2.2329	1.7964
Bias Corrected	-0.2884			
Standard Error	0.6986			
B(X10)				
Original Value	0.0920	| 0.9000	-0.6300	0.9121
Bootstrap Mean	0.0582	| 0.9500	-0.8245	1.0966
Bias (BM - OV)	-0.0339	| 0.9900	-1.1541	1.4692
Bias Corrected	0.1259			
Standard Error	0.4763			
B(X2)				
Original Value	-0.3031	| 0.9000	-1.1787	0.4229
Bootstrap Mean	-0.2354	| 0.9500	-1.4083	0.6034
Bias (BM - OV)	0.0677	| 0.9900	-2.0039	1.1580
Bias Corrected	-0.3708			
Standard Error	0.5038			

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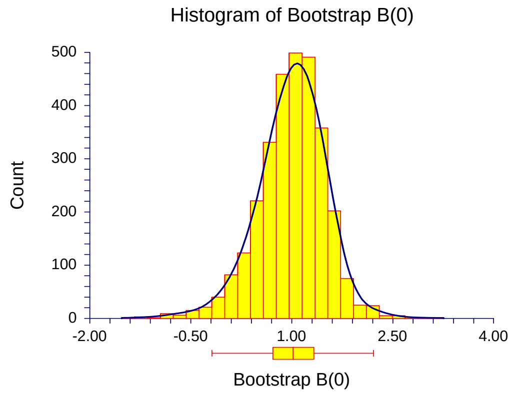
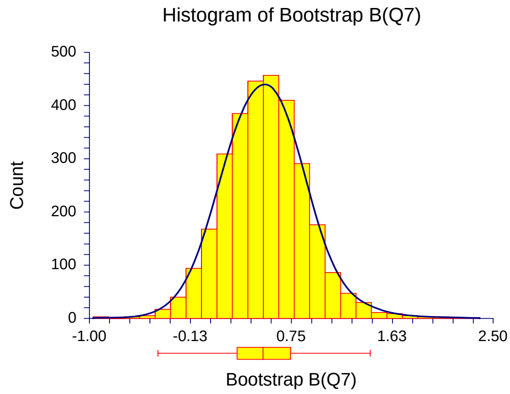
Bootstrap Section

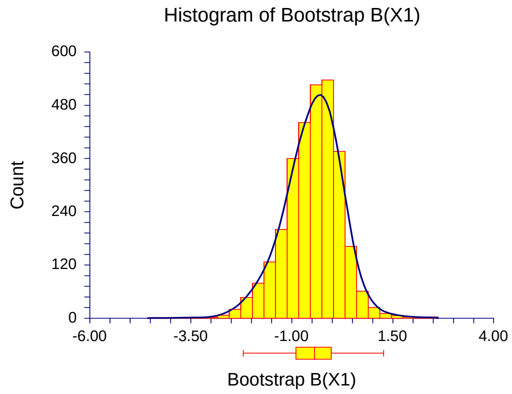
------------ Estimation Results ------------		------------ Bootstrap Confidence Limits ----------------		
Parameter	**Estimate**	**Conf. Level**	**Lower**	**Upper**
B(X3)				
Original Value	-0.1176	0.9000	-0.3321	0.2052
Bootstrap Mean	-0.1508	0.9500	-0.4171	0.2937
Bias (BM - OV)	-0.0332	0.9900	-0.6608	0.4699
Bias Corrected	-0.0843			
Standard Error	0.1725			
B(X4)				
Original Value	0.2107	0.9000	-0.3145	0.7456
Bootstrap Mean	0.2280	0.9500	-0.4355	0.8746
Bias (BM - OV)	0.0174	0.9900	-0.7924	1.2309
Bias Corrected	0.1933			
Standard Error	0.3336			
B(X5)				
Original Value	0.0377	0.9000	-0.8758	0.6785
Bootstrap Mean	0.0775	0.9500	-1.1683	0.9361
Bias (BM - OV)	0.0397	0.9900	-1.7982	1.4154
Bias Corrected	-0.0020			
Standard Error	0.4862			
B(X6)				
Original Value	0.0907	0.9000	-0.4763	0.5832
Bootstrap Mean	0.0647	0.9500	-0.5995	0.6821
Bias (BM - OV)	-0.0260	0.9900	-0.8693	0.8363
Bias Corrected	0.1167			
Standard Error	0.3213			
B(X8)				
Original Value	-0.2079	0.9000	-0.7960	0.2803
Bootstrap Mean	-0.1883	0.9500	-0.9283	0.3936
Bias (BM - OV)	0.0196	0.9900	-1.3265	0.6891
Bias Corrected	-0.2275			
Standard Error	0.3425			
B(X8a)				
Original Value	-0.2942	0.9000	-1.0308	0.4660
Bootstrap Mean	-0.3395	0.9500	-1.3048	0.6306
Bias (BM - OV)	-0.0453	0.9900	-2.0267	1.0405
Bias Corrected	-0.2488			
Standard Error	0.4712			

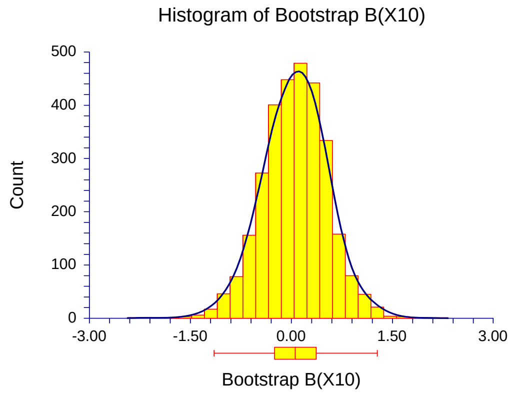
Sampling Method = Observation, Confidence Limit Type = Reflection, Number of Samples = 3000.

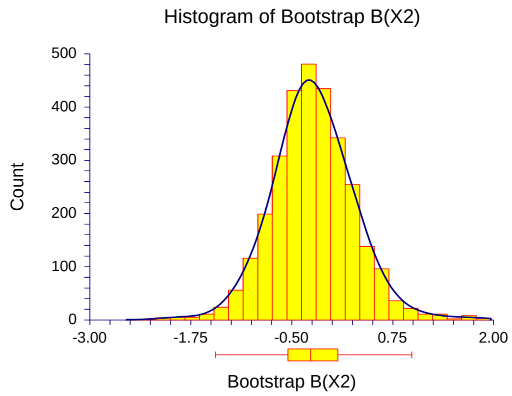
Bootstrap Histograms Section

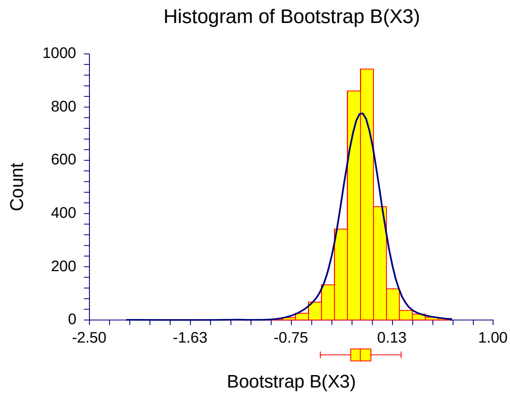












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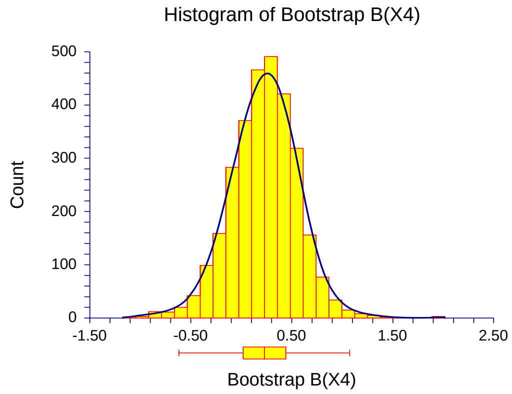

