Manchester Metropolitan University

A Study of Complexity, Innovation and Variety; The Photographic Camera Example

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I would like to dedicate this work to my parents.

ABSTRACT

This thesis is an exploratory research concerned with the investigation and identification of complex systems and their innovation life patterns. There is evidence in the literature to suggest the existence of complex systems, which differentiate themselves not only by organisational structure, but also by the way, they innovate.

Complex systems seem to display a nested hierarchical formation of technological elements and the clustering of those technological elements in a synergistic manner in order to offer an enhanced service. Another distinct element of complex systems is the dependency that some particular elements in the hierarchy seem to display. This dependency of the elements in the nested hierarchy means that changes (innovation) made in one of the elements of the hierarchy might result in changes in other elements or the whole hierarchy. These characteristics not only differentiate complex from simple systems but are also the main reason why complex systems innovate in a different manner from simple systems (classical view of innovation).

There is an important gap in the study of innovation in complex systems in the literature. Firstly, if in fact complex systems innovate differently from simple systems there is no evidence of a model that could clearly identify and separate complex from simple systems. Secondly, previous research on complex systems theory and innovation has studied complexity as a whole; however, the dependency between the elements is the crucial factor that hinders complex systems from innovating according to the classical view of innovation. There is no indication in the literature of a model that could clearly identify those distinct elements within the complex systems hierarchy that display the dependency. If there was a model that could identify the risk elements in the systems that carry the dependency,

marketing/design managers could develop more efficient innovation strategies without putting at risk the performance of some elements of the systems or the whole product.

This research proposes a model that could help to identify the particular elements that display that dependency and the possible effect that it could have in the whole hierarchy. This model is also used as a tool to identify and separate complex systems from simple systems. This research uses cameras in an example study to test the models suggested by this research. Previous research on complexity has been done in an industrial market; however, there is no empirical evidence in the literature of a model that could help the investigation of the evolution of complex systems in a commercial market. Products in a commercial market are subject to heterogeneity of demand, speed of innovation, and sophistication of needs. A model that could map the innovation pattern of commercial complex systems could help marketing and design companies with innovation strategies and decisions.

In this research, this model was applied to the camera example and, in fact, cameras gave high indications and displayed clear evidence that could lead to the classification of cameras as complex systems. Cameras display evidence both of dependency between the elements and of a nested hierarchical formation, which are the elements that separate complex from simple systems.

Subsequent to the finding of the evidences that support cameras as complex systems, this research investigates the innovation pattern of cameras from 1955 to 2011, and compares this innovation pattern to the classical view of both innovation and complex systems. As indicated in the literature, even though cameras have some elements common to the classical view of innovation at the beginning of the innovation life cycle, they display a rather different pattern closer to that offered by complex systems innovation.

By applying this model, this research not only seems to help the classification and distinguishing complex from simple systems but also studies the complex system as a whole, and the identification of the elements that display dependency and could put any innovation activity at risk. This model also offers the possibility of studying innovation and clearly identifying to what extent and in which manner complex systems innovate differently from simple systems.

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CHAPTER 1 – INTRODUCTION

1.1 INTRODUCTION

The driver for this research was an innicial study undertaken by this author (Windrum, Diaz et al. 2009) (see Appendix A) on the linkage between/clustering of technological characteristics of products. Clustering or technological elements seems to be tantamount to and raison d'être for complex systems. Further investigation of complex systems sheds light on the phenomenon that systems of this type do not innovate according to the classical view of innovation, and display a distinct innovation life pattern due to these linkages between the elements in the system.

This thesis is an exploratory research that sets out to investigate, firstly, a definition of complex systems and the distinct differences between complex and simple systems. By identifying a set of requirements that could clearly identify and classify complex and/or simple systems, this research could investigate and shed some light on whether complex systems innovate differently from simple systems and the possible reasons for this different innovation pattern.

The main objective of this thesis is twofold. Firstly, the identification of a model that could clearly identify technological products and classify them into complex or simple systems; and, secondly, the finding of a product that could possibly show signs of complexity in order to investigate the innovation life pattern in order to compare it to the classical view of innovation or simple systems. This research will approach the main objective not only by empirically testing the complexity of a technological product, but also by comparing and identifying its distinct differences (if any) from the innovation life patterns offered by the classical view of innovation and simple systems.

1.2. RESEARCH BACKGROUND

This thesis could be understood as a continuation of prior research conducted by the author (Diaz 2007, Windrum, Diaz et al. 2009). These papers (Diaz 2007, Windrum, Diaz et al. 2009) covered an investigation of the possible relationships between technological and service characteristics of mobile phones. This research tested existing theories of the clustering of technological elements in order to supply a service (Saviotti and Metcalfe 1984). This research found that, in the case of mobile phones, technological elements such as pixels and battery life clustered in order to supply the services of playing music, video-recording and taking pictures. Further investigation into why these technological elements cluster in such a manner gave rise to the notion of complex systems. This clustering of elements in order to supply a service is one of the main characteristics of and the raison d'être for complex systems (Simon 1962, Frenken 2006). The emergence of the notion of complex systems and their relation to technological clustering gave rise to the main question of this research, since there seems to be evidence that the technological elements in mobile phones are linked in order to offer a service: are mobile phones complex systems? In addition, are all products that show clustering patterns complex systems? Further investigation into clustering patterns found that technological elements not only cluster to provide a service but also this clustering pattern could change over time (Saviotti and Metcalfe 1984, Henderson and Clark 1990). This research did not find clear evidence of any empirical study of this sort that could shed some light on the study of clustering changes due to innovation activities. This is an important limitation on the investigation of technological characteristics clustering and the reasons for these clustering changes. The requirement to investigate clustering changes posed a problem to this research; data availability on mobile phones did not span enough time to allow investigation of this clustering change over time. This research needed an example case to test both the clustering pattern characteristics of complex systems that had also been on the market long enough to investigate and explain this phenomenon.

Photographic cameras have been on the market since the 1800s and, at first glance, they offer technological elements that could cluster in order to provide a service (Hicks 1989, Jervis 1990, Warren 2001). Further investigation into the suitability of using cameras as an example study gave rise to two topics of interest. Research on previous studies on photographic cameras (Windrum 2005) found that cameras did not show the classical pattern offered by the literature, where product innovation gives rise to a dominant design, which means the standardisation of the market and the focus of innovation activities will swiftly move toward process innovation (Abernathy and Utterback 1978). This research also found that complex systems innovate differently due to this clustered structure (Frenken 2006). This research again found itself with more questions: why did classical innovation theories not apply to the camera market? Was it because of the possibility of their being complex systems? In addition, did complex systems really innovate differently or were photographic cameras a special case? Again, this author did not find empirical evidence in the literature of investigation that tested the possibility of products being considered as complex systems and which included further investigation of the innovation pattern displayed by these complex systems. All these questions without indication of empirical testing gave rise to the idea for this thesis.

1.3. Research Rationale

The main objective of this research is to shed some light on the phenomenon that complex systems innovate differently, this research is portrayed as an exploratory study to test a new methodology to categorise complex systems and their innovation pattern. The literature suggests that they do and this research is going to investigate issues such as differently from what/which models; how differently; and in what manner are they different? The first issues that concerned this research was: the definition and identification of complex systems; whether all technological products are complex systems; and whether there is a set of requirements that defines and differentiates complex from simple systems. The identification of the distinct characteristics that differentiate complex from simple systems it is vital for the investigation of the suggested possibility that complex systems innovate differently from simple systems. In the same manner, if there is evidence that proves that complex systems innovate differently, then it is important to find a model or approach, which differentiates both systems in order to manage the distinct innovation activities appropriate for both systems. This identification is not only relevant for the literature but also for design and marketing decisions.

One of the main factors that the literature suggests hinders complex systems in displaying normal patterns of innovation is the dependency and/or clustering of the technological elements in the system (Frenken 2006, Yayavaram and Ahuja 2008). Another issue that arose in the investigation of the literature on complex theory was the measurement of complexity. The existing literature measures product complexity as a whole; however, not all technological elements in complex systems might necessarily display dependency, hence there should be a model that identifies which elements display dependency and how they could affect other elements in the system. There is no clear evidence in the literature of a model that allows the identification of the particular elements that display dependency; therefore, this research is going to suggest a model that will help identify the particular elements that display dependency. Since dependency between the elements of systems is the main factor that hinders innovation in complex systems, the identification of a model that identifies those risk elements might help the effectiveness of design and innovation actions.

In other words, this research intends to open up the black box of complexity and examine the inner workings of complex systems.

1.4. RESEARCH CONTEXT

This thesis is an exploratory research concerned with the investigation of complex systems theory and innovation life patterns. Complexity theory in itself is a very wide subject; this research is going to focus on the investigation of the literature that will aid this research to generate a set of requirements or specifications that would identify and separate complex from simple systems. This research looks at the definition of complex systems by Simon (1962–1964), pioneer of the investigation of evolution of complex systems. Simon's (1962–1964) work has been the basis of many complexity studies in recent years (Geisendorf 2009, Meunier, Lambiotte et al. 2010, Frenken and Mendritzki 2012, Zhou 2013).

Within complex systems theory, this research also pays special attention to the classification of complex systems according to the strength of the dependency and location of those dependencies on the systems. Since Simon's (1962) introduction to the notion of near-decomposable complexity, several authors have used this model in order to understand the inner workings of complex systems and manage their difficulties (Frenken, Marengo et al. 1998, Yayavaram and Ahuja 2008, Geisendorf 2010, Zhou 2013). Modular complexity or modularity is another approach that arguably seems to originate from the concept of near-decomposability and illustrates the inner workings of complex systems (Ulrich 1995, Baldwin and Clark 1997, Schilling 2000, Ethiraj, Levinthal et al. 2008, Zhang and Gao 2010). This classification not only helps designers/managers to manage difficulties associated with complex systems but also seems to indicate the innovation activities that are possible or viable for those particular systems.

Another topic that is directly related to the investigation of complex systems is the possible clustering of technological elements. The further investigation by this author (Windrum, Diaz et al. 2009) of the clustering of technological elements in order to supply a service has raised the notion of complex systems. The clustering or synergy of technological elements is one of the characteristics of complex systems. The mapping of complex systems into distinct clusters also helps to manage difficulties of complex systems by allowing a clearer view of the inner workings of complex systems.

The second topic of interest for this research is the phenomenon that complex systems innovate differently. This research takes the classical view of innovation and complex systems innovation. Utterback and Abbernathy (1975) suggested a model to map innovation life cycles for technological products that seems to aid the prediction of the dynamics of innovation processes of product and firms. This research also investigated the different views on innovation life cycles supplied by other authors such as Nelson and Winter (1977), Sahal (1981) and Dosi (1982), among other authors.

The classical view of innovation will later be compared to specific innovation patterns for complex systems given by the literature in order to investigate the possible difference between complex systems innovation and the classical view of innovation. This research will find the stylised facts for innovation in complex systems in the works of Hobday (1989), Frenken (2006), Funk (2009) and Zhang (2010).

1.5. Research Design

This thesis is an exploratory research concerned with investigating the possibility of complex systems innovating differently from the classical view of innovation. This research is going to systematize the investigation of the innovation of complex systems by the following approach. Firstly, this research will investigate complex systems theory in order to reach a set of requirements or characteristics that could help this research to identify whether the photographic cameras example is a complex or simple system. This research will also include investigation to determine a definition of simple systems for the sake of comparison.

This study is going to use cameras as an example study for the testing of complexity and innovation life cycles. The approach of obtaining definitions for both complex and simple systems will aid this research in that it will clearly identify cameras as displaying evidences consistent with characteristics typical of complex systems, simple systems, both or neither.

Previous research on complexity of products has measured complexity as a whole (Kauffman 1993, Page 1996, Frenken 2006). One of the main reasons for complex systems to innovate differently is the epistatic relations between the technological elements (dependency). By dependency, or epistatic relations, this research refers to the possibility that changes in one of the technological elements of a system could trigger changes in the technological elements to which it is epistatically related. By simply measuring the complexity as a whole, this research could miss important information on the particular technological elements that could hinder any innovation activity in the system. This research, therefore, suggests a model that identifies the particular technological elements that display epistatic relations. The identification of those particular elements is relevant to the effectiveness of location of innovation activities and the increased likelihood of success of any innovation strategy.

The length of time that photographic cameras have been on the market also offers the opportunity to investigate the possibility of clustering changes due to innovation activities suggested in the literature (Metcalfe and Saviotti 1984).

Once this research has tested cameras as complex systems, this research will investigate the innovation life cycle pattern displayed by cameras in the period 1955–2011. As in the case of the testing of complex systems, this research will consider particular cameras' innovation life cycles and compare them to both the classical view of innovation and the complex systems innovation pattern in order to shed some light on the possibility that complex systems innovate differently. Again, this approach would offer the possibility of comparing and identifying whether cameras display innovation patterns characteristic of complex systems or the classical view of innovation, a mixture of characteristics from both approaches, and an innovation pattern not covered by any of the approaches. This approach also offers the possibility of investigating and measuring the distinct differences between complex systems innovation patterns and the views suggested by classical models innovation life cycles (ILC).

1.6. Organisation of the Thesis

Chapter 2: the main aim of this research is the investigation of complex systems innovating differently from the classical view of innovation. The first part of this chapter will illustrate a review of the main issues concerning complex systems theory in order to achieve a workable definition that will help this research to identify and differentiate complex from simple systems.

The two main characteristics that separate complex from simple systems are the dependency of technological elements and the hierarchical formation of those technological elements. Not all complex systems will show the number of dependent elements or hierarchical formations (Zhou 2013). This research pays special attention to the investigation of the hierarchical formations because the hierarchical formations and number of dependent technological elements will determine the innovation activities that will be most effective for each system (Brusoni, Marengo et al. 2007, Zhang and Gao 2010).

The most important element of complex systems is the dependency of the elements; this state of dependency not only triggers the possibility of following trends of innovation different from simple systems (Freken 2006) but this dependency might also change the hierarchical formation of the system after innovation activities (Ulrich 1995, Hobday 1998, Tushman and Murmann 1998, Gatignon, Tushman et al. 2002, Allen and Varga 2006, Murmann and Frenken 2006, Yayavaram and Ahuja 2008, Geisendorf 2009).

The second part of Chapter 2 will investigate the stylised facts suggested by the literature on innovation life cycles (Utterback and Abernathy 1975, Nelson and Winter 1977, Sahal 1981, Dosi 1982, Foster 1986, Klepper 1996). These models on innovation life cycles will later be compared to the stylised facts on complex systems innovation (Hobday 1998, Tushman and Freken 2006, Frenken 2006, Funk 2009).

Chapter 3 will investigate the history and technology of camera innovation since the 1880s in order to give the theoretical background that will help to interpret the findings from the camera study. This chapter also highlights the reasons for using cameras as the example studied in order to shed some light on the phenomenon of complex systems innovating differently from the classical view of innovation.

Chapter 4 will lay down the suggested methodology to study the main objective of this research, which is examination of complex systems innovating differently. The nature of the investigation (exploratory study) and the different aspects of complex systems, (from the testing and identification of the elements that hold epistatic relations to the measurement of complexity of cameras and innovation patterns of cameras) allow this research to use a multi-method approach. The reason for this choice is that the different aims and objectives of the study require different distinct approaches that will complement each other to investigate whether cameras are complex systems, and what their innovation patterns are.

Chapter 5 will illustrate the results of the analysis of the study and will compare these results to the existing literature on innovation and complex systems in order to give some insight into the gap in the literature found in Chapter 2.

Chapter 6 will summarise the results of the study and the implications of these results for the literature and contribution to knowledge, as well as possible suggestions for future research or further study on any aspects of the issue of complex systems innovation that are still unclear.

CHAPTER 2 – LITERATURE REVIEW

2.1. INTRODUCTION

The main topic of this research is the investigation of the notion in the literature that suggests that complex systems innovate differently from the classical view of innovation.

Recent advances in complexity theory have shown that complex systems evolve in different ways from simple systems, that selection is usually unable to eliminate inefficiencies in complex systems. The complex structure or interdependencies constrain the adaptive potential of systems, and, thereby, the possible paths of evolution. (Frenken, 2006, p.3)

The further investigation of this statement takes this research to the following structure. Firstly, this research is going to identify and investigate a workable definition for complex systems. The reason for the identification of a clear definition of complex systems arises from the plethora of different approaches and definitions of complex system theory. In addition, a definition with clear requirements or specifications that separates and identifies complex and simple systems will help this research to classify products as either complex or simple systems. Once this research arrives at a definition of complex systems, it will move on to the investigation of innovation patterns for complex systems. This research is going to investigate the innovation pattern suggested by the classical view of innovation and those for complex systems.

This research is using the camera market to test the notions suggested by the literature on complexity of products and innovation theories. Previous research on innovation patterns

(Windrum, 2005) found that cameras in the period 1955–1974 did not follow the classical view of innovation. This research is investigating the innovation life cycle from 1955–2011; the extra 36 years will hopefully give a clearer idea of the innovation pattern in the camera market. The relevance of including this extra 36 years is given by the innovation breakthroughs after the period studies by this author (Windrum 2005). While in the period 1955–1974 the only noticeable innovation was the introduction of inbuilt metering systems, this research includes the increased variety of types of cameras found during the 1980s and 1990s, the emergence of compact camera types, and, most importantly, the digitalisation of the image. There are already empirical tests that seem to indicate that cameras innovated differently during the period 1955–1974 (Windrum 2005); this research merges this topic of interest with the empirical testing of cameras to test whether they are complex systems, in the light of investigation into whether cameras innovate differently due to their potentially complex nature.

Firstly, this research is going to review the literature relevant to defining complex systems. There are a plethora of views on and applications of complex systems. Complex systems could be defined by how difficult they are to describe or solve, how hard they are to create, or what the degree of organisational size-based pairs is (Mitchell 2009). Several authors seem to give similar but distinct definitions of what complex systems are. This research will attempt to test the idea that photographic cameras could indeed be considered complex systems, and therefore a clear definition of what could be considered a complex system is needed to start this research. This research starts with the work on complexity theory (Simon 1962, Simon 1968). Simon is the pioneer of evolution and complexity theory and his work has been the basis of many other authors' research on complexity (Saviotti 1988, Ulrich 1995, Sanchez and Mahoney 1996, Schilling 2000, Langlois 2002, Frenken 2006).

One of the main characteristics of complex systems is the non-simplistic nature of the relations between the elements of the system or product. Non-simplistic relations refer to the dependency that the elements of complex systems display. In complex systems elements seem to show some kinds of interdependences where actions in one of the elements will have an effect on other elements of the systems. This interdependence between the elements is at the core of the notion of complex systems innovating differently from the classical view of innovation. The usual innovation approaches, such as trial and error, are very limited in complex systems since, depending on the number of elements showing interdependences, changes in elements may cause a cascading effect in the whole system (Ulrich 1995, Tushman and Murmann 1998, Gatignon, Tushman et al. 2002, Allen and Varga 2006, Frenken 2006, Murmann and Frenken 2006). This inability to eliminate deficiencies and lack of trial and error strategies is especially relevant to marketing activities since it limits the possible range of marketing and design options for innovation in complex systems.

Not only do elements of complex systems seem to display some kind of dependency between the elements but these elements are also organised in a distinct hierarchical manner. Hierarchical systems refer to systems composed of interrelated subsystems each of which is, in turn, a subsystem of the previous subsystem until it reaches the fundamental component level (Simon 1962). This nested hierarchy helps to manage complex systems since it allows mapping of the interdependences between the elements (Zhou 2013).

The strength and number of interdependences and the shape of the hierarchy can change from system to system (Zhou 2013). This research investigates a model to classify complex systems according to the interdependences between the elements and hierarchical formation. The reason for this classification is that the ease and effectiveness of innovation actions in such products depends on the number, strength and location of the interdependences. As the number of interdependences increases so does the difficulty of developing any innovation activity in that product (Fleming and Sorenson 2001, Strumsky and Lobo 2002, Yayavaram and Ahuja 2008). A common classification of complex systems in the literature is:

- Fully integrated complex systems (all elements of the systems show a dependency level) (Ethiraj, Levinthal et al. 2008).
- Fully decomposable systems (elements do not show any dependecy with other elements) (Yayavaram and Ahuja 2008) (simple systems).
- Near decomposable complex systems, (elements of the systems offer a weak but not negligible dependency) (Simon 1964).
- Modular complex systems (elements within a cluster will show a higher level of dependency than the dependency shown within different clusters) (Ethiraj and Levinthal 2004), (Schilling 2000), and (Langlois and Robertson 1992).

Dependency between elements and nested hierarchy are among the most problematic issues of complex systems; the literature suggests the last two categories (near-decomposable and modular complex systems approach) are a way to manage complexity. These two models offer the solution of dividing the system into more manageable subsystems and, therefore, providing a way to manage complexity (Simon 1962, Ethiraj, Levinthal et al. 2008, Geisendorf 2009, Zhou 2013).

After the identification of a series of patterns or specifications for complex systems, this research will investigate and compare the definition of simple systems. The identification of a clear set of requirements/characteristics for both simple and complex systems it will allow to test whether cameras can be considered simple or complex systems.