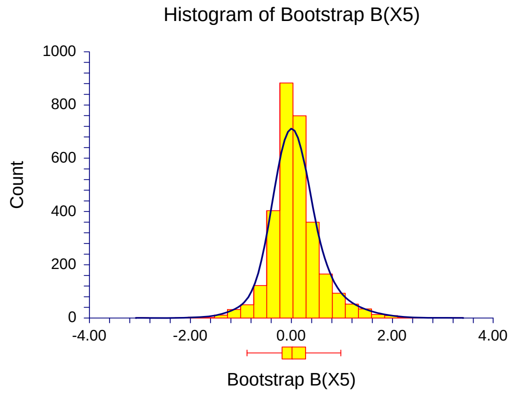

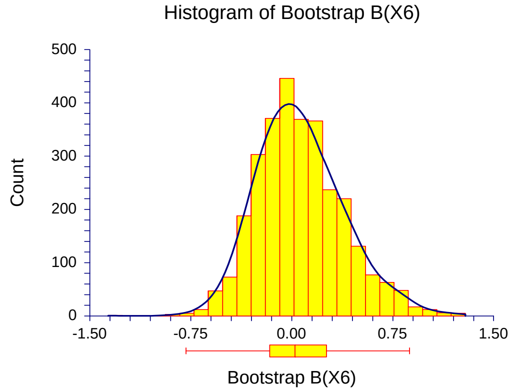

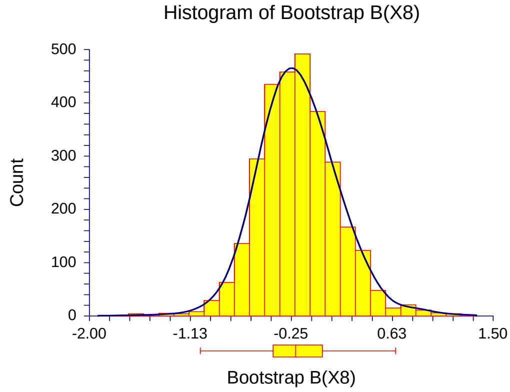

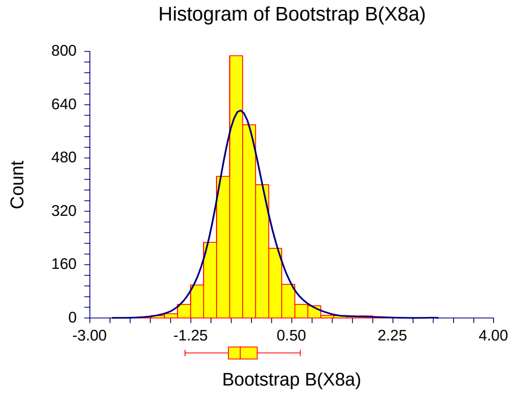

Normality Tests Section

Test Name	Test Value	Prob Level	Reject H0 At Alpha = 20%?
Shapiro Wilk	0.9624	0.337787	No
Anderson Darling	0.4653	0.253570	No
D'Agostino Skewness	-0.6490	0.516345	No
D'Agostino Kurtosis	-0.6295	0.529051	No
D'Agostino Omnibus	0.8174	0.664513	No

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Robust Residuals and Weights

Row	Actual Y1	Predicted Y1	Residual	Absolute Percent Error	Robust Weight
1	0.400	0.386	0.014	3.414	1.0000
2	1.000	0.840	0.160	15.986	1.0000
3	0.900	0.792	0.108	11.985	1.0000
4	1.000	0.825	0.175	17.522	1.0000
5	0.900	0.969	-0.069	7.674	1.0000
6	0.600	0.787	-0.187	31.117	1.0000
7	0.600	0.833	-0.233	38.765	1.0000
8	0.800	0.665	0.135	16.865	1.0000
9	0.500	0.535	-0.035	6.931	1.0000
10	0.500	0.627	-0.127	25.437	1.0000
11	0.800	0.831	-0.031	3.874	1.0000
12	0.600	0.759	-0.159	26.467	1.0000
13	0.700	0.777	-0.077	10.940	1.0000
14	0.800	0.689	0.111	13.922	1.0000
15	0.400	0.567	-0.167	41.673	1.0000
16	0.700	0.578	0.122	17.455	1.0000
17	0.500	0.538	-0.038	7.666	1.0000
18	0.600	0.663	-0.063	10.503	1.0000
19	0.800	0.589	0.211	26.398	1.0000
20	0.700	0.736	-0.036	5.174	1.0000
21	0.800	0.664	0.136	17.006	1.0000
22	0.500	0.547	-0.047	9.484	1.0000
23	0.800	0.705	0.095	11.818	1.0000
24	0.300	0.617	-0.317	105.621	0.8969
25	0.800	0.802	-0.002	0.295	1.0000
26	0.600	0.645	-0.045	7.443	1.0000
27	0.900	0.820	0.080	8.865	1.0000
28	0.600	0.635	-0.035	5.863	1.0000
29	1.000	0.781	0.219	21.947	1.0000
30	0.700	0.804	-0.104	14.861	1.0000
31	0.800	0.627	0.173	21.569	1.0000

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Database
Dependent Y1

Predicted Values with Confidence Limits of Means

Row	Actual Y1	Predicted Y1	Standard Error of Predicted	95% Lower Conf. Limit of Mean	95% Upper Conf. Limit of Mean
1	0.400	0.386	0.146	0.082	0.691
2	1.000	0.840	0.102	0.627	1.053
3	0.900	0.792	0.087	0.611	0.974
4	1.000	0.825	0.078	0.662	0.988
5	0.900	0.969	0.102	0.756	1.182
6	0.600	0.787	0.090	0.599	0.975
7	0.600	0.833	0.117	0.589	1.076
8	0.800	0.665	0.102	0.453	0.877
9	0.500	0.535	0.082	0.364	0.706
10	0.500	0.627	0.110	0.399	0.856
11	0.800	0.831	0.147	0.525	1.137
12	0.600	0.759	0.079	0.595	0.923
13	0.700	0.777	0.084	0.602	0.951
14	0.800	0.689	0.083	0.516	0.861
15	0.400	0.567	0.106	0.346	0.788
16	0.700	0.578	0.117	0.333	0.823
17	0.500	0.538	0.080	0.371	0.706
18	0.600	0.663	0.079	0.499	0.827
19	0.800	0.589	0.108	0.363	0.815
20	0.700	0.736	0.081	0.568	0.904
21	0.800	0.664	0.107	0.440	0.888
22	0.500	0.547	0.120	0.297	0.798
23	0.800	0.705	0.122	0.450	0.961
24	0.300	0.617	0.073	0.465	0.769
25	0.800	0.802	0.101	0.591	1.013
26	0.600	0.645	0.101	0.433	0.856
27	0.900	0.820	0.097	0.617	1.023
28	0.600	0.635	0.073	0.484	0.786
29	1.000	0.781	0.067	0.640	0.921
30	0.700	0.804	0.094	0.609	0.999
31	0.800	0.627	0.077	0.467	0.788

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Dependent Y1

Residual Report

Row	Actual Y1	Predicted Y1	Residual	Absolute Percent Error	Sqrt(MSE) Without This Row
1	0.400	0.386	0.014	3.414	0.171
2	1.000	0.840	0.160	15.986	0.164
3	0.900	0.792	0.108	11.985	0.168
4	1.000	0.825	0.175	17.522	0.165
5	0.900	0.969	-0.069	7.674	0.170
6	0.600	0.787	-0.187	31.117	0.163
7	0.600	0.833	-0.233	38.765	0.153
8	0.800	0.665	0.135	16.865	0.166
9	0.500	0.535	-0.035	6.931	0.171
10	0.500	0.627	-0.127	25.437	0.166
11	0.800	0.831	-0.031	3.874	0.170
12	0.600	0.759	-0.159	26.467	0.166
13	0.700	0.777	-0.077	10.940	0.170
14	0.800	0.689	0.111	13.922	0.168
15	0.400	0.567	-0.167	41.673	0.163
16	0.700	0.578	0.122	17.455	0.166
17	0.500	0.538	-0.038	7.666	0.170
18	0.600	0.663	-0.063	10.503	0.170
19	0.800	0.589	0.211	26.398	0.158
20	0.700	0.736	-0.036	5.174	0.170
21	0.800	0.664	0.136	17.006	0.166
22	0.500	0.547	-0.047	9.484	0.170
23	0.800	0.705	0.095	11.818	0.168
24	0.300	0.617	-0.317	105.621	0.153
25	0.800	0.802	-0.002	0.295	0.171
26	0.600	0.645	-0.045	7.443	0.170
27	0.900	0.820	0.080	8.865	0.169
28	0.600	0.635	-0.035	5.863	0.171
29	1.000	0.781	0.219	21.947	0.162
30	0.700	0.804	-0.104	14.861	0.168
31	0.800	0.627	0.173	21.569	0.165

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R r's Method (C=1.345)

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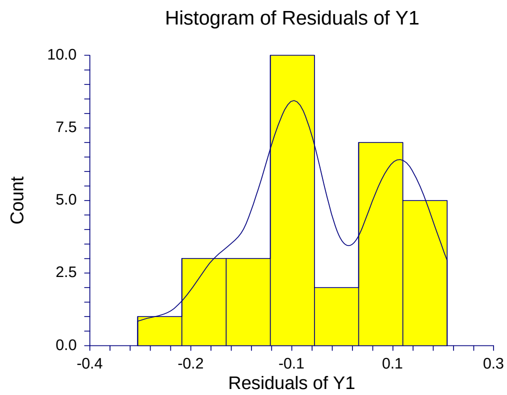
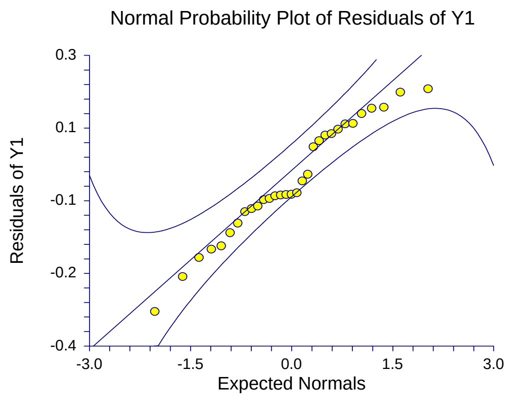
Dependent Y1

Regression Diagnostics Section

Row	Standardized Residual	RStudent	Hat Diagonal	Cook's D	Dffits	CovRatio
1	0.1706	0.1664	0.7686	0.0088	0.3032	7.4767
2	1.2168	1.2325	0.3769	0.0814	0.9585	1.2108
3	0.7601	0.7518	0.2731	0.0197	0.4608	1.7518
4	1.1928	1.2063	0.2209	0.0367	0.6424	1.0022
5	-0.5260	-0.5162	0.3775	0.0153	-0.4020	2.4230
6	-1.3344	-1.3627	0.2933	0.0672	-0.8778	0.8920
7	-1.9596	-2.1248	0.4914	0.3373	-2.0886	0.3313
8	1.0234	1.0247	0.3726	0.0565	0.7896	1.5506
9	-0.2393	-0.2336	0.2429	0.0017	-0.1323	2.2500
10	-1.0155	-1.0163	0.4337	0.0718	-0.8894	1.7342
11	-0.3928	-0.3843	0.7753	0.0484	-0.7139	7.1853
12	-1.0822	-1.0871	0.2226	0.0305	-0.5817	1.1645
13	-0.5325	-0.5227	0.2534	0.0087	-0.3045	2.0125
14	0.7713	0.7632	0.2473	0.0178	0.4375	1.6756
15	-1.2981	-1.3221	0.4047	0.1041	-1.0901	1.1216
16	1.0349	1.0368	0.4967	0.0961	1.0300	1.9069
17	-0.2629	-0.2567	0.2327	0.0019	-0.1414	2.2056
18	-0.4298	-0.4208	0.2238	0.0048	-0.2259	2.0452
19	1.6700	1.7547	0.4227	0.1857	1.5015	0.5837
20	-0.2487	-0.2428	0.2342	0.0017	-0.1343	2.2190
21	1.0689	1.0729	0.4152	0.0737	0.9040	1.5740
22	-0.4110	-0.4023	0.5195	0.0166	-0.4183	3.3329
23	0.8390	0.8326	0.5417	0.0756	0.9051	2.5863
24	-2.1184	-2.3103	0.1923	0.0871	-1.1274	0.1838
25	-0.0178	-0.0174	0.3690	0.0000	-0.0133	2.7856
26	-0.3385	-0.3308	0.3715	0.0062	-0.2544	2.6260
27	0.5908	0.5810	0.3418	0.0165	0.4186	2.2006
28	-0.2348	-0.2292	0.1898	0.0012	-0.1109	2.1051
29	1.4418	1.4846	0.1636	0.0370	0.6565	0.6285
30	-0.7563	-0.7479	0.3170	0.0241	-0.5095	1.8706
31	1.1697	1.1812	0.2144	0.0340	0.6171	1.0264

Plots Section





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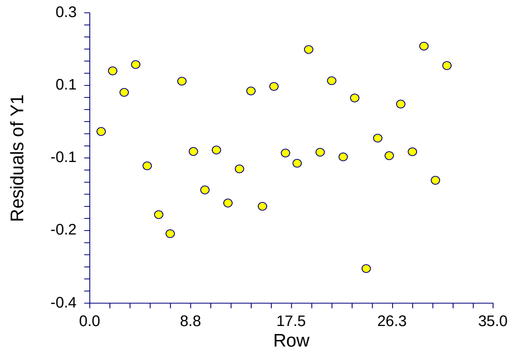
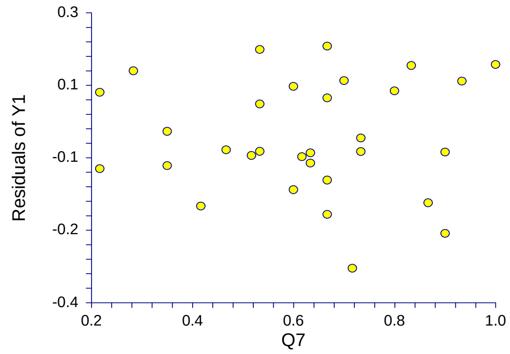
Dependent	Y1	