After the investigation of complex theory, this research will shift its attention to innovation patterns and life cycles in order to test whether complex systems show evidence of innovating differently from the classical view of innovation. Frenken (2006) illustrates that the likelihood of changes (innovations) producing beneficial effects overall is no longer understood based upon the selection environment alone but rather selection conditions and nested hierarchy. This research, therefore, continues the investigation of complex systems through an illustration of innovation theories that could be more relevant to complex systems. There are also a plethora of innovation theories, models and applications in the literature. However, this research is going to focus on radical and incremental innovation for the following reasons. These two approaches (incremental, radical) are not only directly related to the innovation life cycle that will be the subject of investigation for this research, but will also help to test the hypothesis that changes or innovation in one element will cascade into changes in other elements of the system. Innovation activities (incremental, radical) are not only capable of causing effects on other elements but might also change the clustering pattern of the hierarchy. There is the notion in the literature that clustering patterns can change over time due to innovation activities (Saviotti and Metcalfe 1984, Frenken 2006). Yayavaram and Ahuja (2008) also explain that technological innovation is seen as the recombination of the existing technological elements. Architectural innovation refers to the innovation process that changes the way technologies cluster in order to provide a service, leaving the components untouched (Henderson and Clark 1990). Architectural innovation in complex systems can be due to innovation activities that will change the clustering due to an ill fit of the elements or simply a recombination of existing elements in order to supply a different service or enhance an existing one. This research will use this approach to study the possible changes in clustering patterns over 56 years. There is no evidence in the literature of the study of possible changes in clustering of technologies over an extended period. There is a study on the clustering of technologies in the photographic camera industry; however, this only covers one decade, and does not cover possible changes in clustering or architecture innovation (Windrum, Diaz et al. 2009) (Appendix A).

The illustration of the innovation theory takes us to the second part of this research. There is the notion in the literature that complex systems innovate differently from simple systems due to the epitasis of the nested hierarchy. Several authors have argued that complex systems innovate differently from simple systems (Hobday 1998, Frenken 2006, Murmann and Frenken 2006). The non-simplistic relation of the elements and nested hierarchy gives the suggestion of complex systems showing distinct innovation patterns.

As in the case of the investigation and identification of complex systems, this research is going to conduct a twofold investigation of innovation. There is a notion in the literature that complex systems innovate differently due to their epistatic relations (Hobday 1998, Frenken 2006, Murmann and Frenken 2006). This research is going to investigate whether complex systems innovate differently, compared with which other types of innovation, in what manner and with what differences. This research starts the investigation of the innovation pattern of complex systems by an illustration of the innovation life cycles (ILC) offered by the literature (Utterback and Abbernathy 1975, Gort and Klepper 1982), and technological cycles (Nelson and Winter 1977, Sahal 1981, Foster 1986). These approaches illustrate that after a period of increased variety or increased numbers of different technological solutions for the same technological problem, market selection will reduce this variety, resulting in the emergence of a dominant design (DD), and innovation activities will shift their focus from product to process innovation.

There is a notion in the literature that for complex systems variety is the norm; this research will focus on investigating the innovation life cycle on the issues of variety and dominant design. There seems to be a contradiction in the literature about evidence of demand being considered heterogeneous in demand (Windrum and Birchenhall 2005), classical views of innovation suggests that the emergence of a DD indicates the standardisation of the market, this suggestions seems to contradict the notion of heterogeneity of market.

This research will investigate the patterns offered by the classical and complex systems views and compare them to those displayed by the camera market in order to shed some light on the reasons why cameras innovated differently between 1955–1974 (Windrum 2005) compared to the innovation patterns displayed in cameras after 1974. This research's ultimate focus is the investigation of whether complexity has any effect on how cameras innovate and to what degree complexity affects innovation patterns.

2.2. COMPLEXITY

Complexity and/or complexity theory is a very broad term; this research starts with the investigation of the different views and definitions of complexity in order to find a clear and workable definition for this research. There are authors who have suggested different views or definitions of complexity; however, the pioneer of the study of complexity and complexity theory is Simon (1962). Many authors have based their research into complexity on the works of this author, including Ulrich (1995), Sanchez-Mahoney (2002), Schilling (2000) and Frenken (2006) among others. Simon defines complex systems as

> "Systems made up of a large number of parts that interact in a non-simplistic way. In such a system, the whole is more than the sum of the parts, not in an ultimate, metaphorical sense, but in the important pragmatic sense that given the properties of the parts and their laws of interactions it is not a trivial matter to infer the properties of the whole". (Simon 1962, p.86)

This definition seems to indicate that complex systems are not only systems with a large number of components but that there is also a link between these components. This interaction enhances the whole product performance as opposed to products where, even though they might or might not have a large number of components, the components that form this product do not interact in a way that enhances the overall performance of the product. Mitchell (2009) illustrates this relationship with a very simple and clear example: when baking a cake, if an individual mixes two cups of sugar and two cups of flour, the result of mixing these ingredients is two cups of sugar and two cups of flour, meaning the whole is equal to the sum of the parts. However, if an individual mixes two cups of baking soda and one cup of vinegar, the whole explodes. The result is more than three cups baking-vinegar dioxide fizz, meaning the result is more than the sum of the parts. This explosion is due to the interaction of the elements (Mitchell 2009).

Frenken (2006) also uses this interaction between the elements as a basis to define complex systems: “One way to define complexity is by the number of interactions that exist between elements” (Frenken 2006, p.138). Also:

> “A further way to define complex systems is the possibility of weak and strong interaction. Instead of defining complex systems as consisting of elements with dichotomous interactions (present or absent), one can describe interactions between elements along a continuum. In the latter case, one can define complex systems as systems in which all elements interact with all other elements, thus fully connected”. (Frenken 2006, p.138)

Complexity, therefore, according to this author (Frenken 2006), stems from the interdependency of the constituent elements that form the product. This definition not only gives us a further insight into the specification of the definition of complex systems but also suggests the means to measure the level of complexity of a system. There is a direct relationship between the level of complexity and the level of dependency displayed by the elements of the system. It could be hypothesised that, when the dependency levels rise, so that the level of complexity of the system. In other words, the higher the dependency showed by the cluster, the more complex the system is.

Yayavaram and Ahuja (2008) defined interdependence as

> "The degree to which two elements are related to each other in the natural world and it is not known at priory. Thus, element X might be related to element Y such that any action on X will have an effect on the contribution or performance of Y". (Yayavaram and Ahuya 2008, p.334)

This definition of interdependencies adds an extra factor to the identification of complex systems, in which elements not only show dependency between elements but in which the actions of one element might affect the performance of other elements in the system. Frenken (2006) calls these interdependences between the elements of complex systems "epistatic relations".

> "An epistatic relation form one to another element implies that when the allele of one element changes, these changes affects both the functioning of the core element itself and the functioning of the element that it is epistatically affected". (Frenken 2006, p.140)

Other definitions of complexity include that of Almosaawi (2005), who views complex systems as follows: "any system that is made up of parts is naturally complex" (Almosaawi 2005, p.1). Other definitions of complexity offer variations of that illustrated by Simon (1962), such as the following: "The distinctive stance taken by complex systems theory is that it is concerned with systems that exhibit a configuration made up of a large number of elements and significant interactions among these elements" (McCarthy 2003, p.730). "A complex system is a system with a large number of elements, building blocks or agents capable of interacting with each other and with the environment" (Amaral and Ottino 2004, p.148); and "complex systems are dissipate structures that import free energy and expect entropy in a way that enables them to self-organise that structure content and configuration" (Foster 2005, p.874). There is a common theme in these definitions and it is the interaction between elements, which coincides with Simon's (1962) definition. There is, however, a novel aspect, which is that of complex systems as self-organised systems. This self-organised nature refers to the epistatic relations and the effect that changes in one element of a system might have on other elements or the entire system. In other words, the technological elements self-organise in a way that fits the entire system.

The primary investigation of the definition of complex systems gives the basis for the first of the research questions for this study. Complex systems seem to display dependency between the elements of the system, and this interdependency seems to affect the performance of the system (product) due to the effect that changes in one element have on other elements of the system. This research will use Frenken's (2006) term "epistatic relations" for clarity. According to the investigation of the definition of complex system, this research identifies the first of the requirements for complex systems, which results in the formulation of Research Question 1.

Research Question 1*: do the technological elements in cameras display indications of epistatic relations?*

2.2.1. CHARACTERISATION OF COMPLEX SYSTEMS

So far, this investigation has found that the elements of complex systems seem to display epistatic relations; however, there is an extra aspect of the definition of complex systems that has not been covered yet.

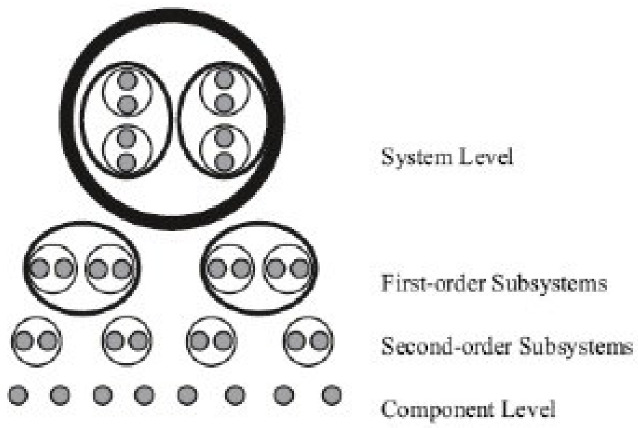
> "The central notion that runs through my remarks is that complexity often takes the form of hierarchy, and that hierarchic systems have some common properties that are independent of their specific content. Hierarchy, I shall argue, is one of the central structural schemes that the architecture of complexity uses". (Simon 1968, p.87)

Simon (1962, 1968) also defines hierarchy as "a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic structure until we reach the lower level of elementary subsystem" (Simon 1968, p.87). Burmakin (neocybernetics.com/report145/Chapter4.pd), on the other hand, argues that the problem is the definition of the elementary elements of the system. Simon (1962) illustrates that it is somewhat arbitrary as to which are the elementary particles; either way, elementary particles in complex systems have a disconcerting tendency not to remain elementary very long. Burmakin (neocybernetics.com/report145/Chapter4.pd) suggests a solution to the definition of the elementary elements of the systems by showing that elementary elements in a system define the specific task's needs.

Simon (1962) illustrates how hierarchical complex systems can take different forms; for instance, diamond could be considered by definition hierarchical in nature since its crystal structure of carbon atoms can be further decomposed into protons, neutrons and electrons. On the other hand, most polymers such as nylon are simply linear chains of large numbers of identical components. Therefore, hierarchy for the purpose of this research is a product that has the property of being divided into subsystems, which can be further divided into smaller subsystems until the component level is reached, as in the example of the diamond. Even though complex systems can be divided into subsystems, elements can easily be part of two subsystems at the same time, a phenomenon that Schilling (2000) calls subsystem overlap. Hierarchy overlapping refers to components that cluster as part of two subsystems in the same or different measures of interdependence (Schilling 2000). Research by the author of this thesis also found that in mobile phones there was element overlap in several subsystems, such as LCD screen pixels on camera quality service characteristic tests (Windrum, Diaz et al. 2009) (Appendix A).

Murman and Frenken (2006) offer a representation of the nested hierarchy of complex systems by what they called a “pleiotropic map”. The “pleiotropic map” represents complex systems as having a core element at the top of the hierarchy and peripheral elements at the lower level of the hierarchy (Figure 1).

Figure 1: Representation of nested hierarchy (Murmann and Frenken 2006)



Technological products could be defined as a combination of a core technology or main/dominant technology, and peripheral elements. This core technology is the heart of the system, and allows the whole system to function. Core technologies can be found, for example, in car engines, and in amateur cameras in the mirroring systems that allow users to capture images. The elements that are at the periphery work in relation to the core technology in order to give enhanced performance of the product; for example, shutter speed and metering in cameras enhance the quality of picture taken.

This hierarchical structure of complex systems is beneficial to the study of complex systems because mapping complex systems onto a pleitory map provides a clear view of the inner workings of the system. This clearer definition of the structure of the system not only offers increased control of the system but also reduces the probability of decision errors and improves decision quality and innovation effectiveness (Burmakin , Zhou 2013). The Hora and Tempus example (Simon, 1962) is a simple explanation of this process (Appendix B).

The Watchmaker example also introduces the next topic of the evolution of hierarchical complex systems. Simon (1962) illustrated in the Watchmaker example that hierarchical structures evolve far more quickly than hierarchical systems. Foster (2005) illustrated that complex systems are inherently self-organised systems. Evolution/innovation activities could take part in any part of the system – both core and peripheral elements (Frenken 2006).

Investigation of the complexity theory in the previous section of this research resulted in the finding that complex systems show indications of interdependences between the elements. In this section, it has been illustrated that there is a notion that complex systems display a hierarchical formation where elements cluster into subsystems. The definition of nested hierarchical structure introduces the notion of interdependences of complex systems. There is the notion in the literature that indicates interdependences in complex systems can be found within elements of subsystems and among subsystems of the hierarchy but not all technological elements need to show dependency on other elements in the system (Frenken 2006, Zhang and Gao 2010, Zhou 2013).

Since there is evidence that complex systems display epistatic relations between the elements of the system, and these elements display a hierarchical organisation, changes or innovation activities in one of the elements might lead to changes in the other components or components' interaction, like a domino or cascade effect. The changes might result in the emergence of new components in the hierarchy or and changes in the way the technological elements are clustered. Both results might affect the fitness of the clustering elements by either enhancing or destroying the function of the product as a whole (Ulrich 1995, Hobday 1998, Tushman and Murmann 1998, Gatignon, Tushman et al. 2002, Allen and Varga 2006, Frenken 2006, Murmann and Frenken 2006). The magnitude of the effects of these changes or innovations will depend on the strength of the interactions and the number of elements epistatically affected. Ethiraj and Levinthal (2004) categorise these changes as positive, negative or unrelated. These changes can affect the function of the systems in a positive manner (competence-enhancing) or by negatively destroying the fitness of the system (competence-destroying), or might not have any effect on the performance of the product as a whole (unrelated). Changes in a component of a subsystem (cluster) can have an impact on the other components of that same subsystem; however, a product might show different clusters or subsystems (Figure 1). Reinstaller (2007) also adds that results of these changes in other elements due to epistatic relations cannot be foreseen a priori, which also gives complex systems an uncertain nature. Almosaawi (2005) and Jianmei (1993) illustrate that the interaction between subsystems is weaker than the interactions between the elements within a subsystem. These subsystems might show a level of dependency among themselves. Therefore, changes in a component might not only have an effect on the other components of the subsystem but also on other subsystems that are dependent (Hobday 1998). Apart from the strength of interactions between subsystems, the literature review also warns that systems with the same number of independences can have different patterns of distribution and strength (Zhou, 2013) and different levels of the hierarchy might display different strengths of dependency (Frenken, 2003) (Burmakin, neocybernetics.com/report145/Chapter4.pd).

There is evidence in the literature that innovation becomes increasingly difficult as the number and strength of epistatic relations increase (Strumsky and Lobo 2002, Yayavaram and Ahuja 2008).

> "At low levels of interdependency, greater interdependency increases the probability of success by providing opportunities to combine components synergistically. Nevertheless, as the degree of independence rises, it becomes increasingly difficult regarding the relationship between the number and interdependence of components combined and the expected usefulness of those combinations". (Fleming and Sorenson 2001, p.1030)

The recognition or identification of epistatic relations is important in the study of hierarchy. As Ethiraj, Levinthal et al. (2008) point out, Simon's (1962) definition of hierarchy refers in a broad sense to "a precedence ordering of interdependence across modules and rules out reciprocal interdependences between modules" (Ethiraj, Levinthal et al. 2008, p.944). Jianmei (1993) also takes into account the strength of the dependency of the elements by illustrating that hierarchy is defined in terms of the intensity of interactions, where the stronger interaction will take place between the closest points in the hierarchy (Jianmei 1993).

The study of the hierarchy and strength of relations brings out the next point in this research and it is that complex systems can be categorised according to their hierarchical formation and the strength of the epistatic relations shown by the elements of the nested hierarchy.

Sanchez and Mahoney (1996) illustrated that the degree of dependency can be "loosely coupled" and "tightly coupled", which refers to the strength of the epistatic relations. The number of epistatic relations that the systems display categorise complex systems into fully integrated complex systems, near decomposable complex systems and fully decomposable systems. Fully decomposable systems (no epistastic relation at all) (Yayavaram and Ahuja 2008) are rarely found (products seem to always show some kind of dependency even if it is very weak) (Schilling 2000). Fully integrated complex systems are those where all the components, to varying levels, show a dependency between the technological elements (Yayavaram and Ahuja 2008). Near decomposable complex systems are hierarchies with a weak but not negligible dependency (Simon 1968) (Figure 2). This type of complex system is more common than the other two extreme cases. The reason for this is that all systems are characterised by some type of clustering of their components, therefore it is easy to say they have some kind of interdependency even if it is very weak (Schilling 2000).

Complex systems are not only characterised by epistatic relations but also by their hierarchical formation; therefore, if we combine both formation/number of epistatic relations and the strength of those epistatic relations, the result will be the following characterisation:

- Fully decomposable system: where none of the elements seems to display any epistatic relations; however, there is no evidence in the literature that this type of system could not display hierarchical structure (Ethiraj, Levinthal et al. 2008).
- Fully integrated complex system: all elements show epistatic relations; there is no evidence whether this type of systems shows a hierarchical formation (Yayavaram and Ahuja 2008).
- Near decomposable complex system: where elements show epistatic relations that are rather weak but still negligible (Simon 1962).

- Modular complex system: these take the shape of a hierarchy formed of units that are highly connected between the elements within the units but loosely connected with other units (Baldwin and Clark 2000, Gao and Zhang 2008).

There is a notion in the literature that the last two models help to manage modularity (Simon 1962, Ethiraj, Levinthal et al. 2008, Geisendorf 2009, Zhou 2013).

2.2.1.1. NEAR-DECOMPOSIBLE COMPLEX SYSTEMS:

One of the most problematic elements in complex systems is the possible complexity of relations and/or epistasis (interdependence), not only within components but also among the subsystems that form the nested hierarchy. "The most important and most obvious structural characteristic of any complex entity is its articulation – that is, the relative density or grouping and clustering of its components elements we will be able to make this precise by means of the concept of decomposition" (Alexander 1964, p.81). The decomposition principle illustrates the division of a complex problem into smaller units, in order to achieve a localised problem-solving activity where needed (Simon 1962, Geisendorf 2009). Decomposition is a process by which "separating interdependent elements into different sub-problems, a problem whose complexity is far beyond available computational resources is reduced to smaller problems, which can be handle but it generally fails to provide the optimal solution" (Frenken, Marego et al. 1998, p. 3). Geisendorf (2009) also warns about the decomposition approach by saying that, due to the epistatic relations between the elements, systems can only be decomposable to a certain degree and bounded rationality might lead to decomposition mistakes. By making improvements in a seemingly independent unit, these improvements might make changes in other subsystems. As the definition of near decomposable complex systems states that independence between the components might be weak but still negligible, therefore the laws of epistatic relations still applies in near decomposable complex systems, and therefore solving problems in the subsystems might not do anything to the fitness of the whole hierarchy. Yayavaram and Ahuja (2008) suggest that exploration across clusters will help to uncover new interdependences.

This near decomposable complexity approach offers a way to manage complexity. If a system is decomposed into smaller subsystems, designers could look more closely at the inner workings and coordinate opportunities (Zhou 2013). Knowledge of the inner workings of a complex system is crucial for the successful articulation and provision of the different service characteristics of the product (Langlois 2000, Brusoni and Prencipe 2001). Yayavaram and Ahuja (2008) also illustrate that near decomposition complexity approaches have other desirable benefits, such as the potential for recombination, persistence and durability, as well as providing an appropriate balance between the breadth and the depth of the innovation search, hence increasing innovation effectiveness.

Figure 2: Representation of near-decomposable complex systems (Simon 2000)

	1	2	3	4	5	6	7	8	9	10	11	12
1	-1	a	a	ε_1	ε_1	ε_1	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2
2	a	-1	a	ε_1	ε_1	ε_1	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2
3	a	a	-1	ε_1	ε_1	ε_1	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2
4	ε_1	ε_1	ε_1	-1	a	a	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2
5	ε_1	ε_1	ε_1	a	-1	a	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2
6	ε_1	ε_1	ε_1	a	a	-1	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2
7	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2	-1	a	a	ε_1	ε_1	ε_1
8	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2	a	-1	a	ε_1	ε_1	ε_1
9	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2	a	a	-1	ε_1	ε_1	ε_1
10	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2	ε_1	ε_1	ε_1	-1	a	a
11	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2	ε_1	ε_1	ε_1	a	-1	a
12	ε_2	ε_2	ε_2	ε_2	ε_2	ε_2	ε_1	ε_1	ε_1	a	a	-1

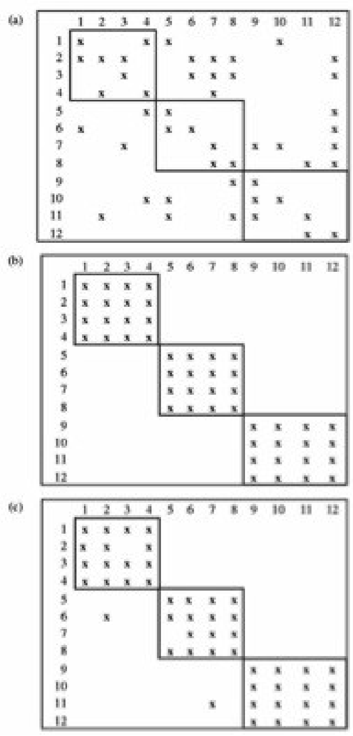
2.2.1.2. MODULAR COMPLEX SYSTEMS:

The properties of hierarchical mapping and near decomposable complex systems form the underpinnings of the next point in managing complexity: the modularity design. Several authors suggest that the concept of modular complexity originates from the idea of near decomposable complex systems (Gao and Zhang 2008, Zhang and Gao 2010). On the other hand, Frenken (2006) argues that modular complexity is distinct from near decomposable complex systems. Modular complexity is also a solution for managing complex systems (Simon 1968, Ethiraj and Levinthal 2004, Ethiraj, Levinthal et al. 2008). By clustering components into discrete modules where relationships can be clearly mapped in the nested hierarchical formation, then innovation and the possible results due to the epistatic relation can be easily target in order to enhance the synergy of the system.