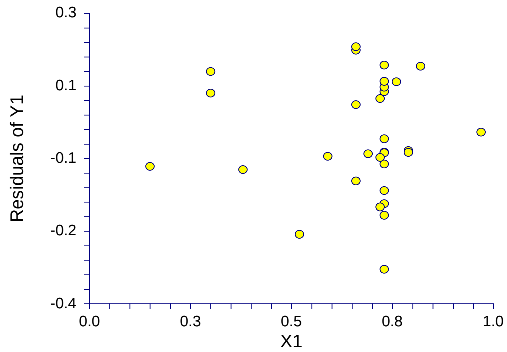
Residuals of Y1 vs Row



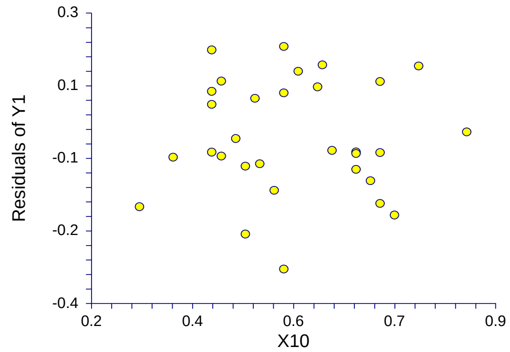
Residuals of Y1 vs Q7



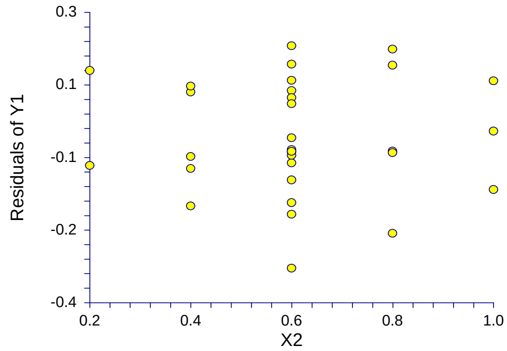
Residuals of Y1 vs X1



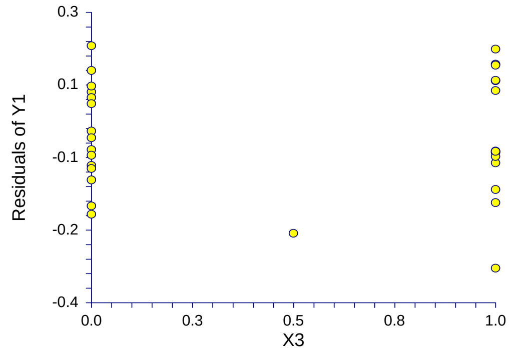
Residuals of Y1 vs X10



Residuals of Y1 vs X2



Residuals of Y1 vs X3



R... r's Method (C=1.345)

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Database
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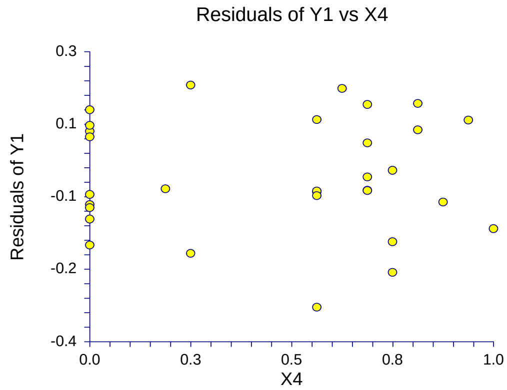

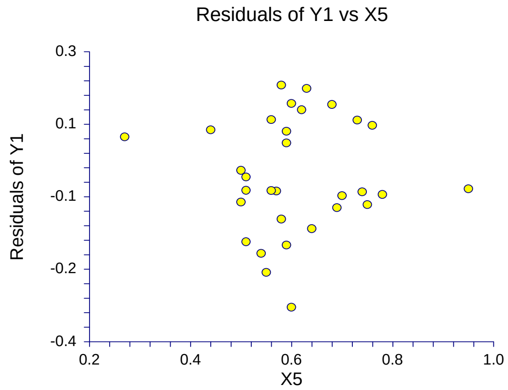

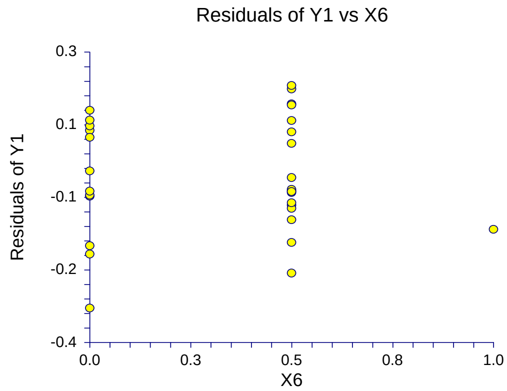

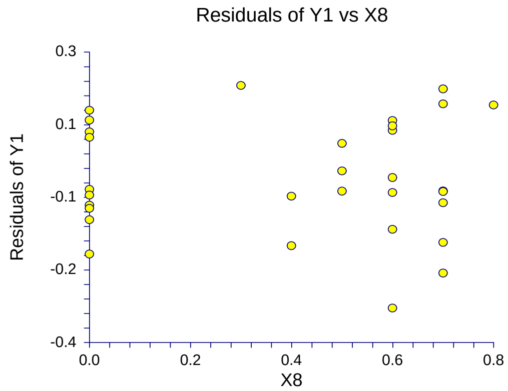

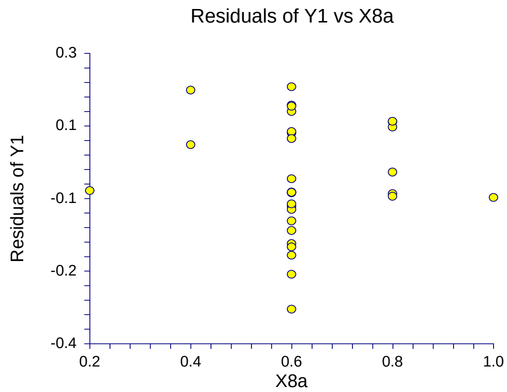

Appendix 3 – Complete regression results for y_2

Robust Multiple Regression Using Huber's Method (C=1.345)
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Database
Dependent Y2

Run Summary Section

Parameter	Value	Parameter	Value
Dependent Variable	Y2	Rows Processed	31
Number Ind. Variables	10	Rows Filtered Out	0
Weight Variable	None	Rows with X's Missing	0
R2	0.6361	Rows with Weight Missing	0
Adj R2	0.4541	Rows with Y Missing	0
Coefficient of Variation	0.2108	Rows Used in Estimation	31
Mean Square Error	0.0156805	Sum of Weights	27.982
Square Root of MSE	0.1252218	Completion Status	Normal Completion
Ave Abs Pct Error	19.151		

Descriptive Statistics Section

Variable	Count	Mean	Standard Deviation	Minimum	Maximum
Q7	31	0.6112133	0.1972833	0.2166667	1
X1	31	0.6627376	0.1665655	0.15	0.97
X10	31	0.5426248	0.1299677	0.2833333	0.85
X2	31	0.5987173	0.189185	0.2	1
X3	31	0.5021641	0.4789621	0	1
X4	31	0.446523	0.333736	0	1
X5	31	0.6114705	0.1202205	0.27	0.95
X6	31	0.3170029	0.2660373	0	1
X8	31	0.3973076	0.2853476	0	0.8
X8a	31	0.6252089	0.1418096	0.2	1
Y2	31	0.5939626	0.1694816	0.2	1

R... r's Method (C=1.345)

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Database
Dependent Y2

Regression Equation Section

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	T-Value to test H0:B(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	0.6182	0.2220	2.785	0.0114	Yes	0.7547
Q7	0.4778	0.1810	2.640	0.0157	Yes	0.7095
X1	-0.3887	0.2742	-1.417	0.1717	No	0.2714
X10	0.6197	0.2047	3.027	0.0067	Yes	0.8209
X2	-0.3760	0.2364	-1.591	0.1274	No	0.3283
X3	-0.3262	0.0869	-3.754	0.0012	Yes	0.9461
X4	0.5470	0.1629	3.358	0.0031	Yes	0.8911
X5	0.2153	0.2157	0.998	0.3302	No	0.1582
X6	-0.3466	0.1420	-2.440	0.0241	Yes	0.6412
X8	-0.1280	0.1387	-0.923	0.3670	No	0.1422
X8a	-0.3536	0.1920	-1.842	0.0804	No	0.4182