A modular complex system is often viewed as a nested hierarchy built on units where the components (technological elements) are highly connected within the distinct units (clusters) but show high independency between the units that form the hierarchy (Baldwin and Clark 1997, Schilling 2000) (Figure 3). These elements show a clustering pattern that in order to provide a service or what are called "modular systems" (Langlois and Robertson 1992). Modular complex systems are "products that consumers treat as an entity" that "may be divided into a group of sub-products that consumers arrange into various combinations according to their personal preferences" (Langlois and Robertson 1992, p.247). Gao and Zhang (2008) also propose a definition of modular complex systems as "a continuum describing the degree to which a system's components can be separated and recombined. It refers both to the tightness of coupling between components and the degree to which the "rules" of systems architecture enable (or prohibit the mixing and matching of components) (Langlois and Robertson 1992, Gao and Zhang 2008). Zhang and Gao (2010) offers an illustration of modular systems that makes a direct link to topics of complex systems' decomposability and interdependence, in which the interdependences between modules are defined by the design rules and the degree of modularity refers to the level of near decomposability. A clear example of this modularity in the case of the photographic camera is exchangeable lenses and flashes. Consumers can choose the characteristics of the body of the camera, and lens and flash that are more appropriate for the type of photography they want to do (landscape, portrait and so on). DSLR offers this flexibility to choose the components that satisfy their needs. The systems might need those modules to offer the service but the consumer has the freedom to mix and match the components that will suit their needs better. The final product after the consumer has chosen the components is called the modular architecture. Modular architecture is

> "A special form of product design that uses standardised interfaces between components to create flexible product architecture. The modular architecture is flexible because product variation can be leveraged by substituting different modular components into the product architecture without having to redesign other components". (Sanchez and Mahoney 1996, p.66)

Figure 3: Representation of modular complex systems (Ethiraj and Levinthal 2004)



Ulrich (1995) offers a categorisation of modular systems with four distinct types according to the level of interchangeability of units.

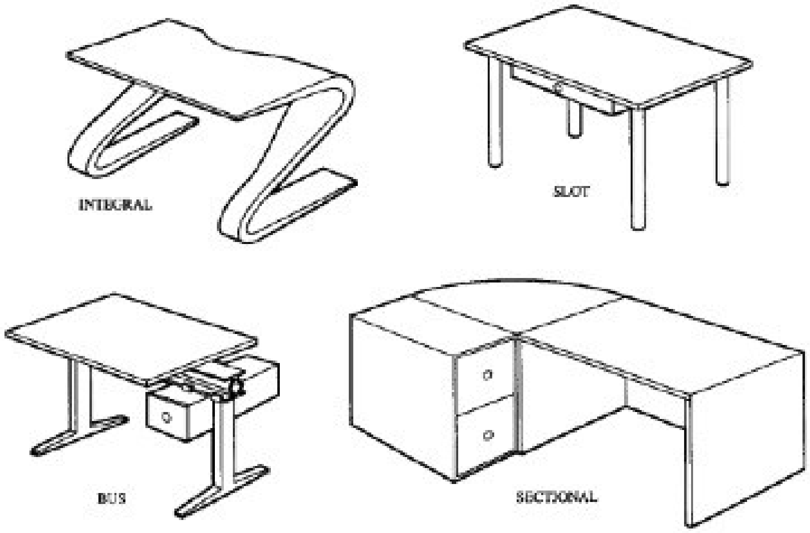
1. Integral: "includes a complex (no one to one) mapping from functional elements to physical component and/or couple interfaces between components" (Ulrich 1995, p.422). "Integral component require changes in every component to effect changes in any single functional element" (Ulrich 1995, p. 426). This type of architecture is what is has been called in this research fully integrated systems where all technological elements will display epistatic relation with any other element in the system. (Figure 4)

2. Slot: "each of the interfaces between components in slot architecture is of a different type from the others, so that the various components in the product cannot be interchanged. An automobile's radio is an example of a component in a slot architecture" (Ulrich 1995, p.424) (Figure 4). Some of the first SLRs did not offer the option of interchangeable lenses.

3. Bus: "in a bus architecture, there is a common bus to which the other physical components connect via the same type of interface (expansion card in a computer)" (Ulrich 1995, p.424) (Figure 4).

4. Sectional: "all interfaces are of the same type and there is no single element to which all other components attach. The assembly is built up by connecting the components to each other via identical interfaces" (Ulrich 1995, p.424) (Figure 4).

Figure 4: Types of modularity, (Ulrich 1995)



As illustrated above, modular complexity not only offers the benefit, to a certain extent, of clarification and simplification of complexity by breaking the hierarchy into smaller subsystems, but also, by offering more flexibility, the capability to satisfy a wider range of customers, therefore helping to manage heterogeneity of the market. This property of mixing and matching components in order to satisfy a larger number of customers is a very promising and beneficial property of modular products. Brusoni (2007) also adds that modular structures can speed up the pace of innovation, since experimentation is possible on the independent modules as opposed to the whole structure, and therefore design teams can work independently on the subgroups without explicit coordination. Zhou (2013) also adds that modular complexity reduces de-coordination burden between divisions.

Zhang and Gao (2010) also demonstrated that another benefit of undertaking a modular structure is the higher advantage for incremental innovation. There is evidence in the literature that trial and error might be possible in modular structures since the experimentation takes place in the independent units as opposed to the whole system

(Brusoni, Marengo et al. 2007). Experience accumulation and trial and error are at the heart of incremental innovation; the epistatic relations between the elements of the system usually hinder this process in complex systems. On the other hand, modulation allows for experimentation on the relatively independent unit; hence, incremental innovation further benefits modular products (Zhang and Gao 2010). Brusoni, Marengo et al. (2007) explain that even though the speed of incremental innovation might increase in modular structures, modular products will eventually fall into a modular lock-in, since the innovation will reduce to a specific unit as opposed to the whole system. Once the local option on that unit is reached, the only way to innovate will be to change the architecture of modules.

Even though modular complexity might seem the perfect solution to complex system management, several authors apply caution to the choice of this strategy. Firstly, though it seems appealing that the increasing number of modules will increase the scope of target markets by mix and match components, designers have to be cautious about the right number of modules; there is a boundary beyond which the number of modules stops being an opportunity and starts being an unnecessary increase in design cost (Schilling 2000, Ethiraj and Levinthal 2004). The more modules a product has, the higher the cost is of designing the product. This strategic approach might not be suitable for all consumers, especially with technological products where a high knowledge of the technology is required to choose the right modules or components to form the final product. In the camera industry, this strategy will only be beneficial for amateur photographers that have a good knowledge of photography. It would be too confusing and time consuming for a snap-shooter (who might only need the camera for birthdays and special occasions) to choose a camera body and appropriate lenses and flashes. There are different views on the recommended level of interdependency of the modules. While some authors show that the greater the interdependence between the module, the more constrained designers will find themselves in designing the different parts of the system (Fleming and Sorenson 2001), other authors suggest that manufacturers should not seek to completely decompose products: there should always be a level of near decomposability by which only the most relevant interdependencies will remain. In this way, products might obtain the global optimum but the not the best solutions (Marengo, Dosi et al. 1999). Brusoni, Marengo et al. (2007) on the other hand show that true modularity can only exist if interdependences are predictable and/or units/modules could be optimised independently; in reality, due to bounded rationality, it is very difficult to guarantee achieving decomposition into perfectly isolated components. Even if the epistatic relations between the modules of the systems are very weak it still might affect the performance of the whole system.

Modular complexity is portrayed in the literature as the most effective and efficient strategy to manage complexity. However, several authors call for caution in using this strategy, as it seems this strategy is more difficult to formulate than might be expected. First, there is a call for deeply understanding the inner workings of the modular architecture, product functionality, and dependencies between elements within units and across subunits; failure to understand epistatic relations might hinder the performance of the systems as a whole (Sanchez and Mahoney 1996, Langlois 2002, Ethiraj, Levinthal et al. 2008).

To sum up the discussion on modular complexity: modularity offers several benefits but this approach is not without risk. A review of the literature gave the following facts.

- Modular structures are hierarchical formations, which show higher independecy between the components of the distinct cluster of the hiearchaichy that across the different clusters of the hierarchy. This lack of dependency between subunits not only allows consumer to select and match the elements of the products, which increases the scope of target consumers, but also allows designers to make changes in the different subunits without changes to the rest of the system.

- Modular products are not able to decompose into perfectly independent units, and therefore designers have to be careful of the weak but nonetheless present epistatic relations within and across units.
- The characteristic structure of modular systems allows companies to capitalised on enhanced incremental innovation action; however, the global optimum will only be achieved through a change of modular architecture.

2.2.1.3. NEAR DECOMPOSABLE COMPLEX SYSTEMS VS MODULAR COMPLEX SYSTEMS:

There is evidence in the literature that modular complex systems originate from nea decomposable ones; however, the difference between the systems seems to be a bit unclear (Gao and Zhang 2008, Zhang and Gao 2010). Frenken (2006) argues that modularity is a distinct approach.

Both near decomposable and modular complex systems seem to display weak but still negligible independences between the elements of the nested hierarchy; however, modular complex systems seem to localise these weak independence levels between subunits as opposed to in any place in the nested hierarchy as in the case of the near decomposable complex systems (Figure 5) (Yayavaram and Ahuja 2008).

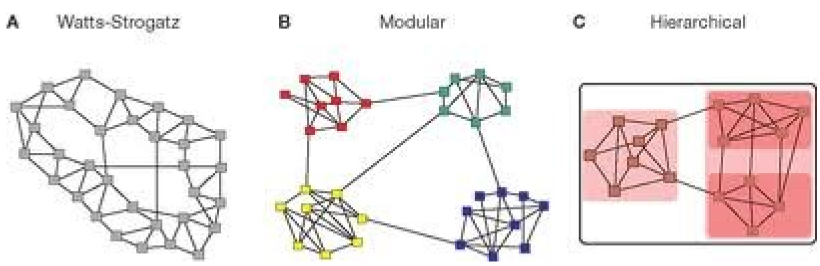
Another distinct difference between these systems is the ability to experiment on the independent units of modular complex systems; this might increase the speed and economise on innovation efforts. The problem of localised innovation efforts for the independent units is that even incremental innovation might be more effective, but to achieve the global optimum there is the need for architectural change, as in the case of near decomposable complex systems (Brusoni, Marengo et al. 2007).

Modular complex systems also offer the opportunity to increase variety in order to reach a wider target market, by allowing mix and match of the technological elements, which is not possible in near decomposable complex systems (Gao, Zhang et al. 2008).

The literature reviewed on both modular and near decomposable complex systems seems to indicate that the distinct difference between both systems is the degree of independence between the elements of the systems and the location of those epistatic relations in the context of the nested hierarchy.

Brusoni, Marengo et al. (2007) show that the choice between near decomposable or modular complex systems depends on the company's goals. If a company wants to capitalise on product performance then the solution will be to opt for near decomposable complex systems, since global performance can be optimised in this structure. On the other hand, if a company wants to capitalise on product variety then the solution will be to opt for a modular complex structure, to allow independent changes in the individual units and mixing and matching of the different modules.

Figure 5: Modularity vs near-decomposable complexity structure (Meunier, Lambiotte et al. 2010)



The discussion on the characteristic nested hierarchy of complex systems and the different formations of this nested hierarchy according to the dependency pattern forms the basis of the second research question for this study.

***Research Question 2**: do technological elements in cameras cluster in a hierarchical structure?*

2.2.2. MODELS TO MANAGE COMPLEXITY:

One of the most problematic issues in complex systems is the epistatic relation between the elements in complex systems (Amaral and Ottino 2004, Frenken 2006, Yayavaram and Ahuja 2008). The identification of elements that show some kind of independence and the elements that are affected by this independence is crucial for the development of any innovation activity in this type of system. Several authors suggest and call for attention to the possible cascade effect that changes in one of the elements in the systems could make in the rest of the hierarchy (Ulrich 1995, Hobday 1998, Tushman and Murmann 1998, Gatignon, Tushman et al. 2002, Allen and Varga 2006, Frenken 2006, Murmann 2006). There is a need to identify a model that allows the investigation of those epistatic relations and the effect they could have on the system. The literature review suggested several methods to study complexity; however, the most popular were the NK model (Kaufman, 1995) and the twin characteristics approach (Saviotti-Metcalfe 1984).

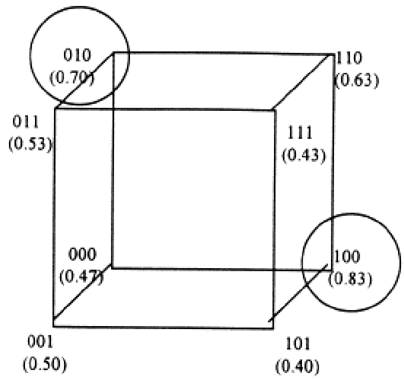
2.2.2.1. NK MODEL:

Geinsendorf (2009) demonstrates that problems are often too complex to solve in an optimal way due to the interaction between the elements; the NK model offers a way to depict such independences.

The NK model helps to simulate the effects of the independencies on system performance (Kauffman 1993). By mapping the relationships between components and systems, this model also helps to identify areas for improvement or innovation and the impact of innovation of particular components on the overall performance of the system. The NK model, as its name indicates, is composed of two elements: N refers to the number of elements, and K refers to the epistatic relations between the components. Therefore, in a case of maximum complexity, K=N-1 and, correspondingly, in a case of null complexity K=0 (Kauffman 1993). According to this, in a system with value K=3 each element's contribution is dependent on the value of another three elements. For instance, in our case of the photographic camera, N would represent the elements of the camera itself, such as shutter, lens, flash and so on, and K would be the relationships between those components (Figure 6).

Figure 6: NK model (Frenken 2001)

	$f_{x..}$	$f_{.y.}$	$f_{..z}$	f_{xyz}
000:	0.6	0.3	0.5	0.47
001:	0.1	0.5	0.9	0.50
010:	0.7	0.9	0.5	0.70
011:	0.3	0.5	0.8	0.53
100:	0.9	0.9	0.7	0.83
101:	0.7	0.2	0.3	0.40
110:	0.6	0.7	0.6	0.63
111:	0.4	0.8	0.1	0.43



The mapping of the systems is done in such a way that it resembles a landscape with valleys and peaks: the "fitness landscape" (Kaufman 1993). Every component is assigned a fitness value "ω". "ω" in the NK model is the mean of the fitness value ωn of each element n. Through the search of the NK technological landscape process via an "adaptive walk" starting from any point in the landscape, the firms can perform a series of trials and error strategies from the combination of the neighbouring configuration; success will depend on the correlation of the combination (Strumsky and Lobo 2002). The independences between the subsystems determine the usefulness of the possible combination or fitness of the elements of the system (Schwoon, Alkemade et al. 2008). Kauffman (1995) explains that the higher the peak the higher is the fitness value or what he named "hill climbing". NK models capture the effect of connectivity and conflicting constraints on a firm's technological search (Strumsky and Lobo 2002).

Again, there are two extreme situations: when K=0, components are independent from each other, and therefore changes in one of the components will not affect any other components in the systems, this type of systems is referred in this research as fully decomposable system. The mapping or fitness landscape for this system will therefore look "smooth" (Figure 7) (landscape B). On the other hand, the higher the K value, the more difficult it will be to find fitness values and therefore the representation will be what is called a "rugged" landscape (Figure 7) (landscape A) (Marengo, Dosi et al. 1999, Simon 2000, Schwoon 2008).

Figure 7: Fitness landscapes (SE 1996)

Geinsendorf (2009) suggests that there are two ways to use the NK model: first, to study the properties of the fitness landscape itself – e.g. more favourable decomposition; and secondly, to use the NK model in the investigation of how a search can be structured given a particular fitness landscape.

The problem with the NK model, as has been hinted at by the definition, is that this model is restricted to architectures where each element is epistatically affected by the same number of other elements (Frenken 2006). There is evidence in the literature (Zhou 2013) that shows that components in same systems might not be equality affected by the same number of elements, e.g. one component might be epistaticaly related to only one other elements while other elements in the same hierarchy might be epistatically related to two or three elements. This phenomenon is supported by empirical tests on mobile phones, where the provision of the service characteristics for camera quality cluster in two components with four elements each; on the other hand, the provision of the video quality the elements cluster in three components with three elements in the first cluster and two in the other two clusters (Windrum, Diaz and Filiou 2009) (Appendix A).

Another problem with the NK model is that the K value is not an accurate measure of complexity since it only indicates the degree of epistasis between elements but does not indicate the level of decomposability of the system (Murmann and Frenken 2006). As the literature suggests, epistatic relations can overlap different subsystems; even in cases where the K shows a very low value the subsystems might still be non-decomposable (Saviotti and Metcalfe 1984, Schilling 2000, Brusoni, Marengo et al. 2007, Windrum, Diaz et al. 2009).

When K increases faster than N this could result in a complexity catastrophe. It can be said that when the complexity (interdependence of the components) is higher than the number of elements of the hierarchy (K>N), this could result in complexity catastrophe. A way to deal with complexity catastrophe is modularity (Fleming and Sorenson 2001). The NK model (Kauffman 1993) promises to ameliorate the problem with near-decomposable or modular systems, by finding the balance between potential combinations and number of modules (Fath and Grant 2007). The NK model has been suggested as a way to map complexity (Frenken 2006).

Altenberg (1995) offered a generalised NK model (Altenberg 1995, Altenberg 1996) that is supposed to ameliorate the weaknesses of the NK model offered by Kauffman (1993). In the generalised NK model, any number of components can affect the N variable. This generalised NK model (Altenberg 1995, Altenberg 1996) also eliminates the K parameter, substituting it with the parameter F or the function performed by the epistasis of the elements. Any number of elements can affect any function and any number of functions can affect any number of elements. The F parameter refers to the function that is being developed thanks to the synergy or clustering of the technologies. This model not only allows the flexibility of function being affected by any number of elements but also, by including the F parameter, takes into account the demand side (Alterberg 1995).

2.2.2.2. MAPPING OF TECHNOLOGICAL RELATIONS:

The generalised NK mode (Altenberg 1995, Altenberg 1996) takes into account the number of components in a system and the function of the system itself. This mapping is similar to the twin characteristics approach (Saviotti and Metcalfe 1984) where technologies cluster in order to perform a function. The N parameter in the generalised NK model is called "technological characteristics" (TC) in the twin characteristics approach, which refers to the technological elements of a product, and the F parameter is "service characteristics" in the twin characteristics approach, which refers to the service that results from the clustering of elements N (TC).

Saviotti-Metcalfe's (1984) twin characteristics approach builds on the notion of technological trajectories (technological clusters) (Dosi 1982) and the characteristics approach (Lancaster 1966). These models offer the possibility of defining products as a combination of three elements: service characteristics, technological characteristics, and process characteristics. Service characteristics are the equivalent of what Lancaster called intrinsic characteristics or intangible characteristics: the characteristics from which customers derive utility. These service characteristics are related to a set of technological characteristics. The level of development of these technological characteristics will enhance the performance of the service characteristics; for instance, in the mobile phone market a higher number of camera pixels relates to higher picture resolution on a camera phone. Using this model can help firms identify products to compete with a set of service characteristics that they think will appeal more to consumers. This approach links to the main issue of Lancaster's approach, since customers take utility from service characteristics. Even though those service characteristics will be backed up by the development of technology, customers will not always be interested in the technical information details. This might be one of the reasons why technological characteristics in most cases are not readily available or advertised to customers (e.g. trade magazines, Internet). This situation does not occur in every market: customers might be interested in technological characteristics in other sectors such as laptops; still, it could be said that companies still capitalise on service characteristics rather than technological details.

Lancaster's characteristics approach (Lancaster 1966) is in essence summarised as follows:

> "The good, per se, does not give utility to the customer; products possesses characteristics, and these characteristics give rise to the utility and the good will possess more than one characteristic, and many characteristics will be shared by more than one good". (Lancaster 1966, p.164)

This approach creates the opportunity for products to offer an array of services (products are not necessarily reduced to offering one unique service), and different products can offer similar services.

Customers' choice of characteristics of goods will depend on which product offers the most effective combination of technological characteristics at minimum cost. This combination of technological elements may not remain the same over time, as, with technological innovation, customers might choose a particular technology at the birth of an industry because their knowledge is reduced (due to a lack of previous experience). However, as the industry develops or evolves and customers enrich their knowledge of this particular technology, they will define their particular needs and wants. Consumer demand for a good could be represented in a linear program (Lancaster 1966). Lancaster (1966) offers an example of the linear representation of a good. Formulas 1 and 2 show the representation of two characteristics (Z^1 and Z^2) and four activities (b^{11}, b^{21}…). According to the formulation provided by Lancaster (1966) (Formulas 1 and 2), the provision of a service characteristic is a function of the clustering of particular technologies, whose synergy gives rise to that particular service characteristic. This synergy clustering of the elements in these formulas also supports the idea of the complex systems theory. This research will use this type of formulation for the photographic camera mapping of service characteristics because their combination of the synergy and clustering of elements is also found in complex systems.

$$Z^1 = b^{11}y^1 + b^{12}y^2 + b^{13}y^3 + by \quad \textit{(Formula 1)}$$

$$Z^2 = b^{21}y^1 + b^{22}y^2 + b^{23}y^3 + by \quad \textit{(Formula 2)}$$

The twin characteristics approach is also based on the technological trajectories approach (Dosi 1982). Dosi (1982) first redefined technology as

> "Economic theory usually represents technology as a given set of factors' combination, defined (quantitative and qualitative) in relation to certain outputs, the definition we suggest here is much broader. Technology as a set of pieces of knowledge but directly "practical" (related to concrete problems and devices) and

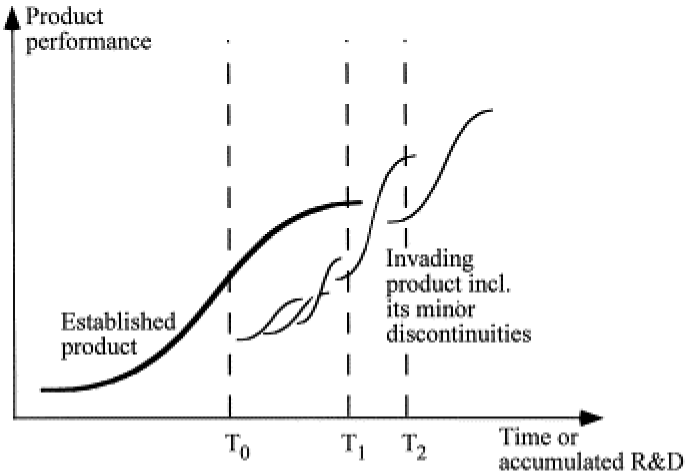
theoretical (both practically applicable although not necessarily already applied), know-how methods, procedures, experience of success and failure and also, of course, physical devices and equipment" (Dosi 1982, p.151)

This definition has a wider meaning and it could be considered more appropriate for current market conditions due to the inclusion of the experience factor, which could be given by consumer reaction to the firms' strategic actions. The economic definition of demand can be seen as too reduced in meaning in regards to the relation of input–output aspects of demand. This argument takes into account the argument that market demand cannot be taken as homogeneous in current market situations and this will be illustrated all through this research.

This redefinition of technology is necessary to understand the following definition of technological innovation. Dosi (1982) states that there is an analogy with the Kuhnian definition of 'scientific paradigm', which could be defined as "an 'outlook' which defines the relevant problem a 'model' and a 'pattern' of enquiry" (Dosi 1982, p.152). Building on this definition of "scientific paradigm", Dosi (1982) defines "technological paradigm" as "a 'model' and a 'pattern' of solutions of selected technological problems based on selected principles derived from natural science and selected material technologies" (Dosi 1982, p.152). Dosi (1982) suggests that it would be better to talk about clusters of technologies, rather than individual or independent technologies.

In this discussion, it is important to define what this study means by innovation. This research takes Dosi's view of innovation as 'technology trajectory', which he defines as "the pattern of 'normal' problem solving activity on the grounds of a technological paradigm" (Dosi 1982, p.152). Dosi (1982) illustrates that when innovation occurs in the same trajectory or direction, it is an incremental innovation. However, when innovation results in a new trajectory it is a radical innovation or creation of a new technology or characteristic (Figure 8).

Figure 8: Innovation trajectories (Garcia-Muina and Navas-Lopez 2007)

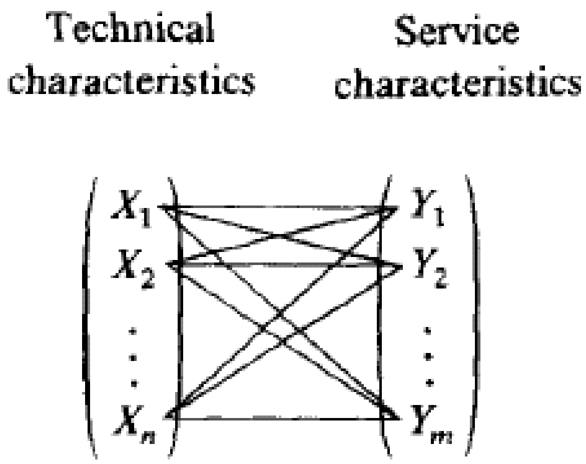


This trajectory relates to the notion of direction or innovation direction. The trajectory or direction of innovation is linked to the notion of who or what is the motivator of those innovation's directions. There has been much research as to whether it is technology "push" or demands "pull" that is the motivator of innovation. This research will not attempt to further investigate this issue, but it is important to mention such arguments since the theories and explanation contained in this research cover both sides of the argument. On the one hand, Dosi (1982) and Saviotti-Metcalfe (1984) might take into consideration consumer demand being on the side of technological "push", since they state that considering the demand side is not enough to completely understand innovation. On the other hand, Lancaster's (1966) characteristics model takes demand-pull as the main motivator of innovation. Dosi (1982) also adds that economic criteria act as selectors and define, more precisely, the actual paths of innovation followed inside a much bigger set of possible ones. Once a path of innovation has been selected and established, it shows a momentum of its own, which contributes to defining the direction towards which "the problem-solving" moves as a natural trajectory. The decision either to follow the same innovation trajectory or to take an innovation trajectory is a highly debatable issue regarding its driving force (the technology push–demand pull debate). A firm following the same trajectory will make incremental innovation in a particular product; on the other hand, when a firm takes the decision to make radical innovations in that particular product, a new trajectory emerges (Figure 8). Those changes might be due to consumer demand (demand-pull) or due to firms offering different solutions to the same problem (technology push).

Saviotti-Metcalfe (1984) also makes a differentiation between "form" and "function". This is related to the service performance or what Lancaster (1966) states is the focus of consumer demand. Lancaster (1966) states that consumers are not interested in the technological details of a good (product) but in the array of services that arise from the performance of a product (consumer pull). On the other hand, "form" refers to the internal structure of the technology. Alexander (1968) also illustrated this breakdown; he called it "form" and "context". The focus of firms in this case will be the creation, development and innovation of a set of technological characteristics that will supply a more appealing array of services than those of rival firms. These same authors indicate that "the combination of those two approaches should improve the applicability of the characteristic approach to the evaluation of the technological and to test the theories of innovation" (Saviotti and Metcalfe 1984, p.154). This model could be considered as a more complete explanation than existing demand theories since it takes both the consumer's demand and firm's supply (consumer pull–technological push) into consideration. Prior research done by this author and colleges has used this model to map the relationships in the mobile phone market; these authors found that not only were technological characteristics (TC) clustered in order to provide a service characteristic (SC), but also ergonomic elements such as volume and weight play an important part in this clustering. This research is going to consider these extra elements for the formulation of photographic cameras.

The breakdown illustrated by Saviotti-Metcalfe (1984) between input (form) and output (function) indicators is very important since Saviotti-Metcalfe (1984) stated that a proper analysis of innovation could not be made without the analysis of both input and output indicators. Saviotti-Metcalfe (1984) suggested that once the product is defined by service and technological characteristics, the relationship between these variables could be represented by a pattern of mapping (Figure 9) and Formula 3.

Figure 9: Twin characteristics representation (Saviotti and Metcalfe 1984)



$Y_1 = X_1 + X_2 + X_3 + X_{N+E}$ (Formula 3)

Where:

Y: service characteristic (enhanced quality of picture)

X: technological elements that cluster in order to offer service Y (shutter speed, metering, flash…)

2.2.3. COMPLEX VS. SIMPLE SYSTEMS:

The review of the literature on complexity theory gave this research its basis for the identification of complex systems and the application of those characteristics to the camera in order to test whether those cameras could be complex systems.

According to the literature, complex systems display the following stylised facts.

1. Complex systems comprise large numbers of components that interact in a non-simplistic way.

2. The components of complex systems interact in such a way that the whole is more than the sum of the parts. Components cluster in a synergetic manner to offer a service.

3. These components nest in a hierarchical structure.

4. Epistatic relations can change strength within subsystems and across the subsystems of the nested hierarchy.

5. The shape of the hierarchical structure depends on the strength of the epistatic relations between the elements and the localisation of those epistatic relations.

6. According to the strength and localisation of the epistatic relations, complex systems could be classified into fully integrated complex systems, fully decomposable, near decomposable complex system and modular complex system. The last two classifications (near decomposable and modular complexity) aid management of complexity.

Amaral and Ottino (2004) illustrate that simple systems have a small number of components that usually act according to well-understood laws (Amaral and Ottino 2004). Hobday (1998) also illustrates that simple systems are relatively stable and display predictable properties. Simple systems are also more characteristic of mass-market conditions as opposed to complex systems that seem to be more characteristic of customised product (heterogeneous demand). This certain nature allows for trial and error innovation activities, as opposed to complex systems where any action in one of the elements might have a reaction in the overall system.

This investigation of the theory of complex systems illustrates that there are two main requirements that products have to satisfy in order to be considered complex systems: the epistatic relations between the elements of the system and the hierarchical structure of the elements of the system. Research Questions 1 and 2 have covered these two requirements.

The merging of Research Questions 1 and 2 forms the basis of the following research question:

Research Question 3*: can cameras be considered complex systems?*

2.3. INNOVATION LIFE CYCLES:

Epistatic relations displayed by complex systems are the main cause that limits complex to innovate/evolve as suggested by the classical literature on innovation (Amaral and Ottino 2004, Frenken 2006, Reinstaller 2007, Yayavaram and Ahuja 2008, Zhou 2013).

The second part of this research will investigate the pattern displayed by complex systems as opposed to the classical view on innovation.

Firstly, this research is going to review a definition of innovation that could be more relevant for the complex system case. Innovation is often described in the literature as "the successful exploitation of new ideas" (Francis and Bessant 2005). However, there is a definition that is more relevant to the complex system example: "the iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to the production, development and striving success of the invention" (Garcia and Calantone 2002, p112). Innovation is also seen as a continuous process, where modification will lead to further modification and so on (Garud, Jain et al. 2008). These definitions highlight some points about this definition, which will help later in this research; first, innovation is an iterative process, and this opens up the possibility of a process that could happen repeatedly until one reaches a goal, and therefore innovation could be understood as a process that could happen several times over the life of a product as opposed to being a one-off process. The second point is that innovation could open up the possibility of new markets; therefore, though innovation does not necessarily improve existing products, it could also open up new niche markets. This is, as illustrated in the definition of innovation (Garcia and Calantone 2002), due to the need to cover new services required by consumers. This could indicate that innovation is also demand-orientated, not only manufacturing-orientated. The last point that is worth mentioning is that an invention has to have market success in order to be an innovation; again, this fact takes consumer demand into account (Saviotti 1985).

There is a clarification, however: it is important to know that innovation and invention, despite being part of the same process (developing a product), are two distinct processes. Invention is “the original solution from synthesis of information about a need or want and information about the technical means with which the needs or wants may be met”(Utterback, 1971). This author explains that the process from invention to innovation has three distinct stages. The first two stages culminate in an invention, and the last stage, which culminates in innovation. Invention is therefore the “best” technological solution for consumer needs, taking into account possible constraints (technological, organisational, societal and so on) and it will not become an innovation until it reaches market diffusion. Market diffusion is the crucial element that underpins the emergence of successful innovation. Among firms undertaking innovation processes, the successful ones will be those that pay more attention to market demand than technological opportunity (Saviotti 1986). There are several interesting points on this illustration of the definition of innovation. Firstly, according to these definitions, an invention will become an innovation only if it is widely diffused in the market. These arguments seem to indicate that there has to be some kind of homogeneity in the market for an invention to be widely adopted. On the other hand, Saviotti’s (1986) argument seems to indicate that innovations are successful due to attention to market demand. It is important to highlight this attention to market demand because it brings out the debate of this research on heterogeneity of demand and standardisation of products in the market. Several authors seem to defend the idea that demand is heterogeneous

(Rigby and Essletzbichler 1997), however, according to given definitions of innovation diffusion in a market concerned with the wide acceptance of a product by consumers. This diffusion of products in the market seems to indicate some kind of standardisation of needs, which in turn seems to contradict the idea of heterogeneity of demand.

2.3.1. INCREMENTAL VS RADICAL INNOVATION:

Research on the innovation literature gave rise to a plethora of terms and processes that explain different types of innovation from incremental to radical, generation, modular, architectural and discontinuous. A reader could get lost with all the different names for innovations and innovation processes. Therefore, this research is only going to focus on the main innovation types that could be most relevant to the study of innovation in complex systems. The only innovations that this research will be taking into account in the light of simplification of terms are incremental and radical innovation, which cover the majority of innovative activities. This research will also take into account architectural innovation. This type of innovation is particularly relevant to complex systems because it deals with changes in the way elements are linked (clustering). Innovation of elements combines with the epistatic relations between the components of a complex system, and can cascade changes in other elements of the systems, but it can also change the way elements cluster in the system.

Firms might take up innovation activities/strategies in order to introduce or improve products or processes, or to redefine the positioning or dominant paradigm of the firm (Francis and Bessant 2005).

Incremental and radical innovation are the extremes of the innovation continuum (Henderson and Clark 1990). On one hand, incremental innovation is smaller changes in an existing product. On the other hand, radical innovation is major changes possibly resulting in a completely new product.

There are various definitions of incremental innovation, such as “new features benefits, or improvements to existing products” (Garcia and Calantone 2002) and “minor changes to existing products, exploiting the potential of the established design, and often reinforces the dominance of established firms” (Henderson and Clark 1990). Both definitions coincide in that incremental innovation involves minor changes to improve the performance of the existing product – for instance, faster shutter speed, an increased number of exposure modes such as panoramic, portrait, and so on, or higher number of pixels in cameras. These changes might be to increase performance or to offer extra benefits. The important issue here is that incremental innovation does not offer a new product, only an improved version of an existing one. These minor changes might seem a minor strategy to improve performance of the existing products on the market; however, this research takes into account this innovation strategy because in the case of complex systems it could again have dramatic competitive consequences (Henderson and Clark 1990). A possible example is the automation of cameras opening up a market for snap-shooters. As well, the before-mentioned phenomenon of minor changes in one component of the systems might destroy the fitness of the subsystem, and ultimately cause the failure of the performance of the product (Allen and Varga 2006).

At the other end continuum, radical innovation is “based on a different set of engineering and scientific principles and often opens up whole new markets and potential markets” (Henderson and Clark 1990, p.9). As opposed to incremental innovations, radical innovation in a way represents a breakthrough turning existing products into completely new products. Several authors agree that a radical innovation has to cover the following requirements (Henderson and Clark 1990, Garcia and Calantone 2002, Francis and Bessant 2005, Rose-Anderson, Allen et al. 2005):

1. The invention has to be a technological breakthrough. It has to be different from any other previous invention. It has to be new.

2. The invention has to be different from current inventions or products in the market. It has to be unique.

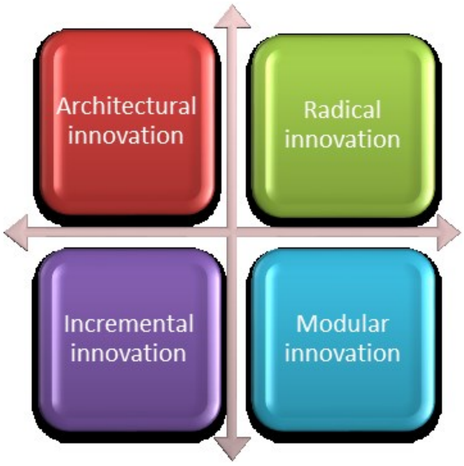
3. The invention has to be diffused in the market. The invention has to supply an enhanced service that will be adopted by consumers.

To be considered a radical innovation the product must satisfy the three conditions; if the product only satisfies conditions one and two then, as illustrated above, the action will be only considered a radical invention – to be considered a radical innovation it has to satisfy the condition of market success. Firms offering a new product have to go beyond existing design, otherwise it is merely a product development (Rose Anderssen, Allen et al. 2005).

The differentiation of incremental and radical innovation seems quite an ambiguous notion. There is no model to measure radicalness; however, the Saviotti-Metcalfe (1984) twin characteristics model has been used to indicate the presence of radical and incremental innovation by various authors (Frenken, Saviotti et al. 1999). Saviotti-Metcalfe (1984) illustrates that if there is a measure of distance between different products then this distance will be smaller between incremental innovations than between radical innovations. This distance and distinction of incremental and radical innovation could also have an effect on the clustering pattern. If the distance between clusters were measured this measure could indicate the changes in the clustering pattern, even clustering overlap (Saviotti-Metcalfe; 1984). This model could be particularly useful for this research since it could help with the identification of incremental and radical innovations. This is important because this research could then identify if there were clustering pattern changes before and after radical innovations,

There is, however, a model that could map the innovation in a matrix according to the magnitude (minor–major innovations) and the relationship between the components (Figure 10).

Figure 10: Classification of innovation (Henderson and Clark 1990)



All these innovation types, whether they are incremental, radical or architectural, could have positive, negative or unrelated results in the overall product. Tushman and Anderson (1990) called these positive/negative effects "competence enhancing/destroying". As the name indicates, these technological shifts either enhance or destroy existing firm competences. "Competence-destroying" refers to a negative effect, the learning of new skills and processes, and on knowledge base; these are more related to radical innovation (Anderson and Tushman 1990). It is important to note that radical, incremental and architectural types can all have both competence-enhancing and -destroying properties (Gatignon, Tushman et al. 2002). In complex systems, we can hypotheses; the impact could be directly related to the level of interdependency between components and the clustering pattern.

2.3.2. ARCHITECTURAL INNOVATION:

So far, this research has considered the literature on incremental and radical innovation, which makes changes in the elements themselves; however, there is also an innovation strategy that changes the way the components are clustered or located in the system.

Technological changes or innovations may lead to a change in the relationship or way that technological elements are linked, hence a further subdivision of technological elements might emerge (Saviotti and Metcalfe 1984, Henderson and Clark 1990). This subdivision could become part of the pattern of mapping if these sublevels are of relative importance for the main services and /or technology evolution.

The change in the clustering pattern is known as "architectural innovation" (Henderson and Clark 1990). Henderson and Clark explained that, in essence, architectural innovation refers to changes in which existing elements are linked. This change in the reconfiguration of the systems does not necessarily mean that the elements are left untouched, since architectural innovation usually emerges due to changes in existing components. These changes in the components might change the fitness of the system, hence the reorganisation of the way components are linked, which is directly linked to innovation in complex systems.

Frenken (2006) also applied the definition of architectural innovation to complex systems. As illustrated above, the components of complex systems cluster into different subsystems; these clusters have a certain structure, which Frenken (2006) called "technological architecture". Technological architecture refers to the arrangements of functional elements, the mapping from functional elements to physical components (technological characteristics are needed for distinct service characteristics) and the specification of the physical components (Brusoni and Prencipe 2001).

Some other authors, on the other hand, consider that the sources of new products are the syntheses of pre-existing technologies (Fleming and Sorenson 2001, Runde, Jones et al.

2009). Empirical studies on technological innovation also show that most of the innovation arises through the combination of existing technologies (Frenken 2006, Schwoon 2008).

This research suggests that since innovation due to epistatic relations might change other elements of the system, which at the same time might change the hierarchical pattern due to the ill fit of the new components, architectural innovation might be a current topic in complex systems. If this research combines the idea of architectural innovation and the literature on innovation being an iterative process, then this research hypothesises that architecture on complex systems might change due to innovation, both radical and incremental, of complex systems. This research suggests the hypothesis that changes in the way components cluster together could be an indication of architectural innovation. It is crucial for managers and designers to be aware that innovation in the components of a system might not only result in competence-enhancing/-destroying effects but might also change the way the hierarchy is shaped (Ulrich 1995, Hobday 1998, Tushman and Murmann 1998, Gatignon, Tushman et al. 2002, Allen and Varga 2006, Frenken 2006, Murmann and Frenken 2006).

Lancaster (1966) and Saviotti-Metcalfe (1984) support the idea that architecture might change over time; these changes can happen at any level of service or technological characteristics. These changes might influence change in other levels of the services, or product characteristics, or may affect the characteristics themselves.

The definition of innovation as an iterative process and the literature on architectural, incremental and radical innovation and their possible effects on complex systems form the basis of the next research question.

Research Question 4: *does the clustering of technological elements change over time due to innovation activities?*

There is little research done on changing architectures in fitness landscapes or complex systems (Frenken 2006), which makes the testing of the changing clustering patterns offered by this research a very rich opportunity to cover that gap in the literature. This research question (4) will also be very interesting to investigate since there is no evidence that the changes in clustering patterns over different periods has been addressed in this way before. One study investigates the clustering of TC in order to offer a service in the mobile phone industry; however, due to unavailability of data, this could only be done in one period (Windrum, Diaz et al. 2009) (see Appendix A). The fact that this research covers 1955–2011, combined with the fact that cameras seem to show both radical and incremental innovations, could shed some light on the possible changes of clustering patterns over different periods and on the way innovations, both radical and incremental, affect this architectural structure (architectural innovation).