Estimated Model

.618157891280308+ .477763184217771*Q7-.38869143293018*X1+ .619678583966632*X10-.376007109798185*X2-.326230471123455*X3+ .547043679702225*X4+ .215267674116516*X5-.34658067735888*X6-.128002123806395*X8-.353632153878581*X8a

Regression Coefficient Section

Independent Variable	Regression Coefficient	Standard Error	Lower 95% C.L.	Upper 95% C.L.	Standardized Coefficient
Intercept	0.6182	0.2220	0.1551	1.0812	0.0000
Q7	0.4778	0.1810	0.1003	0.8552	0.5561
X1	-0.3887	0.2742	-0.9607	0.1833	-0.3820
X10	0.6197	0.2047	0.1926	1.0467	0.4752
X2	-0.3760	0.2364	-0.8691	0.1171	-0.4197
X3	-0.3262	0.0869	-0.5075	-0.1450	-0.9219
X4	0.5470	0.1629	0.2072	0.8869	1.0772
X5	0.2153	0.2157	-0.2347	0.6652	0.1527
X6	-0.3466	0.1420	-0.6429	-0.0503	-0.5440
X8	-0.1280	0.1387	-0.4173	0.1613	-0.2155
X8a	-0.3536	0.1920	-0.7542	0.0469	-0.2959

Note: The T-Value used to calculate these confidence limits was 2.086.

Database
Dependent Y2

Robust Regression Coefficients Section

Robust Iteration	Max % Change in any Beta	Robust B(0)	Robust B(1)	Robust B(2)	Robust B(3)
0	100.000	0.7887	0.3233	-0.4543	0.4502
1	188.135	0.7318	0.3959	-0.4282	0.5435
2	70.831	0.6807	0.4335	-0.4121	0.5910
3	12.025	0.6532	0.4508	-0.3987	0.6049
4	13.342	0.6352	0.4613	-0.3898	0.6154
5	4.145	0.6260	0.4684	-0.3865	0.6189
6	2.182	0.6217	0.4724	-0.3861	0.6201
7	0.601	0.6200	0.4748	-0.3869	0.6200
8	0.367	0.6190	0.4763	-0.3877	0.6199
9	0.207	0.6185	0.4772	-0.3883	0.6197
10	0.127	0.6182	0.4777	-0.3887	0.6196

Robust Percentiles of Residuals Section

Iter. No.	Max % Change in any Beta	---------------------- Percentiles of Absolute Residuals ---------------------- 25th	50th	75th	100th
0	100.000	0.030	0.080	0.167	0.382
1	188.135	0.016	0.069	0.143	0.466
2	70.831	0.020	0.070	0.142	0.495
3	12.025	0.021	0.068	0.134	0.502
4	13.342	0.023	0.068	0.125	0.510
5	4.145	0.023	0.067	0.120	0.514
6	2.182	0.023	0.068	0.117	0.516
7	0.601	0.023	0.068	0.116	0.517
8	0.367	0.023	0.068	0.116	0.517
9	0.207	0.023	0.068	0.116	0.517
10	0.127	0.023	0.068	0.116	0.517

Analysis of Variance Section

Source	DF	R2	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (5%)
Intercept	1		9.871952	9.871952			
Model	10	0.6361	0.548111	5.481109E-02	3.495	0.0083	0.9358
Error	20	0.3639	0.31361	0.0156805			
Total(Adjusted)	30	1.0000	0.8617209	2.872403E-02			

Analysis of Variance Detail Section

Model Term	DF	R2	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (5%)
Intercept	1		9.871952	9.871952			
Model	10	0.6361	0.548111	5.481109E-02	3.495	0.0083	0.9358
Q7	1	0.1268	0.1093028	0.1093028	6.971	0.0157	0.7095
X1	1	0.0366	0.0315058	0.0315058	2.009	0.1717	0.2714
X10	1	0.1667	0.1436621	0.1436621	9.162	0.0067	0.8209
X2	1	0.0460	3.967503E-02	3.967503E-02	2.530	0.1274	0.3283
X3	1	0.2565	0.2209885	0.2209885	14.093	0.0012	0.9461
X4	1	0.2051	0.1767788	0.1767788	11.274	0.0031	0.8911
X5	1	0.0181	1.561631E-02	1.561631E-02	0.996	0.3302	0.1582
X6	1	0.1083	9.335541E-02	9.335541E-02	5.954	0.0241	0.6412
X8	1	0.0155	1.335917E-02	1.335917E-02	0.852	0.3670	0.1422
X8a	1	0.0617	5.318409E-02	5.318409E-02	3.392	0.0804	0.4182
Error	20	0.3639	0.31361	0.0156805			
Total(Adjusted)	30	1.0000	0.8617209	2.872403E-02			

Bootstrap Section

------------ Estimation Results ------------		| ------------ Bootstrap Confidence Limits ----------------		
Parameter	**Estimate**	**| Conf. Level**	**Lower**	**Upper**
Intercept				
Original Value	0.6182	| 0.9000	-0.3949	1.1121
Bootstrap Mean	0.7865	| 0.9500	-0.6199	1.2441
Bias (BM - OV)	0.1683	| 0.9900	-1.1550	1.6409
Bias Corrected	0.4498			
Standard Error	0.4752			
B(Q7)				
Original Value	0.4778	| 0.9000	-0.1108	1.2587
Bootstrap Mean	0.4012	| 0.9500	-0.2314	1.4259
Bias (BM - OV)	-0.0766	| 0.9900	-0.7635	1.8128
Bias Corrected	0.5543			
Standard Error	0.4301			
B(X1)				
Original Value	-0.3887	| 0.9000	-1.3032	0.5186
Bootstrap Mean	-0.4696	| 0.9500	-1.5387	0.7156
Bias (BM - OV)	-0.0809	| 0.9900	-2.2402	1.3974
Bias Corrected	-0.3078			
Standard Error	0.5936			
B(X10)				
Original Value	0.6197	| 0.9000	0.2358	1.8239
Bootstrap Mean	0.3651	| 0.9500	0.0697	1.9895
Bias (BM - OV)	-0.2546	| 0.9900	-0.3488	2.3265
Bias Corrected	0.8742			
Standard Error	0.4948			
B(X2)				
Original Value	-0.3760	| 0.9000	-1.3085	0.3142
Bootstrap Mean	-0.2779	| 0.9500	-1.4811	0.4814
Bias (BM - OV)	0.0982	| 0.9900	-1.8376	1.0633
Bias Corrected	-0.4742			
Standard Error	0.5036			

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Bootstrap Section

------------ Estimation Results ------------		------------ Bootstrap Confidence Limits ----------------		
Parameter	**Estimate**	**Conf. Level**	**Lower**	**Upper**
B(X3)				
Original Value	-0.3262	0.9000	-0.7087	-0.0872
Bootstrap Mean	-0.2517	0.9500	-0.7630	-0.0293
Bias (BM - OV)	0.0746	0.9900	-0.9211	0.1640
Bias Corrected	-0.4008			
Standard Error	0.1960			
B(X4)				
Original Value	0.5470	0.9000	0.2422	1.4356
Bootstrap Mean	0.3415	0.9500	0.1237	1.5615
Bias (BM - OV)	-0.2055	0.9900	-0.1900	1.9686
Bias Corrected	0.7526			
Standard Error	0.3792			
B(X5)				
Original Value	0.2153	0.9000	-0.3859	1.4102
Bootstrap Mean	0.0750	0.9500	-0.6309	1.8141
Bias (BM - OV)	-0.1403	0.9900	-1.2691	2.6467
Bias Corrected	0.3555			
Standard Error	0.5790			
B(X6)				
Original Value	-0.3466	0.9000	-0.9173	-0.0598
Bootstrap Mean	-0.2267	0.9500	-1.0369	0.0249
Bias (BM - OV)	0.1198	0.9900	-1.3061	0.2769
Bias Corrected	-0.4664			
Standard Error	0.2717			
B(X8)				
Original Value	-0.1280	0.9000	-0.9773	0.0772
Bootstrap Mean	0.0475	0.9500	-1.1626	0.1460
Bias (BM - OV)	0.1755	0.9900	-1.6143	0.3809
Bias Corrected	-0.3035			
Standard Error	0.3460			
B(X8a)				
Original Value	-0.3536	0.9000	-1.3293	0.2179
Bootstrap Mean	-0.2837	0.9500	-1.6005	0.4134
Bias (BM - OV)	0.0699	0.9900	-2.1982	0.8735
Bias Corrected	-0.4235			
Standard Error	0.4810			

Sampling Method = Observation, Confidence Limit Type = Reflection, Number of Samples = 3000.

R r's Method (C=1.345)

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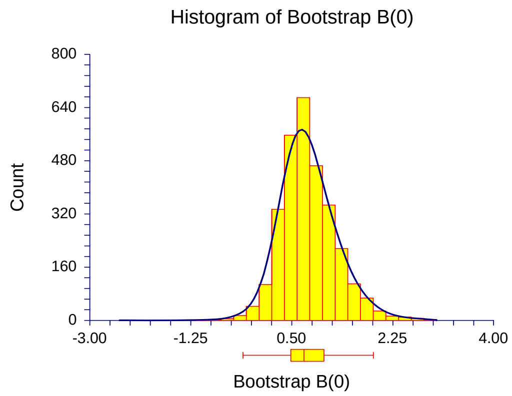
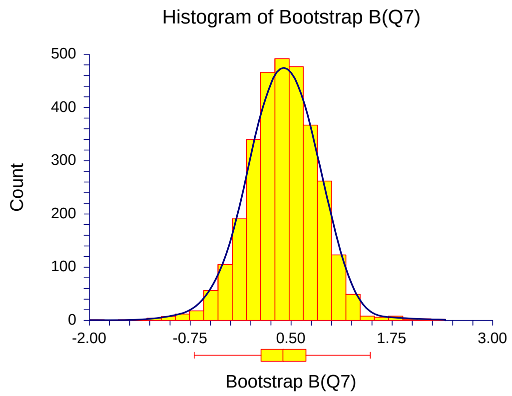
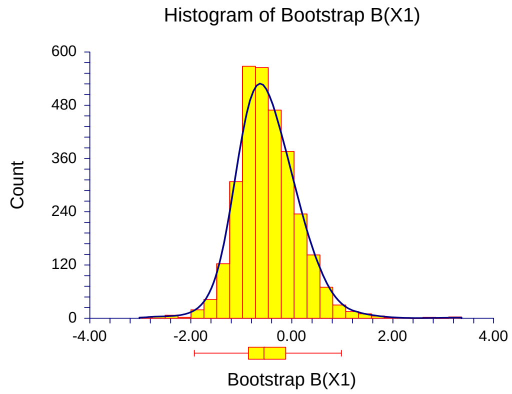
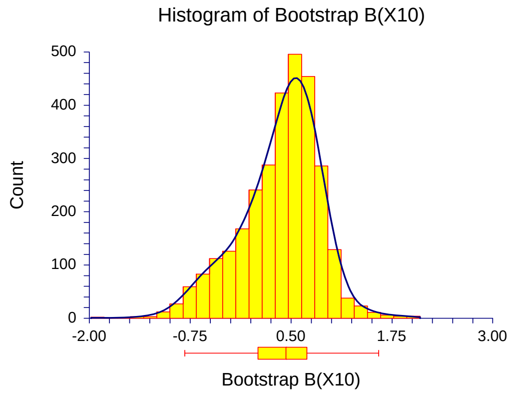
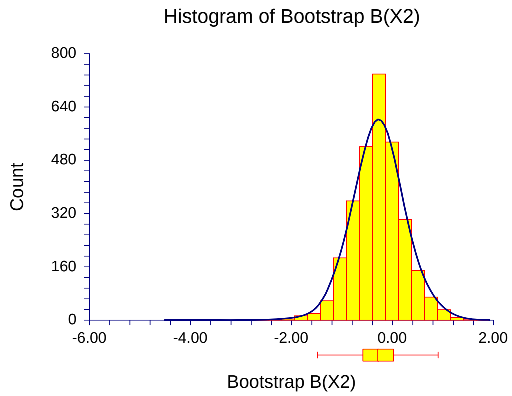
Bootstrap Histograms Section

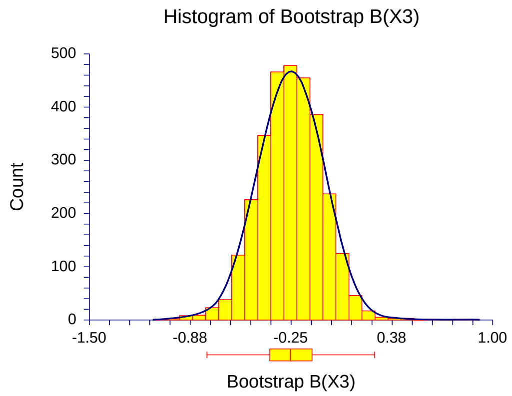












R r's Method (C=1.345)

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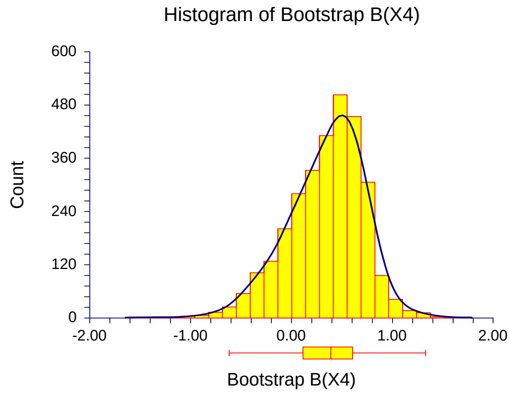