2.3.3. INNOVATION PROCESS AND APPROACHES:

The second part of this research is based on the hypothesis that complex systems innovate differently from simple systems. There are several reasons for this argument; on one side, authors such as Hobday et al. (1995) explained that traditional views of innovation are better suited for mass-market products and complex systems are highly customised products. On the other hand, authors such as Frenken (2006) and Murmann and Frenken (2006) illustrated that, due to the epistatic relations between the elements, complex systems are unable to evolve normally or eliminate deficiencies. Fosters (2005) illustrates that many systems nowadays considered complex could not be fully understood by standard approaches of modelling and theorising. This research is going to focus on these last two points. First, there is the notion that traditional views are more suited to mass-market standardised products; this brings up the question, can mass-market products be considered complex systems as in the case of cameras? Are only customised products complex systems? If that is the case, why did cameras not follow traditional patterns of innovation during the period 1955 to 1975? The second point that this research is concerned with involves epistatic relations and nested hierarchy structure. This research is going to investigate and test whether the traditional view of innovation cannot indeed be applied in the complex systems case. Can the dependency of the elements really stop a product from following traditional patterns of innovation? This research will consider whether the epistatic relations and/or nested hierarchy structure give rise to an entirely different innovation life cycle or simply to slight variations of the existing models of innovation life cycles (the classical view of innovation).

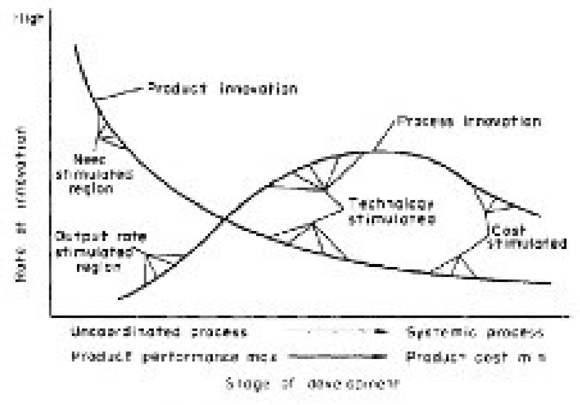
This section will give an overview of the different classical models of innovation trajectories before the investigation of and comparison with the model of complex systems innovation in order to shed some light on the distinct difference between the approaches to innovation life cycles.

2.3.3.1. TRADITIONAL INNOVATION MODELS

One of the first models to map the innovation process was the innovation life cycle (Utterback and Abernathy 1975). Utterback and Abernathy observed that products develop over time in a predictable manner, and suggested an innovation life cycle that could serve to predict statements about the dynamics of the innovation process and the firm.

These authors explained that a firm goes through different stages in the innovation life cycle (Figure 11).

Figure 11: Innovation life cycle (Utterback and Abernathy 1975)



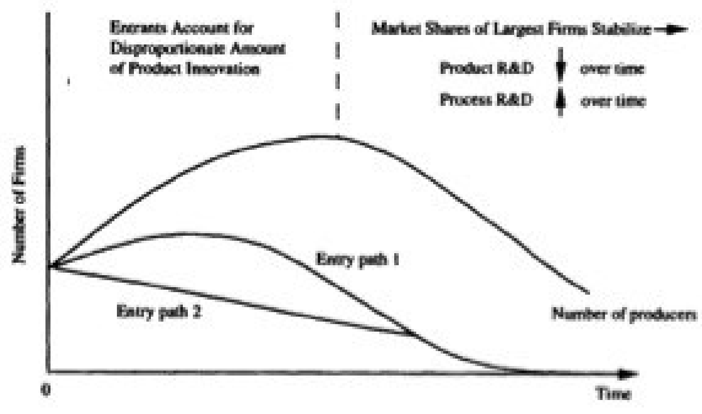
High levels of uncertainty and great product variety characterise the first stage. Uncertainty in this case refers to the extent to which the future cannot be predicted or anticipated. Hence, its higher level of uncertainty defines this stage, because firms offering different variants to solve technical problems are waiting for consumers to decide which of the available "solutions" is more appropriate for their needs (Tushman and Anderson 1986). In the case of very new technologies, this could be quite ambiguous task; if a new technology appears, customers do not have a basis to refer to in order to make a decision since they do not have complete knowledge of technology or of how much benefit they can obtain from that technology. The sources of uncertainty are often found in imperfect foresight and human inability to solve problems (Alchian 1950). On the other hand, other authors support the idea that the sources of uncertainty are not only consumer tastes and size of the market, but also the constraints found in the technological skills and appropriateness of the technological problems (Windrum 2005). In this first stage, rival companies offer experimental versions of the product, or in other words offer different solutions to a technical problem, in the quest to identify customer needs.

This stage will finish with the emergence of a dominant design, or the establishment of a standard in the market. Customers finally decide which company offers the product that satisfies their needs. Dominant design (DD) is also suggested as the outcome resulting from a series of technical decisions about the product that are constrained by prior technical choices and by the evolution of customer preferences (Utterback and Suarez 1993). The research will investigate further the DD effect/result later in this chapter.

Abernathy and Utterback (1975) stated that emergence of the dominant design signifies the start of a new stage where uncertainty and product variety is greatly decreased (Figure 11).

This second stage is also characterised by the shakeout of the market. Companies that do not offer the dominant design either go out of the market or follow the market leader or producer of the dominant design. At the beginning of the industry, the number of firms might rise, offering the different variants of a technological solution. However, this number of firms will decline over time and the leadership of the market will stabilise with the diffusion of a main product (Gort and Klepper 1982) (Figure 12). Once the DD stabilises, companies might feel forced to adapt to this design in order to succeed. Offering a completely new product in this situation might be a very risky situation, unless there is a gap in the market for other needs, or market niche. Firms that are not able to make the transition towards greater product standardisation and process innovation will be unable to compete effectively and will fail (Utterback and Suarez 1993).

Figure 12: Entry–exit on innovation life cycle (Klepper 1996)



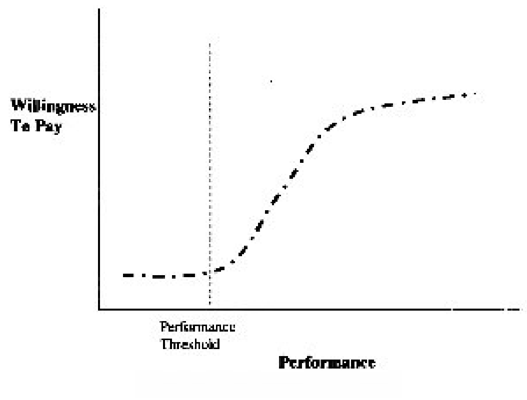
At the last stage of the innovation life cycle, there is a swift rise in emphasis towards process innovation. Process innovation focuses on the making of the product, leaving the functionally of the product untouched (Adner and Levinthal 2001). The focus is on production, to gain economies of scale, scope and price and minimise cost. Companies will not embark on process innovation until the ILC is sufficiently stable or the possible emergence of the DD shows indications of standardisation. Companies might not want to run the risk of investing resources, time and financial expenditure in innovating the process of manufacturing a product if they suspect that uncertainty of product designs is very high (Klepper 1996) (Utterback and Abernathy 1975). The reason for this caution is the high level of uncertainty that characterises this stage of the ILC.

One of the weaknesses of this theory of innovation is that these authors take the view that demand is homogeneous and, in market conditions nowadays, demand tends to be heterogeneous in nature. Authors have suggested that this model will be only applicable in the mass market where the demand is more homogeneous (Windrum and Birchenhall 1998). These authors explain that at the beginning of the market customers have very little or no information about the product or the service that the product might provide; however, as knowledge increases, customers become increasingly demanding about their needs or wants about that particular product, hence market demand becomes heterogeneous. However, a rise in income can be one of the reasons for the increase in variety and range of demand services. Therefore, one product (dominant design) will not be likely to satisfy all those needs, based on one common set of core technologies being able to provide the full range of Service in demand (Murmann and Frenken 2006). In the long run, technical specialisation is expected to take place (Freken, Saviotti et al. 1999). This argument seems to contradict the idea of dominant design. These statements could lead to the hypothesis that variety does not only occur at the beginning of the ILC but could also occur once the dominant design emerges.

Other authors, on the other hand, support the idea that innovation is highly unpredictable; if innovation can be predicted then it is not novel. Even though innovation is unpredictable, innovation does not appear to be totally random and unrelated, but rather occurs in orderly paths (Patel and Pavitt 1997, Rigby and Essletzbichler 1997, Silverberg and Verspagen 2005). There is evidence in the literature that illustrates technological change moving along a distinct technological trajectory – “path dependency” (Allen 2010). Other authors have also suggested there are distinct paths such as “technological paradigms” (Dosi 1982), natural trajectories (Nelson and Winter 1977) and technological guideposts (Sahal 1981).

Innovation has also seen a series of technological cycles, depicted here on an S-curve diagram (Figure 13).

Figure 13: S-curve innovation cycle (Foster 1986)



Other authors have also used this Foster's S-curve to illustrate technological cycles (Anderson and Tushman 1991, Tushman and Murmann 1998). This technological cycle resembles Abernathy-Utterback's (1975) ILC. They have periods of variation (ferment) initiated by technological discontinuities, which are closed by the selection of a DD; during this period of ferment, the innovation activity will be mainly incremental. The only difference between the models is that technological cycles seem to indicate that the innovation process can have different rounds of innovation. As the name suggests, these cycles or S-curves can repeat themselves if another phase of discontinuity appears. Research done on photographic cameras found that indeed there is an indication that there could be different rounds of innovation and even different DDs (Windrum 2005).

There is a highly debate about whether this approach could be applied to current market conditions; some research shows that in fact the ILC could be applied to a multitude of products (Rosenkranz 2003). Other research shows that the ILC was only applicable in the period 1950–1960 where markets were characterised by single segmentation and relatively stable technologies, and the ILC could be used as a tool for market dynamic prediction (Grantham 1997). Lastly, other research seems to indicate that ILC was not even applicable during those years and was only applicable for mass-market products. Nor do the classical models take into consideration the possibility of the unpredicted effects that innovation in the elements might have on the rest of the system (product). The possible applicability of the traditional innovation life cycle model brings out the next research question.

Research Question 5*: could the ILC model explain the innovation process of complex systems?*

2.3.3.2. DOMINANT DESIGN EFFECT AND VARIETY:

There is a very important notion that comes out from the illustration of the ILC: that is, the emergence of the DD. The emergence of the DD appears to indicate the standardisation of the market and a decrease in variety. This notion contradicts the notion that demand is heterogeneous in nature (Windrum and Birchenhall 1998).

As illustrated above, at the beginning of the ILC there are a high number of product variants offering solutions for a technological problem. The DD is the result of firms offering the "best" technological solutions (according to technological, societal, economic, and political constraints), and consumers choosing the best available solution among those technical solutions offered by firms. After the DD emerges, there is a decrease in variety and shift to standardisation of the market.

The emergence of the DD has been widely investigated (Utterback and Abernathy 1975, Henderson and Clark 1990, Anderson and Tushman 1991, Utterback 1994, Murmann and Frenken 2006). There are different views of the definition of DD. The DD has been seen as the best technological compromise that then forces other companies to copy this design (Utterback and Abernathy 1975). This suggestion of companies copying rather contradicts the literature on complex systems where the complex systems literature seems to indicate the high risk and difficulty of copying/imitating existing products due to epistatic relations. For a company to be able to copy a complex system requires an in-depth knowledge of the inner workings and clustering patterns of the entire hierarchy in order for a product to function (Allen and Vargas 2006). This notion also seems to raise the debate of the possible applicability of the classical view of innovation on complex systems.

DD has also been seen as the necessary precondition for a product to achieve dominant market success (Utterback 1994). Not all these definitions seem applicable for complex systems since they do not seem to take into account the nature of complex systems as nested hierarchies. However, there is a definition that is more relevant to complex systems:

> "a design that is characterised both by a set of core design concepts embodied in components that correspond to the major function performed by the product and by a product architecture that defines the way in which these components are integrated". (Henderson and Clark 1990, p.14)

This research is going to take this definition since it differentiates between core and peripheral components of the hierarchy, and takes into account the design architecture of the system. There seems to be a contradiction among literature reviewed for this research. On the one hand, the literature seems to indicate that the emergence of a DD will eventually happen. In the case of complex systems, the DD seems to emerge in the core technology or higher level of hierarchy. This hierarchical emergence is because of epistatic relations. Innovations are less likely to be successful since they might result in changes to the whole hierarchy. Due to the epistatic relations between the components of the hierarchy, change occurring higher up the hierarchy or closer to the core technology could affect more sublevels if the changes resulted in an unfit epistatic relation, like a domino effect. Companies might opt to undertake innovation in lower levels of the hierarchy, which might be more cost-effective than changing the core technology. On the other hand, complex systems are viewed as more customised products, hence contradicting the DD literature, which claimed the emergence of a DD as the indication of standardisation of the market. Again, for a design to be widely adopted would that not indicate, to certain extent, homogeneity of demand? This research will attempt to test the hypothesis stated in the literature reviewed that DD emergence will be an indication of the standardisation of the market.

A compilation of the research done by several authors on DD could give us the basic characteristics of the DD (Utterback and Abbernathy 1975, Henderson and Clark 1990, Anderson and Tushman 1990, Utterback 1994, Murmann and Frenken 2006).

1. DD is the best technological compromise to satisfy consumer demand. There is a clarification to make: according to the best solution, consumers, who view DD as the product that satisfies their need, choose this DD. By no means is this product the best technology, or higher quality. There are a plethora of examples where DDs have emerged which were not the most technologically advanced, or best quality; examples are VHS vs Betamax (Rosenbloom and Cusumano 1987), and even, in the case of photographic cameras, daguerreotype vs Calotype (Warren 2001). Some authors seem to argue that the emergence of DD is a socio-cultural evolutionary process (Anderson and Tushman 1990, Warren 2001), (Utterback 1994).
2. DD are widely diffused in the market.
3. DD often emerge after an era of technological discontinuity; however, not all technological discontinuities can be considered as DD.
4. DD often signifies a decrease in variety of product versions.
5. The standardisation of the market could signify economies of scale and scope for the firm, hence the benefits of finding a DD.

As illustrated before, innovation can have a competence-enhancing or -destroying effect on the product. DD emerging from competence-destroying discontinuities will be initiated by new entrants in the industry (Anderson and Tushman 1990), while DD emerging from competence-enhancing discontinuities will have been started by companies whose entrance will have been made pre-market-discontinuity (Anderson and Tushman 1990).

The ILC states that eventually a DD will emerge, and, as illustrated, some others see DD as a necessary requirement for market growth (Utterback 1994). However, there are examples where markets have not seen the emergence of a DD, like in the case of super computers and photolithographic alignments (Murmann and Frenken 2006). In some other cases, the DD seems to bifurcate during its emergence into two distinct DDs (Saviotti 1996, Windrum 2005).

This research hypothesis is that, according to ILC literature, DD will eventually emerge in order for the market to grow, but that it will mean a standardisation of the market. Therefore, it could be that if consumers agree on one design then demand can be understood as homogenous in nature. This seems to contradict both the notions in the literature – that demand is heterogeneous in nature, and that in complex systems variety is the norm (Frenken 2006). Does the dominant design really signify the loss of variety? Does the dominant design effect emerge in consumer markets such as the camera market? This debate brings out the sixth of the research questions.

Research Question 6*: does the photographic camera see the emergence of a DD?*

The DD seem to be directly related to the notion of variety of product. The literature reviewed seems to indicate that the emergence of a DD indicates a period of standardisation of products in the market, hence a drop in variety. However, the literature also seems to indicate that consumer demand tends to be heterogeneous in nature (Windrum and Birchenhall 1998). This contradiction leads this research onto further investigation for the purpose of acquiring a deeper understanding of this variety.

The first point at hand is the heterogeneity of the market. A homogeneous market could be defined as a market where demand for a product will coincide with the same product (mass market); while heterogeneous markets will be varied in terms of services desired from a product (customised products). Frenken (2006) illustrates how differences in individual reactions to the same good are seen as expressing different preferences with respect to the collection of characteristics possessed by that good and not the different perceptions of the properties of the good. This definition gives rise to a debate where people as individuals might have different reactions to the services sought or that seem to arise from a product. The rise of heterogeneity is due to the increase in disposable income, giving rise to a divergence of taste, hence increasing heterogeneity of the market (Saviotti 2001). There is another aspect to take into account with this notion of heterogeneity for technological products. Consumers might follow trends, fashions and the majority will want the technological product that is in fashion, even if that product does not satisfy their needs, or they have limited knowledge of how to make the best of the benefits of the product (Windrum and Birchenhall 1998). An example of this copying could be the popular iPhone: a section of the market might buy for the benefits offered; however, other sectors of the market might want the product just to be seen with it. In addition, if the technology is new, consumers might find little information about what extra benefits (services) could come from the product. Repeat purchases of that product might be a way to obtain that type of knowledge (Windrum and Birchenhall 1998); another source of information could be friends or family that have a particular product, therefore influencing the individual towards or away from purchasing that product.

These societal influences might lead market demand towards a more homogenous market. However, as knowledge of the product increases, consumers are able to form their own opinions and decisions, hence taking the market towards a more heterogeneous demand (Windrum and Birchenhall 1998).

A cause or effect of this heterogeneous demand is variety. Variety is defined as follows: "if an economic system is considered a set of elements then the variety of this set will increase when the number of distinguishable elements of the set increases" (Saviotti 1988, p. 91). Another definition that considers the economic system is: "variety as the number of distinguishable actors, activities and objects required to characterise an economic system" (Saviotti and Mani 1995, p.6). The last definition sees variety as "the number of variants within a specific product" (Lancaster 1999, p.189). Therefore, it could be understood that variety refers to the increasing/decreasing number of different versions to solve a technological problem. As has been seen, variety increases at the beginning of the ILC and decreases with the emergence of the DD.

Growth in variety is a necessary requirement for long-term economic development (Saviotti and Mani 1995, Nguyen, Saviotti et al. 2004). Variety could be seen as a protection of the market against market consolidation or possible death.

However, there is a limit to the variety of products which a market could offer before it stopped being profitable. The number of appropriate variants is proportional to "the degree of scale of economy, the intensity with which consumers view the differences between similar products, and the "competitiveness of the market increases the degree of product variety" (Lancaster 1999, p.193).

The definition of variety refers to the number of variants of a specific product; these variants do not only refer to similar products with different attributes or different products. There are four outcomes of variety:

1. "Product 2 (P2) completely substitutes Product 1 (P1)" (Saviotti 1988, p.100).
2. "P2 is almost identical to P1 except for a few new technologies and service characteristics" (Saviotti 1988, p.100).

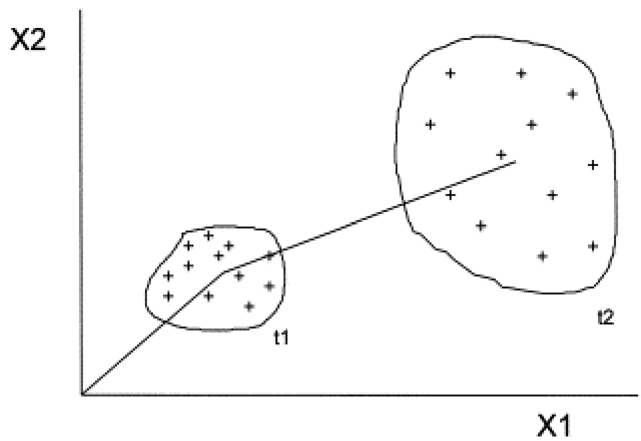
3. “P2 has a new internal structure, some services similar to P1 and some new service characteristics” (Saviotti 1988, p.100).

4. “P2 has a new internal structure, new services” (Saviotti 1988, p.100).

The first process could be understood as radical innovation, which substitutes an existing product; the new product takes leadership of the market leaving obsolete the existing product. An example of this process, for instance, could be the DVD player acquiring monopoly of the market after making the VHS player obsolete. Even though this example might take into account other elements such as network externalities, it is an easy example with which to illustrate this process (Rosenbloom and Cusumano 1987).

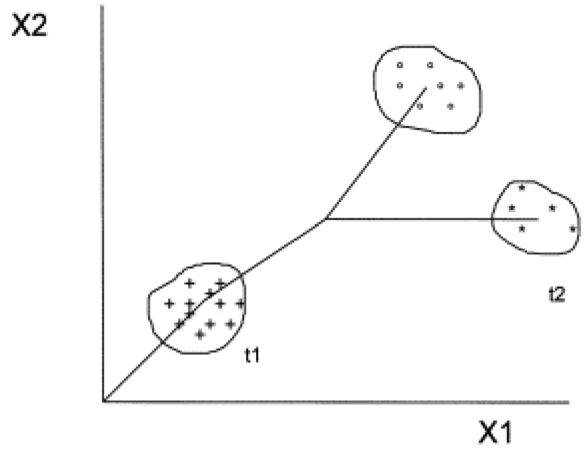
The second process is more of an incremental innovation process; the products might be similar apart from some different attributes (Figure 14).

Figure 14: Clustering of variety (Frenken, Saviotti et al. 1999)



The third process is the emergence of a second product without discontinuing the first product; this second product could be understood as a diversification of the market or market niche. When multiple designs are each adapted to cover the specific needs of the users, there could be talk of specialisation of the market (Murmann and Frenken 2006). This process offers a more customised product for the needs of different markets. This bifurcation process can be illustrated with the help of technological trajectories splitting into two (Figure 15).

Figure 15: Bifurcation of variety resulting in niche markets (Frenken, Saviotti et al. 1999)



This bifurcation might be due to the satisfaction of heterogeneous demand, or market potential. Examples of this bifurcation of the market are found by Saviotti's (1996) study of the aircraft industry (commercial, military). In addition, Windrum (2005) found that the photographic camera showed bifurcation into two distinct niches: amateur photographer and snap-shooter. Windrum and Birchenhall (1998) adds that DDs can also be found within those niches; each niche could see the emergence of a specific DD. Niche theory illustrates that the number of niches that can be created in a market is proportional to the size of the market (Henderson and Clark 2001)

The process of specialisation seems to contradict the DD theory. The emergence of the DD in the market is an indication of the standardisation of the market. On the other hand, specialisation seems to cater for specific needs of consumers, which indicates a certain level of heterogeneity in the market. Due to possible heterogeneous demand and increase of disposable income, the technological process is not rare to expect specialisation of the market (Henderson and Clark 2001). The illustration of heterogeneity demand and niche market theory seems to indicate that in markets where demand tends to be heterogeneous in demand, the dominant design seems to bifurcate into distinct niche markets in order to cover all consumer needs. Each niche market might have a distinct dominant design.

To sum up the argument concerning variety: variety has to satisfy at least one of the following requirements:

1. “Each individual consumer seeks variety in his own consumption” (Lancaster 1999, p.190).
2. “Different consumers want different variants because taste varies” (Lancaster 1999, p.190).
3. “Individual firms can increase profit by producing a variety of models” (Lancaster 1999, p.190).
4. “Firms can increase profits by differentiating their product from those of competitors” (Lancaster 1999, p.190).

This difference in taste might lead to the creation of a niche market; the reason for the bifurcation could also be found in the four requirements given by Lancaster (1999). Each niche market can have a distinct DD. This idea, again, agrees with the previous argument that product evolution is expected to see the emergence of a DD or, in the case of the bifurcation of the market, several DDs to cover specific needs. The emergent of multiple DDs will cater for heterogeneity of demand.

This argument leads this research to the second part of the sixth research question: ***Research Question 6a****: does variety in photographic cameras give rise to one DD or to the creation of different niche markets?*

2.3.4. INNOVATION PROCESS IN COMPLEX SYSTEMS:

There is a notion in the literature that complex systems innovate differently from simple systems/the classical view of innovation, and therefore existing models can't fully explain the innovation of complex systems (Murmann and Frenken 2006, Murmann and Frenken 2006).

There are several reasons why complex systems innovate differently from simple systems; however, the most important of the reasons according to the literature is the dependency between the elements of the system (epistatic relations) (Frenken 2006, Murmann and Frenken 2006, Yayavaram and Ahuja 2008, Zhang and Gao 2010).

Frenken (2006) illustrates that the epistatic relations between the elements of the system limit the ability of complex systems to evolve normally. Zhang and Gao (2010) explain that independences play a very important role in the performance of the system, especially in the dissemination, generation or modification of incremental innovation. Incremental innovation is characterised by cumulative learning and trial and error, and dependencies between the technological elements hinder the possibility of innovation by trial and error due to the risk of unpredictable effects on other elements in the system (Zhang and Gao 2010). Innovation in complex systems has to be a more systematic, exhaustive, ad hoc process. Error in the fitness of the product can be fatal for the provision of the function. That is the main reason why professional R&D labs with scientific bases usually undertake innovations in complex technologies, whereas individual inventors can develop simple systems. For innovations in complex systems to be successful, organisations have to have a complete and in-depth knowledge of the system components at fitness levels (Murmann and Frenken 2006). Kauffman (1993) illustrates that dependencies might also limit the transfer of a technological breakthrough in one module and hinder the implementation in the whole system. The degree and number of independencies will constrain the successful implementation of innovation activities. The higher the number and strength of dependency between components or subsystems, the more difficult it will be and the longer it will take to develop any innovation process, whether incremental or radical. Yayavaram and Ahuja (2008) explain that complex systems become progressively more difficult to improve upon as the number of interdependences increases. The probability of success of innovation in high interdependency systems is directly related to the parts or dimensions that are changing simultaneously (Murmann and Frenken 2006). There is evidence in the literature that illustrates that modular products, due to their formation of quasi-independent modules, actually increase the speed and facilitate the implementation of incremental innovation. This research hypothesises that the location of the independences between the elements also affects the way in which the product innovates.

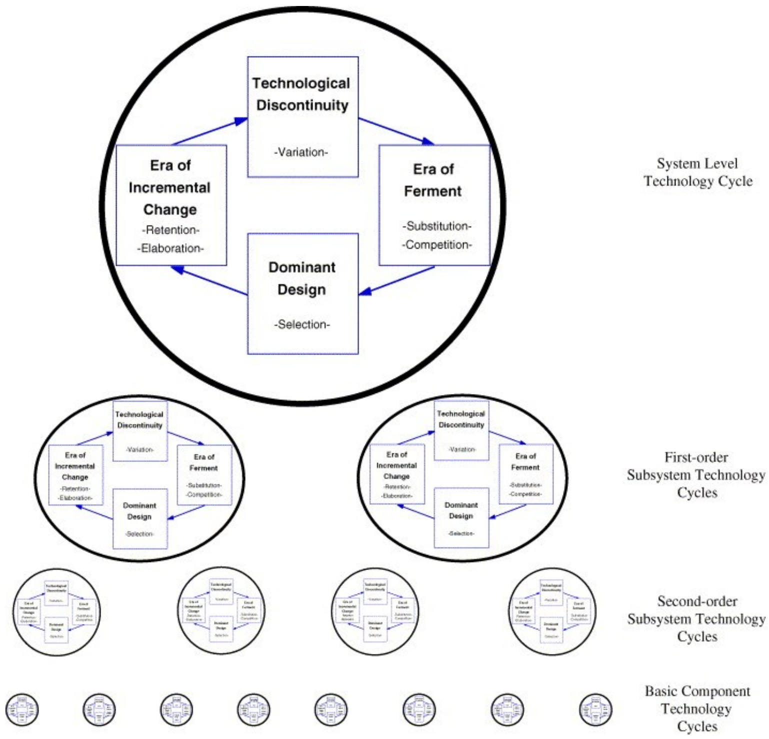
Another factor that limits complex systems from evolving like simple systems is their characteristic hierarchical structure. Interdependence between the elements of the systems might limit implementation of innovation since changes might have an effect (negative, positive or unrelated) in other elements of the system, but elements in complex systems have a hierarchical structure of order. This formation means that where the innovation is located (high or low in the hierarchy) might have an effect on the basic component level (lower hierarchy) or the whole hierarchy (higher in the hierarchy). Funk (2009) illustrates that

> "As we move further down the hierarchy of subsystems the relationship between the top level systems and the lower level components becomes more complex and intractable, hence as we move further down the nested hierarchy of subsystems, the importance of science grows". (Funk 2009, p.28)

This is due to the interdependencies within components and within subsystems. The further we go down the hierarchy the more subsystems and subsystem components are involved (Figure 16), hence the need for in-depth knowledge of the inner workings of the system. Simple systems, on the other hand, since they do not show significant dependencies between elements, are easier for independent inventors to market.

Innovation in core subsystems (top of the hierarchy) will have a wider effect on the hierarchy than innovation in peripheral subsystems (Tushman and Murmann 1998). Innovation in core subsystems will have a cascade effect on the whole hierarchy while changes at the periphery will have a minor effect on the hierarchy (Figure 16). Innovation attempted in core technological elements will be very risky with a very low level of success (Frenken 2006). This can be a potential reason for a dominant DD to emerge in the core technology of a complex system.

Figure 16: Innovation in complex systems (Frenken 2006)



This research is going to take a special interest in the investigation of the DD. DD, in the classical view of innovation, usually means the standardisation of the market, whereby companies will copy the DD or they will be forced to exit the market. There are several debatable arguments that seem to contradict complex systems theory. Firstly, standardisation of the market, or homogeneous demand, seems to contradict complex systems theory, which suggests that in complex systems variety is the norm (Frenken 2006). Secondly, the suggestion of firms copying the DD contradicts complex systems theory that warns against copying as a very risky if not impossible strategy for complex systems. For a company to copy a product (complex systems) they will have to copy exactly not only the whole hierarchy but also the clustering patterns and epistatic relations that come with it.

There are several arguments as to what is considered a DD in complex systems. Some authors support the view of DD occurring at the subsystem level and linking elements of the hierarchy (Tushman and Murmann 1998). Others view DD as the standardisation of high pleiotropy elements of the hierarchy, hence the higher subsystems in the hierarchy (Frenken, Marengo et al. 1998). Once the core technology has emerged, as DD innovation will focus on incremental changes on the lower peripheral elements of the hierarchy. This process, to certain extent, resembles the classical view of innovation. Simon (1939) makes an analogy of the “boss” (core elements, or DD) and “subsidiaries” (peripheral systems), each system containing a boss (DD) and subsidiaries (Simon 1962, Frenken 2006, Murmann and Frenken 2006) (Figure 16).

Some ways of innovating complex systems are: improving existing elements (incremental innovation), introducing new elements, and technological breakthrough (radical innovation). A further innovation approached covered in this research is architectural innovation. The literature shows that most technological innovation comes from the recombination of existing technologies (architectural innovation) (Yayavaram and Ahuja

2008). Frenken (2006) calls this combination of existing technologies in complex systems the combinatorial problem. The problem in complex systems is that the number of combinations increases exponentially with the increase in number of elements in the system, and with the number of elements in the system the number of possible epistatic relations also increases and hence there is also a possible increase in complexity (Frenken 2006, Reinstaller 2007, Yayavaram and Ahuja 2008). Frenken (2006) explains that each product is composed of a certain number of components, with each component having a distinct number of possible mutations. Simon (1969) illustrates this design space with a clear example of a lock with ten dials and each dial having 100 possible settings. In the case of the lock example, the number of possible combinations is $100^{10} S = A_1.A_2. \cdots . A_N = \prod_{n=1}^{N} A_n$ (Formula 4).

$$S = A_1.A_2. \cdots . A_N = \prod_{n=1}^{N} A_n \text{ (Formula 4) (Frenken 2006)}$$

Where A_N stands for the number of possible states of elements n and S is the size the design space. In Simon's example N=10 and $A_N = 100$ for each N

Again, complex systems face two main problems. Independences between elements might hinder the fitness of any possible combinations, so the higher the degree of dependency of the elements the more difficult it will become to achieve fitness. On the other hand, even if designers achieve fitness within any of the subsystems of the hierarchy. Still, this combination might have an effect on other subsystems of the hierarchy if the elements of this particular subsystem display any epistatic relation with any other element in the other subsystem of the hierarchy. This might ameliorate with a modular structure however still caution is on hand since the literature warns that modules are not perfectly independent and effects might occur in other parts of the hierarchy and, the more elements there are, the more combinatory problems and possible epistatic relations there will be (Yayavaram and Ahuja 2008, Zhang and Gao 2010).

Complex systems face crucial problems, such as which elements to change and when to change them. With Complexity increases, achieving the right balance between what to change and determine the new state of the organisation technology became increasable more difficult (Strumsky and Lobo 2002). Schwoon (2008) illustrates that the path followed is dictated by the alternatives that are preferred at that moment; however, due to the path's dependent and irreversible nature those actions might cut off possible alternatives that could be more favourable in the future.

The decision of which innovation to undertake is further hindered by the maladaptiveness and self-organised nature of complex systems, which might lead to an irreversible and path-dependent direction. Wrong or careless innovation might lead a firm to irreversible undesirable strategic directions (Foster 2005). As opposed to simple systems, trial and error strategies to test the possible state of the different innovation possibilities are very limited in complex systems (Strumsky and Lobo 2002, Frenken 2006, Zhang and Gao 2010). Epistatic relations and fitness between the components of the subsystems trigger this path-dependent direction. The reduced number of possible combinations hinders innovations or recombination strategies. In spite of the path dependency that complex systems seem to take, the direction still seems to remain uncertain due to their unpredictability and self-organisation and the effect on the systems of any innovation activity.

The illustration of the innovation process of complex systems provides a compilation of the stylised facts for the innovation life cycle in complex systems.

1. The foremost crucial element in complex systems is the epistatic relations between the elements. This dependency between the elements means that any action on any element of the systems might have a consequence (positive, negative, or unrelated) on any other element that is epistatically related. Epistatic relations might hinder complex systems in

their ability to innovate, as proposed by the classical view of innovation; also trial and error strategies for innovation are not feasible in complex systems. The dependence between the elements of the systems is also the main feature that differentiates complex from simple systems. Complexity is measured by the strength of the epistatic relations: the stronger the dependency between the elements, the higher the complexity of the elements.

2. Another characteristic of complex systems that separates them from simple systems is the hierarchical formation of the elements of the system. In nested hierarchies of complex systems, elements seem to cluster in a synergistic manner in order to offer an enhanced service. In complex systems, as opposed to simple systems, the whole is more than the sum of the parts. The nested hierarchy takes a shape such that there is a core technology at the top of the hierarchy followed by different sub layers of clustered subunits until it reaches the component level. Innovation in complex systems due to this hierarchical formation and the epistatic relations might have a cascade effect the higher up the hierarchy one goes.

3. Higher complexity leads to greater hierarchy.

4. Magnitude and number of epistatic relations vary between subsystems and within different subsystems; not all elements in one hierarchy necessarily show the same level of dependency between the elements.

5. The location, strength and number of epistatic relations determine the innovation activities possible. While modular products seem to benefit incremental innovation, the localisation of the epistatic relations hinders possible global optima.

6. The higher the level of complexity of the system the more complicated it will be to develop innovation strategies.

7. The higher up the hierarchy one goes the more difficult/effective it will be to develop innovation activities. Since innovation activities due to epistatics might trigger a

cascade effect in the entire hierarchy, innovation in high layers of the hierarchy might make changes in more elements than if innovation activities were developed in lower layers of hierarchy, hence the DD emerges in the core of the hierarchy.

8. The DD in complex systems refers to the core elements of the hierarchy (higher-level subsystem of the hierarchy); once a DD emerges, innovation will focus on the peripheral elements or lower-level subsystem in the hierarchy.

9. Each subsystem could show distinct technological cycles and emergence of DDs.

10. Complex systems seem to follow a path-dependent innovation pattern due to the maladaptiveness of some innovations in the system. Innovation actions in the present might hinder possible desirable directions in the future due to the irreversibility of complex systems.

The following table shows a summary of the differences between traditional views of innovation and the innovation in complex systems (Table 1).

Table 1: Complex vs. traditional innovation life cycles

Stylized Facts	Traditional ILC	Complex systems ILC
1	Innovation starts with an increase of variety, focus on product innovation. Trial and error of different technological solutions to solve a technological problem (consumer needs).	Complex systems due to epistatic relations are limited to the possible designs offered to the consumer. Trial and error not possible.
2	Variety, after reaching a peak, will fall, resulting in the emergence of a dominant design and standardization of the market.	Dominant design in complex systems refers to the core technology. Innovation, both radical and incremental, is still active in the sub layers of subsystems; however, each cluster might show signs of having its own DD.
3	Once the dominant design emerges, the focus of the innovation efforts will smoothly change direction towards process innovation. Product will only show incremental innovation.	Once the market sees the emergence of a DD in the core technology innovation efforts will focus on the peripheral elements of the systems in order to enhance the performance of the core technology. The different subsystems might show radical, incremental and even their own dominant designs for particular subsystems. Radical innovations are rarely found in core technologies due to the restriction of the epistatic relations and the results that these changes might cause in the rest of the hierarchy. Innovation might take the shape of recombination of existing technological elements to achieve a better fitness.

Literature on innovation in complex systems and the comparison to the classical view seems to indicate that complex systems have a distinct pattern of innovation, which also differentiates complex from simple systems. The literature on the pattern of innovation of complex systems forms the basis for the next research question.

***Research Question** 7: Can the stylised facts of the innovation life cycle process on complex systems be applied to the case of photographic cameras?*

The investigation of both classical view of innovation (ILC) and complex systems innovation gave very distinct pattern of innovation. However there is the common theme of the DD this phenomenon since to rise in different manner; DD as a whole product in the ILC, as opposed to the core technology DD follow by the rise of the possible DD in the periphery elements. The reason for this distinct ILC seems to be rotted on the epistatic relation and nested hierarchy that characterised complex systems. These findings raise the relevance of the identification of the epistatic relation and nested hierarchy that could hinder that systems innovation. It is critical the identification of cameras epistatic relation and nested hierarchy in order to offer some light over the suggestion that complex systems innovation differently. The combination of the investigation of all research questions above mentioned (research question 1-7) forms the bases to main research question for this research.

***Research Question 8:** do complex systems innovate differently?*

2.4. CONCLUSIONS:

This research was triggered by the notion in the literature that complex systems innovate differently. The investigation of this notion gave rise to the following structure of the research.

Firstly, this research investigated the literature on complex systems for the identification of a workable definition for technological products. The identification of a clear definition could give a basis or specification in order to test and identify cameras as complex or simple systems.

The literature review on complex theory started with the works of Simon (1962, 1969), pioneer of complex system theory and evolution. Simon (1962, 1969) explains that complex systems are products, which comprise a large number of components that interact in a non-simplistic way. Components of a complex systems show an interdependence relation (epistatic relation) by which changes in one component might results in changes in other components in the system. The level of dependency of the elements of the system measures the complexity of the product (Frenken 2006). The literature review seems to indicate that the dependency between elements in complex systems is not only the most complicated element of complex systems but also one of the elements that separate complex from simple systems. This differentiation gave rise to the first research question:

Research Question 1*: do the technological elements in cameras display indications of epistatic relations?*

Further investigation of the definition of complex systems found that the elements in complex systems also clustered in a synergistic manner in order to offer an enhanced service. In complex systems, the whole is more than the sum of the parts. This clustering of elements seems to take a nested hierarchical formation, where elements cluster in hierarchical subunits until the elementary component level is reached (Simon 1968) (Figure 1).

In the first part of this research, it was found that complex system elements seem to show dependency between the elements of the system; on further investigation of complex systems it was found that these elements seem to be organised into a nested hierarchy formation. The literature review shows that these epistatic relations can be found anywhere in the system and this strength can vary within subsystems and across subsystems.

Complex systems can be classified according to the strength of the epistatic relations into "loosely coupled" or "tightly coupled" (Sanchez and Mahoney, 1996). A further classification divides complex systems by the strength of the relations and the number of elements that show epistatic relations in the systems into: fully integrated complex system (all elements, to different degree of independences, show epistatic relations), fully disintegrated (no elements seem to show any epistatic relations) and near decomposable complex syste (elements show weak epistatic relations but still negligible) and modular complex system. Fully integrated and fully disintegrated are very rarely found; systems where some of the elements show epistatic relations between the elements are more common (Schilling 2000).

This research found that their epistatic relations do not only define complex systems but also by their hierarchical formation, hence the need of a classification that took both terms into account. This research found that complex systems could be classified, according to the location of the epistatic relations and the strength of these relations, into modular or near-decomposable systems. This classification of systems into modular or near-decomposable systems also seems to be suggested as a model to help manage complexity.

On the one hand, near decomposable complexity approach suggests helping manage complexity since this model's principle is to decompose problems into more small manageable problems. By identifying the elements in the systems that show most independent relations, firms can localise and optimise problem-solving (Simon 1962, Geisendorf 2009) (**Error! Reference source not found.**). This model has to be used with caution, even though dissecting problems into small, more manageable problems will help to map optimisation strategies; dependencies, even though weak, are still negligible, therefore any innovation action in any of the systems might still affect the rest of the hierarchy. There is a need for an exhaustive and in-depth knowledge of the interdependencies of the elements of the systems and clustering patterns of the hierarchy for any innovation activity to be successful. Near decomposable complexity offers the possibility of having that in-depth knowledge.

Some authors suggest modular complexity as a model distinct from near decomposable complexity (Frenken 2006); on the other hand, some other authors suggest that modularity originates from the idea of near decomposable complex systems (Gao and Zhang 2008, Zhang 2010). In essence, modularity clusters elements into units where the unit seems to be independent or the dependency with the other units in the systems are very low (Figure 3). By coupling elements into units that seem to be independent with the other units in the systems, customers can mix and match the components of the system (Langlois and Robertson 1992). This model not only offers the benefits of near-decomposability but also offers the extra benefit of being able to cater for heterogeneous demand. There are several dangers with this model. The first concerns the identification of the number of modules to offer within a product. There is a boundary where the number of modules stops being an opportunity and starts being an unnecessary financial cost and resource. Another important factor is that, even though consumers can mix and match components (e.g. lenses in a camera), there is still a relationship between components. Modular complex systems also favours incremental innovation since there innovation activities could be manage between the modules without the need for coordination among them, or in other words innovation activities can be done independently from other units. Since units in modular complex systems are seemly independent innovation action in one unit or module would not affect the performance of the other units in the system. In addition, experimentation, or trial and error, is possible in these units as opposed to near decomposable complex systems (Brusoni, 2007, Zhang 2010). In spite of the benefit of increased speed of incremental innovation, the literature seems to show that modular complex systems cannot achieve the global optimum because the localisation of innovation of distinct units limits the transfer to the whole system and results in a lock-in of the innovation activities in that particular unit. The global optimum can only be achieved with the change of architecture possible in near decomposable complex systems (Brusoni 2007).