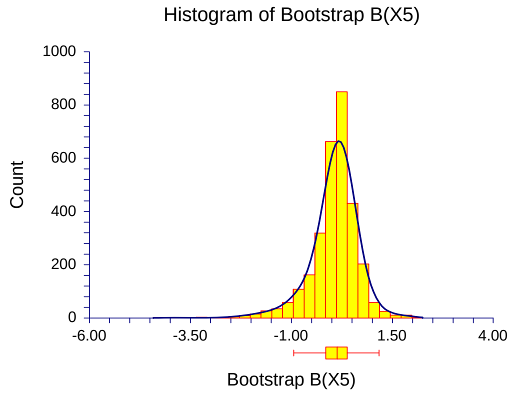

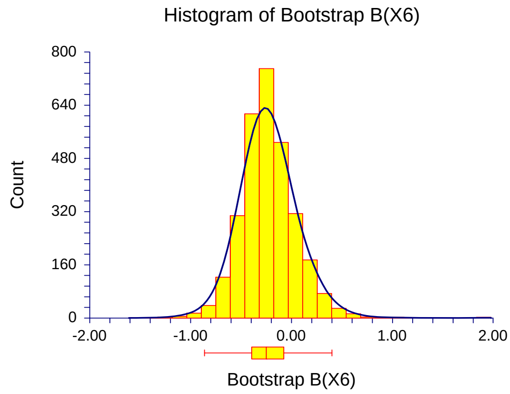

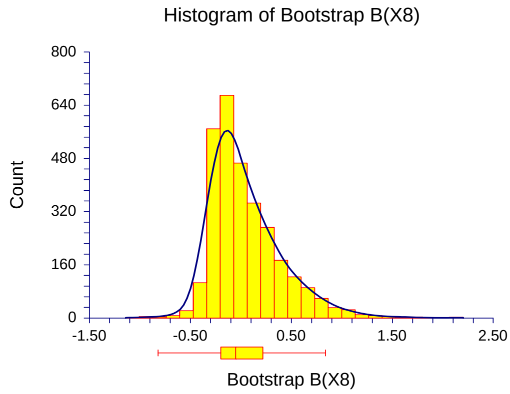

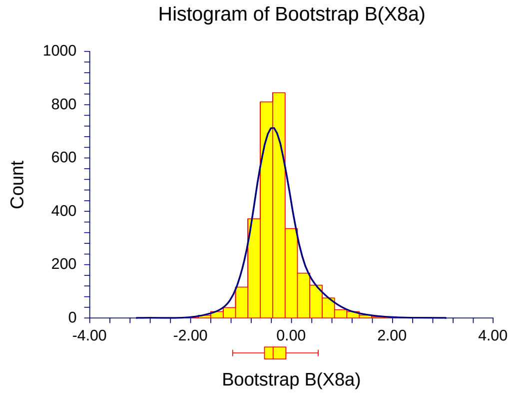

Normality Tests Section

Test Name	**Test Value**	**Prob Level**	**Reject H0 At Alpha = 20%?**
Shapiro Wilk	0.8874	0.003553	Yes
Anderson Darling	1.2820	0.002491	Yes
D'Agostino Skewness	-1.3526	0.176185	Yes
D'Agostino Kurtosis	2.9936	0.002757	Yes
D'Agostino Omnibus	10.7909	0.004537	Yes

R… r's Method (C=1.345)

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Robust Residuals and Weights

Row	Actual Y2	Predicted Y2	Residual	Absolute Percent Error	Robust Weight
1	0.800	0.730	0.070	8.741	1.0000
2	0.800	0.829	-0.029	3.624	1.0000
3	0.400	0.527	-0.127	31.674	0.9849
4	0.800	0.731	0.069	8.661	1.0000
5	0.800	0.717	0.083	10.371	1.0000
6	0.400	0.917	-0.517	129.353	0.2414
7	1.000	0.725	0.275	27.510	0.4533
8	0.400	0.637	-0.237	59.301	0.5270
9	0.800	0.381	0.419	52.382	0.2981
10	0.200	0.288	-0.088	44.127	1.0000
11	0.800	0.754	0.046	5.795	1.0000
12	0.600	0.675	-0.075	12.569	1.0000
13	0.600	0.595	0.005	0.902	1.0000
14	0.600	0.668	-0.068	11.339	1.0000
15	0.400	0.426	-0.026	6.542	1.0000
16	0.600	0.641	-0.041	6.868	1.0000
17	0.400	0.367	0.033	8.131	1.0000
18	0.600	0.501	0.099	16.489	1.0000
19	0.200	0.316	-0.116	57.802	1.0000
20	0.600	0.602	-0.002	0.281	1.0000
21	0.600	0.526	0.074	12.378	1.0000
22	0.400	0.422	-0.022	5.394	1.0000
23	0.600	0.577	0.023	3.890	1.0000
24	0.600	0.603	-0.003	0.560	1.0000
25	0.600	0.762	-0.162	26.939	0.7738
26	0.600	0.558	0.042	6.927	1.0000
27	0.800	0.768	0.032	3.973	1.0000
28	0.600	0.583	0.017	2.814	1.0000
29	0.800	0.623	0.177	22.154	0.7039
30	0.600	0.617	-0.017	2.893	1.0000
31	0.600	0.580	0.020	3.297	1.0000

R r's Method (C=1.345)

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Dependent Y2

Predicted Values with Confidence Limits of Means

Row	Actual Y2	Predicted Y2	Standard Error of Predicted	95% Lower Conf. Limit of Mean	95% Upper Conf. Limit of Mean
1	0.800	0.730	0.114	0.493	0.968
2	0.800	0.829	0.079	0.665	0.993
3	0.400	0.527	0.067	0.388	0.666
4	0.800	0.731	0.061	0.603	0.859
5	0.800	0.717	0.079	0.553	0.881
6	0.400	0.917	0.038	0.838	0.997
7	1.000	0.725	0.073	0.573	0.877
8	0.400	0.637	0.066	0.500	0.774
9	0.800	0.381	0.038	0.303	0.459
10	0.200	0.288	0.086	0.108	0.468
11	0.800	0.754	0.113	0.517	0.990
12	0.600	0.675	0.060	0.550	0.801
13	0.600	0.595	0.065	0.458	0.731
14	0.600	0.668	0.064	0.535	0.801
15	0.400	0.426	0.084	0.252	0.601
16	0.600	0.641	0.089	0.456	0.826
17	0.400	0.367	0.065	0.233	0.502
18	0.600	0.501	0.063	0.370	0.632
19	0.200	0.316	0.087	0.135	0.496
20	0.600	0.602	0.062	0.473	0.730
21	0.600	0.526	0.083	0.352	0.699
22	0.400	0.422	0.093	0.228	0.615
23	0.600	0.577	0.095	0.378	0.775
24	0.600	0.603	0.059	0.480	0.727
25	0.600	0.762	0.072	0.611	0.913
26	0.600	0.558	0.081	0.389	0.728
27	0.800	0.768	0.077	0.608	0.929
28	0.600	0.583	0.055	0.469	0.697
29	0.800	0.623	0.045	0.529	0.717
30	0.600	0.617	0.073	0.465	0.770
31	0.600	0.580	0.060	0.455	0.706

R r's Method (C=1.345)

Database
Dependent Y2

Residual Report

Row	Actual Y2	Predicted Y2	Residual	Absolute Percent Error	Sqrt(MSE) Without This Row
1	0.800	0.730	0.070	8.741	0.123
2	0.800	0.829	-0.029	3.624	0.128
3	0.400	0.527	-0.127	31.674	0.124
4	0.800	0.731	0.069	8.661	0.127
5	0.800	0.717	0.083	10.371	0.126
6	0.400	0.917	-0.517	129.353	0.113
7	1.000	0.725	0.275	27.510	0.117
8	0.400	0.637	-0.237	59.301	0.120
9	0.800	0.381	0.419	52.382	0.116
10	0.200	0.288	-0.088	44.127	0.125
11	0.800	0.754	0.046	5.795	0.126
12	0.600	0.675	-0.075	12.569	0.127
13	0.600	0.595	0.005	0.902	0.128
14	0.600	0.668	-0.068	11.339	0.127
15	0.400	0.426	-0.026	6.542	0.128
16	0.600	0.641	-0.041	6.868	0.128
17	0.400	0.367	0.033	8.131	0.128
18	0.600	0.501	0.099	16.489	0.126
19	0.200	0.316	-0.116	57.802	0.123
20	0.600	0.602	-0.002	0.281	0.128
21	0.600	0.526	0.074	12.378	0.126
22	0.400	0.422	-0.022	5.394	0.128
23	0.600	0.577	0.023	3.890	0.128
24	0.600	0.603	-0.003	0.560	0.128
25	0.600	0.762	-0.162	26.939	0.122
26	0.600	0.558	0.042	6.927	0.128
27	0.800	0.768	0.032	3.973	0.128
28	0.600	0.583	0.017	2.814	0.128
29	0.800	0.623	0.177	22.154	0.123
30	0.600	0.617	-0.017	2.893	0.128
31	0.600	0.580	0.020	3.297	0.128

R… r's Method (C=1.345)