The literature review of complex systems theory found that complex systems not only show epistatic relations but these epistatic relations are structured in a hierarchical shape. This finding forms the basis of the second research question.

Research Question 2*: do technological elements in cameras cluster in a hierarchical structure?*

This research found that the most problematic issues in complex systems are not only the existence of epistatic relations between elements of the system but also the clear identification of the location of those epistatic relations.

There are several models that help to map complex systems to manage complexity. Kauffman (1993) suggested the NK model. The NK model (Waters 2008) shows the fitness of the components via "fitness landscapes"; this model is useful to manage complexity because it shows the fitness level within the elements. Therefore, this model could help the indication of whether changes in particular elements will fit in the total hierarchy. This model, however, does not provide a clear measurement of complexity, because it does not noticeably show the relationships between elements; rather, it maps the elements that will be most efficient for optimisation.

The generalised NK model (Altenberg 1995, Altenberg 1996) developed as a solution to the original NK (Kauffman 1993). The essential difference from the original NK (Kauffman 1993) model is that the K parameter is substituted by the function (f) parameter. This model covers the characteristic synergy of complex systems, thanks to the inclusion of the parameter F. This model illustrates the clustering of technology in order to provide a service.

The other model that illustrates this clustering is the twin characteristics model (Saviotti and Metcalfe 1984). This model bases its mapping on Lancaster's characteristics approach (Lancaster 1966), and Dosi's technological paradigm (Dosi 1982). This model covers both the supply and demand side of demand.

The twin characteristics approach illustrates a mapping of products as the clustering of technological elements to offer an enhanced service. This model has been widely used in the literature to show clustering patterns of technologies (Frenken, Nuvolary 2004, Murmann, Freken 2006). It is also a clear indicator of incremental and radical innovation (Metcalfe and Saviotti 1984). This research will use this model in order to help with the definition of the photographic camera.

This research so far found that the epistatic relations between the elements of the system and the hierarchical formation of those elements define complex systems. Epistatic relations between elements can vary in strength and number; according to the number, strength and location of those epistatic relations, complex systems can be fully integrated complex system, fully disintegrated system, near decomposable complex system and modular complex system. This research, after obtaining this information from the literature, furthered the research to find a definition of simple systems. Having both definitions of simple and complex systems could bring more clarity to the identification of cameras as simple or complex systems. The literature review on complex systems found that the main difference between complex and simple systems is the epistatic relations (simple systems do not show indication of any interdependence between the elements of the system) and hierarchical formation (only characteristic of complex systems). This research suggests, then, in the light of the definition of simple systems, that the acceptance or rejection of Research Questions 1 and 2 could shed light on the identification of cameras as complex systems. The study of the definition of simple and complex systems gave a basis for the formation of Research Question 3.

Research Question 3*: Can cameras be considered complex systems?*

Once this research reached a workable definition of the characteristics of complex and simple systems, the next step was the investigation of whether complex systems innovate differently from the classical view of innovation/simple systems. The research set out the investigation of both models of innovation life cycles (simple/complex systems) in order to find the distinct characteristics of each model and compare them to the innovation of the example case for this study: cameras.

Initial investigation revealed a plethora of literature on innovation process, strategies, and approaches; this research then investigated the theories that could be more applicable to the case of complex systems.

Firstly, this research focused its attention on incremental and radical innovation. These innovation activities would either make improvements or change the elements in a product. The literature on complex systems seems to indicate that changes in any of the elements in the product might affect or trigger changes in other elements of the systems; by including two approaches this research could test for possible changes in clustering patterns of the elements due to innovation activities.

This research also found that a source of innovation is the recombination or re-clustering of the existing technologies in complex systems. This is what Henderson Clark (1990) called "architectural innovation". Frenken (2006) called architectural innovation in the case of complex systems “technological architecture”. This model of innovation is characterised by changes in the way technological elements linkages/cluster of, leaving the elements of the system untouched.

In complex systems, this technological architecture change can be triggered by the ill fitness of a changing element. Innovation in one of the elements of a cluster means these new elements might not fit with the rest of the elements; the self-organising nature of complex systems might move this element to another cluster with higher fitness value.

Metcalfe and Saviotti (1984) also suggest that the way elements cluster might change over time. This research takes advantage of the fact that the length of time that this research covers could help the investigation of possible changes in clustering patterns due to innovation activities or just architectural innovation. The identification of the innovation approaches that could affect complex systems gave rise to Research Question 4.

Research Question 4*: does the clustering of technologies change over time due to innovation activities?*

Once this research had established the definitions of complex systems and innovation approaches that could affect complex systems, it was ready to investigate innovation patterns. The definition of innovation taken by this study is the iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to the production, development and striving for success of the invention (Saviotti 1986). The important point here is that for an invention to become an innovation it has to show diffusion and market success. The definition taken by this research also adds the fact that innovation can be an iterative process. There are a plethora of innovation approaches and processes; however, this research in the light of simplification is only going to take the notions that are more relevant to complex systems. These innovation processes are incremental, radical and architectural innovation. Incremental and radical innovations indicate a magnitude innovation (minor and major or radical changes) in complex systems. Architectural innovation involves innovation in the way technology clusters.

After considering the definition of innovation processes, this research reviewed classical views of the innovation process to have a base to compare to those patterns suggested for complex systems innovation life patters. Again, as in the case of the complex systems investigation, in order to investigate whether complex systems innovate differently, this research wanted to have something to compare against in order to identify the possible differences.

This research offers the view of the innovation life cycle (Abernathy and Utterback 1975), which shows a predictable pattern of rise of variety offer by firms as possible technological solutions followed by consumers choosing the "best technological solution"; this results in a standardisation of the market and emergence of a dominant design. This "best technological solution" is purely chosen by consumer taste of demand does not necessarily mean to be the best or more advance technology or the best quality product. The innovation attention then shifts from product to process. There are different views about this model: some authors support this innovation process; other authors disagree on the grounds that it is only applicable to the mass market where demand is homogeneous.

This research has also taken into consideration other models of the innovation life cycle which also take into account the possibility of innovation being an iterative process (Nelson and Winter 1977, Abernathy and Utterback 1978, Sahal 1981, Dosi 1982, Foster 1986).

The illustration of this classical view gave rise to the fifth research question.

***Research Question 5**: can the ILC be applied to photographic cameras?*

The contradiction between the dominant design phenomenon and the heterogeneous nature of the market allowed this research to gain further understanding of the DD phenomenon and variety in the market. The DD phenomenon is widely documented in the literature (Utterback and Abernathy 1975, Henderson and Clark 1990, Anderson and Tushman 1991, Murmann and Frenken 2006, among other authors). There seems to be an agreement that DD is the best technological compromise that then forces companies to copy that design. The fact that the DD emergence seems to lead companies to offer that same product seems to indicate some kind of homogeneity of the market. On the other hand, there seems to be evidence in the literature that demand takes on a more heterogeneous nature (Windrum, Birchenhall 1998). Frenken, Saviotti and Trommeter (1999) suggest that DD could bifurcate into two or more distinct niches in order to cope with the heterogeneity of the market.

The discussion and contradiction between DD and variety in the market lead to the formation of the next set of research questions.

***Research Question 6**: does the photographic camera see the emergence of a DD?*

***Research Question 6a:** Does variety in photographic cameras give rise to one DD or to the creation of different niche markets?*

The last part of this research will investigate the notion that complex systems innovate differently. Literature gives several reasons why complex systems innovate differently, such as their nested hierarchical structure and independency patterns (Frenken, 2006). In complex systems there is also evidence in the literature that a DD emergences, however instead of referring to the whole of the product in complex systems refers to the core technology. The standardisation of the core technology seems to indicate the stabilisation of the market (single-reflex lenses in photographic cameras in 1861) (Coe, 1978). The standardisation of this part might be due to the hierarchical structure; changes in core technologies will cascade changes in the entire hierarchy. Changes after the standardisation of the core technologies seem to shift to the peripheral elements. This innovation, to a certain extent, resembles the classical view of the innovation process. However, there does not seem to be any empirical evidence that complex systems' innovation patterns have been tested against the classical view. This notion will make this research novel and cover a gap in the literature. The illustration of the stylised facts on complex systems innovation and the possible application to cameras give rise to the next research question and next steps on the investigation of whether complex systems innovate differently.

Research Question 7: *Can the stylised facts of the innovation life cycle process on complex systems be applied to the case of photographic cameras?*

The investigation of the innovation patterns displayed by cameras and the comparison to both the classical view and complex systems innovation will help this research to shed some light on whether complex systems innovate differently, as suggested by the literature. The analysis of the innovation pattern displayed by cameras, the comparison to the stylised facts for both complex (Hobday 1989, Freken 2006, Yayavaram 2008, Funk 2009, Zhang 2010) and classical view of innovation (Nelson and Winter 1977, Abernathy and Utterback 1978, Sahal 1981, Dosi 1982, Foster 1986) could shed some light on the notion that complex systems innovate differently. This innovation model of complex systems could help managers with more effective marketing and design decisions and activities. The main research question for this research was formulated as followed:

Research Question 8: *do complex systems innovate differently?*

CHAPTER 3: CAMERAS AS AN EXAMPLE STUDY

3.1. INTRODUCTION:

This chapter is dedicated to the investigation of photographic cameras, from the history of photographic cameras to the outline of the main innovation occurring in this market. This research is concerned with the investigation of the innovation patterns displayed by cameras. Previous chapters also raised the importance of knowing the inner workings of complex systems, since innovation in one of the elements could not only result in changes in other elements of the systems but also the way elements related (clustering pattern). The investigation of the main innovation in the camera market will be carried out in the light of the identification of those main innovations so that this research can focus on those innovations for their possible effect on the clustering pattern of the cameras.

This chapter starts with a brief illustration on how photographic cameras emerged in the market. The history of the camera in itself is very interesting because from the early emergence of cameras there are possible signs of dominant designs and the hypothetical influence that demand could have on these particular cameras becoming the dominant design in the market. One of the aims of this research is to investigate the innovation life cycle displayed by cameras and the possible application of the classical view of innovation or complex systems innovation models. This illustration of the historical background of how cameras emerged gives this research useful background information on how cameras evolved.

The second part of this chapter is going to outline the different types of core technologies that cameras have had since 1955. This research pursued this illustration of the cameras not only to give the reader a clearer idea of the cameras analysis results in later chapters but also because the aim of this illustration is to help this research with the sampling of markets for later analysis. This research is concerned with the investigation of the innovation life cycle. There are several points that this research should highlight. Firstly, complex systems innovation theory suggests that dominant design in complex systems occurs in the core technology elements; the identification of those core technologies in this chapter will help this research to identify the possible application of those innovation theories to the camera market. Secondly, the classical view suggests that variety at the beginning of the life cycle increases until it reaches a peak and this variety decreases with the emergence of a dominant design; the examination of camera type will help this research to test those theories in the camera market.

Investigation of complex systems theory gave rise to the notion of the clustering of elements in complex systems in order to supply a service (function). This research is going to investigate the inner workings of cameras in the light of the identification of the possible relations suggested in the literature that could offer enhanced quality of picture. This research is going to use this investigation not only to test those possible relationships in the camera market – it is also going to use this suggested association to help with the sampling of the technological elements that will be part of the analysis of the camera clustering in order to supply a service.

After studying the different types of core technologies and technological characteristics that will play a part in the provision of the service characteristics of photographic cameras (enhanced quality of the picture), this chapter will illustrate the main innovations that this market has seen since 1955. The photographic camera market has a very rich history of incremental and radical innovation: periods of high variety followed by a drop in variety with possible emergence of a dominant design followed by possible bifurcation into different niche markets.

This research is concerned with the innovation of complex systems; investigation of complex systems suggested that complex systems are composed of nested hierarchical clustering of elements, which display a certain level of dependency of elements. Another element of complex systems is that they innovate differently. Cameras offer technological elements, which, according to the literature, offer some kind of association pattern. Also, the camera market at first sight offers a rich background of innovations, both incremental and radical. There is also an empirical study in the literature that seems to suggest that cameras do not follow the innovation life patterns suggested by the classical view of innovation (Windrum 2005). These factors combined make them the perfect candidate for the testing of complexity and innovation in complexity theory.

3.2. HISTORY OF THE PHOTOGRAPHIC CAMERA

Trying to illustrate all the innovation in the photographic camera since 1800 would take too long for this research; however, this section is going to attempt a very short and concise summary of the history of the photographic camera to give the reader an idea of the different innovations that have come into being in the camera industry. This short illustration is obtained by the compilation of information found on different technological photography literature (Coe 1978, Warren 2001). (For a listing of major innovations and launches in connection with the photographic camera, see the chronological list in Appendix C).

The first camera reported in the history is the camera obscura. Johann Heinrich Schulze, who in 1725 discovered that certain silver salts darkened when exposed to light, made the first discovery. Nobody really investigated the properties of these silver salts until

1800, when Thomas Wedgwood and his friend Sir Humphry Davy produced some temporary pictures in white leather treated with silver nitrate. These images, however, disappeared when in contact with light.

The first permanent picture came in 1826 when Niepce turned to a different process using pewter plates coated with bitumen of Judea, an asphaltic varnish that hardens on exposure to light. Initially the process of developing these pictures started by exposing these plates to sunlight with an oil etching on paper, washing them with lavender oil after exposure to remove the unhardened part of the image. These photographs were firstly called "heliographs", from the Greek "sun writing". The exposure for these pictures was eight hours! In addition, they could only represent dark and light, not colour, and they were one-of-a-kind pictures.

At around the same time, in France, Louis Jacques Daguerre was testing photographic processes. In 1839, he made public the daguerreotype. He used a copper sheet plated with silver which was polished and fumed with iodine vapour, producing light-sensitive silver iodine on the surface; after exposure the plate was treated with fumes of mercury, which produced a stronger, more visible image, and then washed with salt water.

At this time, 1839, in England William Henry Fox Talbot presented to the Royal Society and the Royal Institute the calotype. The calotype was a paper sensitised with silver chloride. This sensitised paper was exposed to an image in a camera and then fixed with salt water. The negative image was converted by placing it in contact with a second piece of paper. This process improved on the one-of-a-kind picture produced by the daguerreotype.

Even though this type allows for multiple pictures, with one even being used in the first book of photography *The Pencil of Nature*, this type was not as popular as the daguerreotype. This is very interesting since it shows early signs of demand choosing a product not by the technology quality (advantage of being printed on paper) but for the superior quality of the picture.

In 1851, Frederick Scott Archer discovered collodion wet plates. For the purposes of photography, the collodion was mixed with potassium iodide and applied to the glass plate. The plate was sensitised by dipping it in silver nitrate, forming silver iodine. The results were excellent and offered the benefit of several prints; the end of the 1850s seldom used the daguerreotype.

Even though the quality and reproduction were excellent, this type had the disadvantage that, since the picture had to develop while wet, the photographer had to carry a complete dark room with them.

Further development of the cameras resulted in dry gelatine emulsion; this had the advantages and qualities of the wet plates but a photographer could take the picture to develop in the factory. The next step in the revolution of the photograph was substituting the fragile glass plates with a lightweight material. George Eastman was the first to invent the flexible film base, giving rise to the roll film camera by Kodak in 1888. This camera was also easy enough for the public to use. The Kodak motto was "you push the button, we do the rest". This gave rise to commercial photography and the early indications of the snapshot market.

The transition from wet to dry gelatine and then film are the most important innovations in photography (Acton and Miller 2009).

An interesting fact is that photography came about because the only available way to immortalise a picture in those times had been paintings (portraits and so on). Due to their high cost, paintings were only available to the well off in society. Photography was more affordable for a wider group of people. However, after the emergence of photography, paintings were rarely used any more (Coe 1978). This is interesting since it seems like photography was substituted for painting, as we have seen in the literature – one product substituting for another due to higher quality, better price and so on.

Before World War II, there were competing versions of cameras such as box cameras, folding cameras and viewfinders. Viewfinders were found to be the DD of the market in the 1930s. However, after WWII this DD seems to have been replaced by two other radically new designs: the SLR and 126 compact cameras. SLR cameras appear to have remained the DD to this day (Windrum 2005).

Photography saw an important innovation in 1994 with the introduction of the first digital camera. Digital technology involves change-couple devices (CCDs) that convert light images into binary data and offer the potential for dramatic price/performance improvements over film technology (Sekaran and Bougie 2010). These first digital cameras were too expensive to be a threat for the film cameras; however, process innovation made these cameras more affordable by 1997 when customers moved to digital cameras, leaving film cameras obsolete.

The types of cameras that used this digitalisation of image were the same SLR and compact cameras that emerged as DD after WWII.

(See appendix C for a detail chronological listing of the main innovation in photographic cameras)

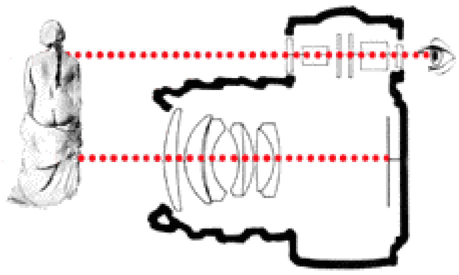
3.3. TYPES OF CAMERAS (CORE TECHNOLOGY)

This research categorises cameras according to their core technology, or main technology, of the camera itself – or in other words, what makes the camera work. In the camera industry case, this mirror system captures the image. This research shows as complementary technology or the technological elements that aid and enhance the functioning of the core technology, as the namely shutter speed, exposure and metering systems, lens and flash. This categorisation is made in the light of the investigation of the emergence of dominant design in the classical view and the notion of the emergence of dominant design in core technologies in the complex systems theories.

The process of making the photograph has two stages – releasing the shutter to let light in through the lens and this being reflected into the light-sensitive film (35mm cameras) by the mirrors in the camera (Jervis 1990). This mirroring system of the image is used in this research to categorise the cameras into viewfinder/rangefinder, single lenses reflex, and twin lens reflex cameras.

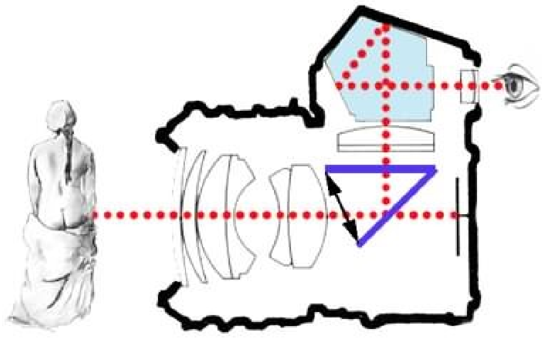
- **Viewfinder/rangefinder camera:** in this camera, viewing is done through an eyepiece with its own simple lens. Since the viewfinder is not in the same position as the camera lens, this shows a slightly different view. This slight difference is called parallax error (Warren 2001) (Figure 17).

Figure 17: Viewfinder camera (Ellis 1999)



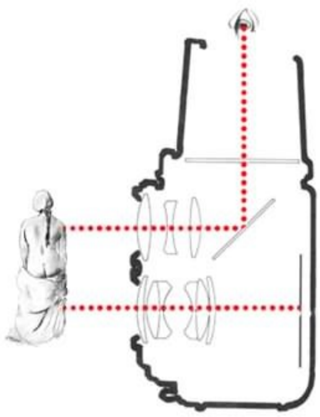
- **Single-reflex lenses:** the image from the lens is detected to a glass by a mirror, which swings out of the way when the shutter release is operated. The image on the mirror is then reversed right to left. The use of a pentaprism in the top of the camera allows display of the correct orientation of the image (Warren 2001) (Figure 18). This SLR allows photographers to view the actual images as they will be printed on film. No parallax error.

Figure 18: SLR camera (Ellis 1999)



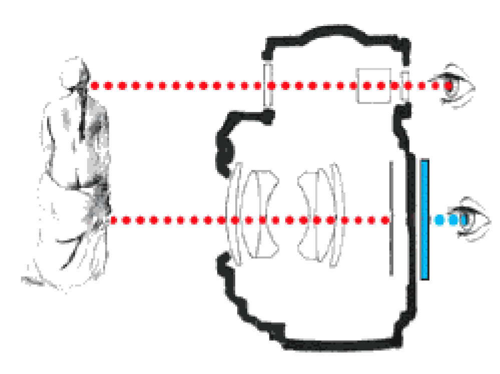
- **Twin lens reflex camera:** this cameras uses two identical lenses; one forms the image in the film and the other is defected by a mirror onto a ground glass for viewing and is reversed left to right (Warren 2001) (Figure 19).

Figure 19: Twin-reflex camera (Ellis 1999)



- **Digital cameras:** uses the same process as the cameras above illustrated where the mirrors detect the image and then expose on film but instead of the tradicional silver hadise film the image is capture by a block array Charge Couple Devise (CCD) or Complementary Metal Oxide Semiconductor (CMOS) sensor (Figure 20) (Ellis 1999).

Figure 20: Digital Camera (Ellis 1999)



The cameras included in this research according to their core technology are as follows.

3.3.1. ROLL FILM

The roll film camera was first introduced in 1880; however, it was not until 1885 that George Eastman really established this type of camera in the market (White 1986). These cameras are based on Fox Talbot's idea of putting pictures on paper, which later was in rolls rather than separate pieces of paper (White 1986).