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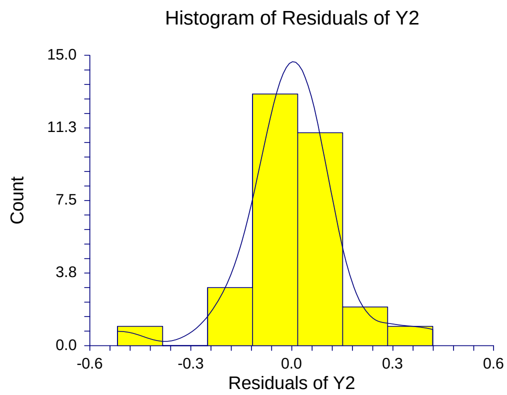
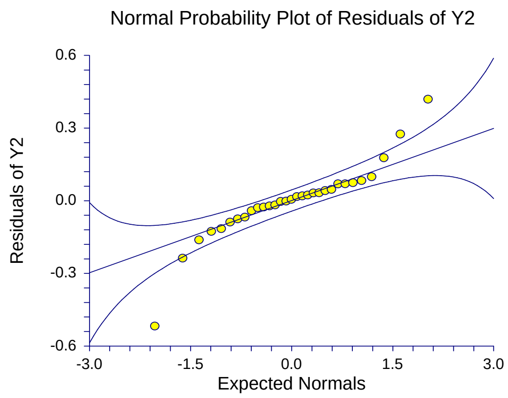
Dependent Y2

Regression Diagnostics Section

Row	Standardized Residual	RStudent	Hat Diagonal	Cook's D	Dffits	CovRatio
1	1.3405	1.3695	0.8265	0.7779	2.9886	3.5968
2	-0.2976	-0.2907	0.3950	0.0053	-0.2349	2.7673
3	-1.1944	-1.2074	0.2824	0.0503	-0.7575	1.0995
4	0.6349	0.6252	0.2406	0.0116	0.3519	1.8504
5	0.8514	0.8454	0.3945	0.0429	0.6823	1.9344
6	-4.3394	-4.8114	0.0933	0.0425	-1.5435	0.1137
7	2.6984	2.8782	0.3371	0.1526	2.0526	0.3648
8	-2.2242	-2.3247	0.2747	0.0898	-1.4307	0.5215
9	3.5079	3.7836	0.0899	0.0329	1.1892	0.2080
10	-0.9726	-0.9712	0.4749	0.0778	-0.9236	1.9648
11	0.8750	0.8697	0.8210	0.3192	1.8622	6.3916
12	-0.6873	-0.6780	0.2323	0.0130	-0.3729	1.7605
13	0.0506	0.0494	0.2718	0.0001	0.0302	2.4110
14	-0.6319	-0.6222	0.2608	0.0128	-0.3696	1.9052
15	-0.2810	-0.2744	0.4469	0.0058	-0.2467	3.0435
16	-0.4657	-0.4564	0.5008	0.0198	-0.4571	3.1234
17	0.3031	0.2962	0.2659	0.0030	0.1782	2.2766
18	0.9140	0.9101	0.2528	0.0257	0.5293	1.4715
19	-1.2792	-1.3012	0.4791	0.1368	-1.2480	1.3199
20	-0.0154	-0.0150	0.2414	0.0000	-0.0085	2.3173
21	0.7932	0.7855	0.4409	0.0451	0.6975	2.2123
22	-0.2561	-0.2500	0.5473	0.0072	-0.2749	3.7459
23	0.2874	0.2807	0.5794	0.0103	0.3294	3.9936
24	-0.0305	-0.0297	0.2235	0.0000	-0.0159	2.2629
25	-1.5824	-1.6229	0.3346	0.0886	-1.1508	0.8614
26	0.4365	0.4275	0.4217	0.0126	0.3651	2.7365
27	0.3216	0.3142	0.3769	0.0057	0.2444	2.6652
28	0.1499	0.1462	0.1907	0.0005	0.0710	2.1457
29	1.5174	1.5428	0.1300	0.0220	0.5964	0.7976
30	-0.1709	-0.1667	0.3419	0.0014	-0.1201	2.6290
31	0.1802	0.1758	0.2314	0.0009	0.0964	2.2470

Plots Section





R… r's Method (C=1.345)

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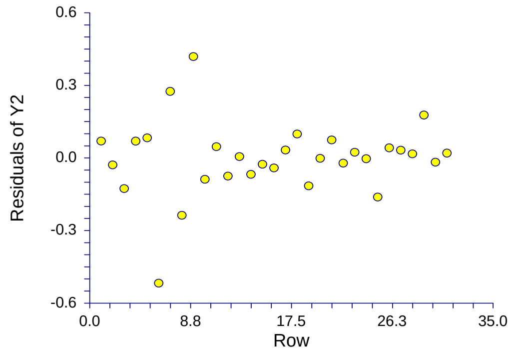
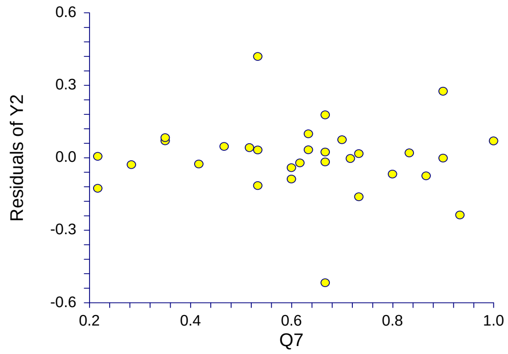
Dependent Y2

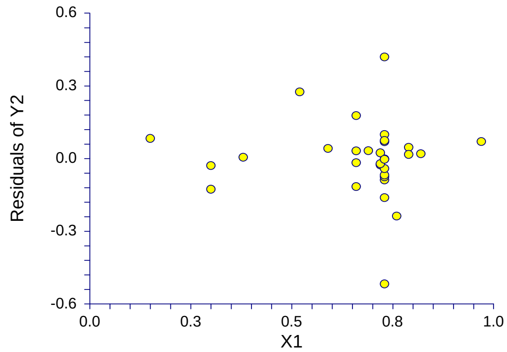
Residuals of Y2 vs Row



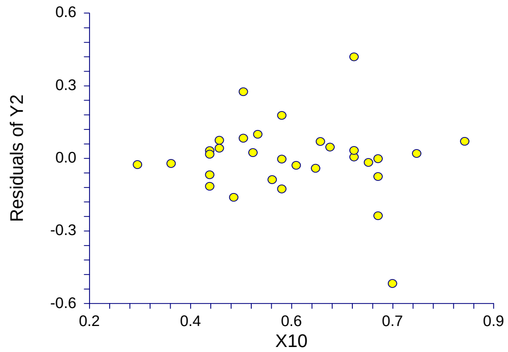
Residuals of Y2 vs Q7



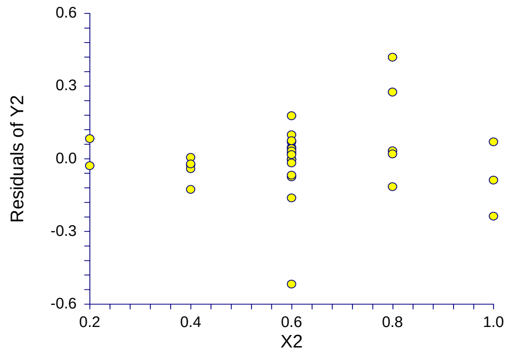
Residuals of Y2 vs X1



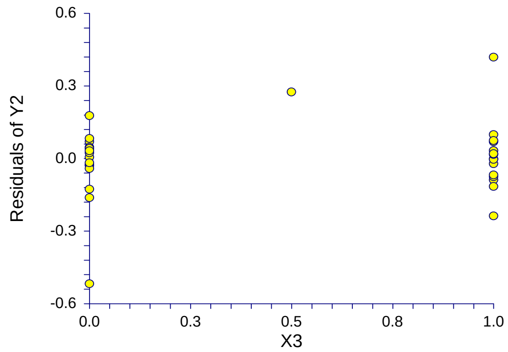
Residuals of Y2 vs X10



Residuals of Y2 vs X2



Residuals of Y2 vs X3



R r's Method (C=1.345)

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Database
Dependent Y2