There are different types of roll film cameras: box roll film and folding roll film. The idea of the box cameras was a box with inbuilt roll film, enough for a hundred exposures, and very simple controls. George Eastman named this camera in a way that could sound more or less the same in most countries; the name chosen was Kodak. The idea of this camera was that when the roll film was finished consumers would send the camera away and would then receive the camera with the pictures developed and camera loaded again. This camera was very popular due to its ease of use but it became even more popular with the introduction of the celluloid negative (White 1986). A very popular example of this type of camera is the George Eastman Kodak Brownie (Figure 21).

The other type of roll film camera was the folding camera; even though they started like the box cameras with very simple and easy-to-control mechanisms, with time they become very sophisticated cameras (Figure 21). The most popular camera of this type was the Kodak Number 3. Folding pocket cameras launched in 1900; this camera set the standard for this type of camera for the next 50 years.

3.3.2. Non-Reflex Cameras (rangefinder)

The difference from a reflex camera (SLR) is that the photographer has to use a side viewfinder, as you are not looking through the lens with this type. In addition, parallax correction needs to be taken into account since what the image on the viewfinder is not at the same angle as the lens (Figure 21).

3.3.3. 126 Cameras

Kodak introduced these cameras with the famous "Instamatic" in 1960. Other popular cameras in this range are the Minolta "Autopak" and Olympus "Quickmatic", Even though there are 126 cameras with single-reflex focusing and rangefinder, these cameras are essentially cheaply made cameras with little or no exposure control. The name of this camera refers to the type of film used. These cameras emerge as the solution to ease the loading process that the 35mm cameras involved (Mr Martin) (http://www.mrmartinweb.com/126.htm#history) (Figure 21).

3.3.4. 110 Cameras

Again, this camera refers to the type of film used. These cameras came on the market in 1972 and soon became very popular, even replacing other sub-miniatures such as the 126. These cameras were also very cheaply made with little or no exposure control and cheap lenses. Kodak's response to this was the launch of the "Pocket Instamatic", which used the 126 films and was much smaller in size (Figure 21).

3.3.5. Disc Cameras

This type of camera did not stay in the market long. The pictures were rather blurry, grainy, and of bad colour quality. Another thing that was lacking in these cameras was a good-quality lens, and consumers were uncertain if they had actually pressed the button right when taking pictures. In addition, they were inordinately large for the film they used; this was the result of the circular disc fan and other inbuilt options such as motor drives and electronic flashes (Figure 21).

3.3.6. SLR Camera

As illustrated above, this camera technology had the advantage of allowing the user to see exactly what would go onto the film. A disadvantage of this camera was its weight due to the mirror lenses. These cameras usually offered the flexibility of manual controls, exchangeable lenses, and flash units (Figure 21).

3.3.7. Compact Cameras

These cameras differed from SLR in two respects: the lenses were built into the camera body, and they used direct viewing. These cameras did not require a mirror; therefore they could be smaller and lighter than SLR. One disadvantage again was the parallax error. These cameras were designed to make photography as simple as possible and are often seen as the descendants of George Eastman Kodak Brownies (Jervis 1990) (Figure 21).

3.3.8. Instant Cameras

The idea of these cameras is that the film develops inside the camera itself; hence, consumers can have instantly developed pictures. Polaroid made the most popular of this type of cameras. These cameras were widely used by consumers that wanted an instant picture but were also very popular for taking ID pictures, and for police and fire departments to take instant photographic evidence. These cameras, however, have been in a way supplanted with the advent of digital imaging (Figure 21).

Figure 21: Camera types

 ROLL FILM: KODAK BROWNIE	 FOLDING ROLL FILM CAMERA	 RANGEFINDER (NON-REFLEX) CAMERA
 126 CAMERA	 110 CAMERA	 DISC CAMERA
 SLR	 COMPACT CAMERA	 INSTANT CAMERA

3.4. CAMERA TECHNOLOGY

This chapter has illustrated that the mechanism of the cameras starts with the releasing of the shutter to allow the light into the camera to be reflected by the mirror systems onto the film. However, for the negative to have enhanced quality of picture, the camera has to be able to perform the following functions. The lens must be adjusted so that it precisely focuses light waves coming into the camera. Secondly, the camera must be able to control the exposure. This exposure is determined by the intensity of light and length of time that it is allowed to reach the film for. The shutter controls the length of time that the film is exposed to the light (35mm cameras) (Jervis 1990, Warren 2001). According to this definition of enhanced quality of picture, the elements that will form part of this research are as follows:

3.4.1. SHUTTER

The first step in taking a picture is releasing the shutter to allow the light into the camera. This mechanism controls the duration of the exposure, or, in other words, the time that lenses are open to allow the light in (Hicks 1989). Cameras with very fast shutter speed are capable of extremely fast exposures which makes them ideal for freezing moving objects (Jervis 1990). There are two types of shutter mechanism, the leaf shutter and the focal plane shutter. The leaf shutter is composed of overlapping metal blades. These blades are usually located in the body of the lens. The advantage of this shutter mechanism is its low weight and ability to synchronise with flash at any speed. The disadvantage of this mechanism is the difficulty of achieving high speed and extra provision of mechanisms for metering systems also located in the lens of the camera, such as TTL (through the lens metering system) (Warren 2001). The other type is the focal plane shutter; this mechanism is located in the body of the camera. This mechanism contains two cloth curtains or sets of metal blades that form a slit that travels across the film. For this type of shutter, the disadvantages and advantages are reversed. The advantage of this camera is its high speed and provision for metering systems on the lens, and the disadvantages are the bulkier structure and difficulty of synching with flash at specific speeds (Warren 2001). The shutter speed is usually expressed as the minimum–maximum speed of the camera (30s–1/14000s). This research translated this range of speeds into the total number of stops of the shutter. Stops are calculated by the doubling of the shutter speeds (Windrum 2005) e.g. a camera with a shuter speeding ranging

1s–1/1000s would have ten f stops. Digital cameras allow for one-third stops; however, since this research handles a combination of digital and non-digital cameras, this research will use whole/precise stops in order to ensure continuity of information.

3.4.2. LENSES

The lenses in the cameras bend the light waves coming from the subject being photographed (Jervis, 1990). In the simplest form, a lens is a single piece of glass curved at the sides. These types of lenses are often used in the most inexpensive cameras. High-specification lenses can contain about 8 pieces of glass, called elements. These elements are usually in different shapes, allowing the bending of the image inwards and outwards to enable increased picture resolution (Jervis 1990). The danger of this increased number of elements is the reduced amount of light that reaches the film.

The strength with which a lens bends light determines its focal length. The focal length is the distance between the centre of the lens and the film (Warren 2001). The focal length of the lens determines the size of the image (image magnification). The longer the focal length, the more the image is magnified.

The diaphragm determines the intensity of light that is allowed in the camera, and is a hole of adjustable size in the lenses. The aperture of this hole is expressed in f-stops according to how big or small the opening letting in the light is. The greater the number of f-stops, e.g. f/16, the lower the amount of light that is let in (Jervis 1990).

3.4.3. METERING SYSTEM

As illustrated so far, the shutter speed and aperture of length control the light getting onto the film, and metering measures what the “right” strength of light is for different occasions. Different pictures needs different strengths of light, such as close-up pictures, landscapes – e.g. with a bright background the main subject might be underexposed. Light metering systems help the photographer to decide the shutter speed and aperture needed in each situation. Light metering systems started as separate elements of the camera to aid photographers. The first clip-on meter was offered by Leica in 1932 (Hicks 1989); however, this metering system was uncoupled. Uncoupled metering systems only gave a reading, which had to be then transferred to the camera. It wasn't until the late 1950s that cameras started offering coupled built-in metering systems in cameras such as the Contax III, and the Lordomatic II (Hicks 1989). Metering systems are often located in the lens of the camera TTL (through the lens metering system); cameras nowadays can offer a whole range of metering systems to opt for according to the picture to be taken – centre weighted, average, spot and matrix to name a few.

This research is fortunate since it started at 1955, just when metering systems and the further innovation illustrated here were taking place. The introduction of this new element in the camera promises very interesting results.

3.4.4. EXPOSURE

As illustrated above, the aperture of the lens and the shutter speed of the camera determine the exposure. There is a direct relationship between the aperture and the shutter speed. The aperture is measured in f-stops (f/11, f/16, f/22); for instance, increasing the aperture from f/11 to f/16 will have the same effect as increasing the shutter speed one stop, let's say from 1/125 to 1/250. This relationship is called reciprocity (Jervis 1990). Cameras offer a different range of exposure options according to the reciprocity. In manual cameras, photographers have full control to set the shutter speed and aperture size. The event of the introduction of the inbuilt metering system allowed manufacturers to offer additional automatic exposure cameras, where photographers can set either aperture or shutter speed and the camera automatically sets the other (aperture priority, shutter priority). The most simplistic form of exposure is programmed exposure where the camera automatically sets both aperture and shutter speed (Warren 2001). Most cameras nowadays offer what is called PASM (Programmed, Aperture priority, Shutter priority, Manual).

3.4.5. FLASH

In early photography, it became apparent that artificial light would help with poor sensitivity (Jervis, 1990). The flash only lasts a fraction of a second, in some cases as little as 1/30000s. Therefore, it is very important that the flash is synched with the camera shutter so the flash fires while the shutter is still open. In automatic cameras, the flash will fire when the metering system indicates poor lighting conditions. Cameras offer a whole range of flash synch options according to their shutter speed, such as M, F, FP, X and HSS synch (Rockwell 1973) (http://www.kenrockwell.com). Nowadays, cameras also offer other options such as fill in (forces flash to fire regardless of lighting conditions), flash off (stops flash firing regardless of conditions, useful to avoid reflections or too much light), and red eye reduction option to enhance the quality of the picture (Lindner 2007) (http://www.adventurequilter.com/e-Learning/Articles/Photography_flash.html).

The account of these technological elements seems to indicate already a relationship between the technological elements of the photographic camera. This gives rise to the following formulas (4–8) (Warren 2001) (Hicks 1989, Jervis 1990):

$$Picture\ f\ (shutter + lens + mirroring\ systems + light\ sensitive\ film\ (35mm)\ light\ sensitive\ cells\ (digital\ cameras) + \varepsilon)$$ *(Formula 5)*

$$Exposure\ f\ (shutter\ speed + aperture + \varepsilon)$$ *(Formula 6)*

$$Metering\ f\ (shutter\ speed + aperture + \varepsilon)$$ *(Formula 7)*

$$Lens\ f\ (aperture + focal\ length + \varepsilon)$$ *(Formula 8)*

$$Flash\ synch\ f\ (shutter\ speed + \varepsilon)$$ *(Formula 9)*

3.5. Innovation in Photographic Cameras

Photographic cameras are a very rich market for the investigation of innovation patterns. There are different reasons for this research; not only have they been on the market for more than two centuries but, since 1955 (the period covered in this research), this market has seen a plethora of innovations, both radical and incremental. The innovations that are covered in this research start from the incremental innovation in the technological characteristics that shaped the hypotheses that will be tested in following chapters. All the technological characteristics covered (exposure, metering, shutter speed, lens speed, focal length, flash, pixels (digital cameras)) have experienced a gradual steady increment since 1955.

This market has also seen the introduction of extra technological systems such as metering systems, as well as the replacement of a technological characteristic by a new technological characteristic in the form of digitalisation of the image instead of 35mm film. Despite all this innovation over a wide period of time, cameras aesthetically look essentially the same as in 1955.

This research has illustrated the hypothesis that technological components cluster in order to provide a service in the photographic market (Formulas 4–8); there also seems to be some kind of hierarchical clustering. It could be said that improvements in the elements in Formulas 4–8 could offer enhanced picture quality. This research hypothesises that technological characteristics cluster in order to provide enhanced quality picture. It has also been illustrated that changes or innovation of all types – incremental, radical and the introduction of new technologies – can change the pattern according to which these technologies cluster.

This research, therefore, is focused on the testing of the possible effects that incremental innovation could have on the clustering pattern or linkages between the cameras technological elements. In addition, how the introduction of the metering systems and swapping from 35mm to the digital image affected the clustering pattern of the different types of cameras involved is addressed in this research. This is interesting since there is evidence in the literature on changes of clustering pattern in order to provide a service but there is no clear empirical evidence of an investigation of this sort in a consumer market, which is so highly affected by consumer demand.

Another interesting factor about this research is that it takes into account all types of cameras that have been part of the photographic market. It could be hypothesised that innovations might affect clustering patterns differently regarding their core technology. Does incremental innovation affect compact cameras' clustering patterns in same way that SLR, 110, 126 or even roll film cameras do?

3.6. CONCLUSION

A brief illustration of the history of photographic cameras was given in order to enhance readers' knowledge of cameras prior to this research period.

The illustration of the core technology of the cameras was given in order to define a workable way of classifying cameras according to their core technology. The reason for this definition is given by the complex systems definition of core technology and peripheral elements. The investigation of the photographic cameras as possible complex systems required the definition and classification of the photographic cameras as the core and peripheral elements that will later be used in the analysis. This research found the mirroring systems that transfer the image from the subject to the light-sensitive film to be the core technology.

Once the core technology was defined, the definition of the possible technological elements that relate to this core technology was also considered. This research found that there seem to be several relations between the technological elements that allow the picture to be taken. This gave rise to the following formulas (Formulas 4–8) (Warren 2001) (Hicks 1989, Jervis 1990):

ERROR! REFERENCE SOURCE NOT FOUND.□$(35mm)\ light\ sensitive\ cells\ (digital\ cameras) + \varepsilon)$
(Formula 4)

ERROR! REFERENCE SOURCE NOT FOUND.□ *(Formula 5)*

ERROR! REFERENCE SOURCE NOT FOUND.□ *Formula 6)*

$Lens\ f\ (aperture + focal\ length\ + \varepsilon\ )$ (Formula 8)

ERROR! REFERENCE SOURCE NO*) (Formula 8)*

The investigation of complex systems and complex systems definition gave rise to the notion of technological elements clustering in a synergetic manner in order to provide an enhance service. There is already some indication of clustering of technological elements and it seems to involve clustering in a hierarchical manner. The investigation of the technological elements in photographic cameras gave rise to the formulation of Formulas 4–8. This offers the perfect opportunity to test the photographic cameras as complex systems.

This research is also focused on the innovation patterns displayed by photographic cameras. This market offers marked breakthroughs such as digitalisation of the image and the introduction of the inbuilt metering system. In addition, there is the incremental innovation that the other technological elements have experienced. This radical and incremental innovation, as well as the time span covered by this research (1955–2011), offers the perfect opportunity to test innovation theories.

There is evidence of previous research on innovation in photographic cameras (Windrum 2005). However, what makes this research novel is that it, firstly, includes more years (1955–2011, as opposed to 1955–1975); also, this research includes all camera types. This research also uses a different methodology to investigate this innovation pattern, and this provides the opportunity to test and compare with existing results.

CHAPTER 4 – RESEARCH METHODS

4.1. INTRODUCTION

The main notion that runs through this thesis is the investigation exploration of whether complex systems innovate differently. This research undertook the following structure for the study of cameras as complex systems. The investigation of complex systems innovating differently starts with the investigation of a definition of complex systems in order to identify how they are differentiated from complex systems. Investigation of the literature gave rise to two main characteristics that separate simple from complex systems: epistatic relations (dependency between the elements) and hierarchical clustering (Research Questions 1–2). Hence, the characterisation of cameras as complex systems is based on the indication to support that cameras display evidences that are consistent with both characteristics of complex systems (epistatic relations, hierarchical structure). This research hypothesises that if cameras show indications of epistatic relations and hierarchical clustering then there is a possibility of considering cameras as complex systems. There is a novel aspect to the investigation of complexity of elements for this research: previous research has investigated complexity of products as whole. This research suggests a model that, in a way, opens the black box of complexity, and investigates the inner workings of complex systems. This research attempts not only the identification and classification of cameras as complex systems but aslo to identify the distinct elements that show epistatic relations and the particular elements that could be affected by those epistatic relations. The basis for this structure it is the evidence of the literature which seems to indicate that epistatic relations are the main reasons that hinder the innovation in complex systems. Epistatic relations seems to support the notion that changes in one element, due to dependencies on the elements of the systems, could trigger changes in other elements in the systems or ultimately the malfunctioning of the system (Ulrich 1995, Hobday 1998, Tushman and Murmann 1998, Gatignon, Tushman et al. 2002, Allen and Varga 2006, Frenken 2006, Yayavaram and Ahuja 2008, Geisendorf 2009). The understanding of these phenomena is crucial for the undertaking of any innovation activity (incremental, radical or architectural). Investigation of the complexity of a product as a whole might result in the lost of crutial information or the possible identification of the elements that carry or characterise the complexity of that product. Another benefit of identifying the distinct elements that display the dependency combined with the investigation of the clustering pattern or nested hierarchy is that it also allows this research to classify complex systems according to the strength of the epistatic relation and hierarchicar structure into:

- Fully integrated complex system.
- Modular complex system.
- Near decomposable complex system
- Fully decomposable or simple system

This classification is also relevant to the innovation activities that a firm may choose to engage in or the function of that product. While modular architectures might be more flexible towards incremental innovation, this strategy is not able to adopt global optima or architectural innovation.

After the investigation of the possibility of cameras being complex systems, this research will test the idea that complex systems innovate differently. This research is going to take the innovation pattern displayed by cameras and compare that pattern with those offered by the classical view of innovation and complex systems. By comparing camera innovation patterns with both the classical view and complex systems, this research will have a clearer view on whether cameras, after being considered complex systems or not, display patterns similar to those of complex systems or the classical view, or have traits from both or neither.

Firstly, this research is going to take the research question that arises from the gaps in knowledge in the literature review and translates those research questions (Research Question 1-8) (aims and objectives) into workable hypotheses ready for use in testing whether complex systems innovate differently.

This research is portrayed as exploratory research on the possibility of cameras being complex systems and investigation of the innovation patterns displayed by cameras as a comparison of complex systems and the classical view of innovation. This research is an investigation of the possibility of identifying whether complex systems innovate differently. At this moment in time, this study it is not sufficient for theory grounding since there is no clear evidence of any other studies of this kind in the commercial market literature and this study only covers one example study. This investigation, it will be used to explore the applicability of the suggested new approach to test complexity, complexity characterisation and innovation patterns but cannot defined the results as a rule or norm within complex systems theory. The results of this study, however, open up the possibility of the replication of this study in relation to other commercial technological products in order to achieve theory grounding /confirmation of the innovation found for this research.

4.2. RESEARCH APPROACH

This research will attempt an exploration of the fact that complex systems in fact innovate differently from simple systems. By exploratory, it is meant that this research is going to investigate the phenomena occurring in the camera market regarding the research questions. Exploratory research is usually used to achieve a better understanding of the phenomena at hand since there is little research done in that area (Sekaran and Bougie 2010). For this research, there is extensive literature on complex systems and innovation cycles; however, there is no clear evidence of empirical testing on those theories in a consumer market. In addition, there is no clear evidence of an investigation that follows the structure of this research, which is the empirical testing of the complexity of a product followed by the investigation of the innovation cycle of that market and the applicability of existing theories to this particular market.

This research uses the example of the camera market in order to test the hypothesis for this research (Table 2). The reason for using this market is that previous research by Windrum (2005) found that cameras did not show the innovation pattern indicated by the classical view of innovation. This research will attempt to test whether cameras do not show classical innovation patterns due to their complexity.

The use of case studies has been suggested as a theory building instrument (Eisenhardt 1989); however, at this moment this research cannot make any generalisation that the phenomena emerging in the analysis of the camera market could be considered as rules for innovation of complex systems. This research holds back on making any generalisation of a rule by using only one example study; however, the findings might open the possibilities for further research in other technological markets in order to achieve theory building on innovation on complex systems. This research is only choosing a single example study at this moment because it is concerned with the testing of existing theories (Ghauri and Gronhaug 1995). However, regarding the results for this study, it would be interesting to apply the same investigation to other technological elements in order to achieve not only confirmation and validation for the results of this research but also in order to achieve ground theory building.

Case studies are most suited for the investigation of phenomena which are difficult to study outside their natural setting (Ghauri and Gronhaug 1995). Case studies are also most appropriate for areas of research where existing theory does not seem adequate (Eisenhardt 1989). This research is concerned with the empirical testing and applicability of existing innovation theories in complex systems and the camera market in order to test the applicability of these existing theories. This research takes the case study route to give empirical validity to those findings, which could not be investigated outside the natural setting of the testing in a real-life example.

The review of the literature on complexity theory and innovation gave rise to several research questions:

Research Question 1*: do the technological elements in cameras display indications of epistatic relations?*

Research Question 2*: do technological elements in cameras cluster in a hierarchical structure?*

Research Question 3*: can cameras be considered complex systems?*

Research Question 4: *does the clustering of technological elements change over time due to innovation activities?*

Research Question 5*: can the ILC be applied to photographic cameras?*

Research Question 6*: does the photographic camera see the emergence of a DD?*

Research Question 6a: *Does variety in photographic cameras give rise to one DD or to the creation of different niche markets?*

Research Question 7: *Can the stylised facts of the innovation life cycle process on complex systems be applied to the case of photographic cameras?*

Research Question 8: *do complex systems innovate differently?*

Further investigation of camera technology gave rise to the finding that the literature already seems to give evidence consisten with the linkages between the elements of the cameras, expressed in Formulas 4–8 (Hicks 1989, Jervis 1990, Warren 2001).

$$Picture\ f\ (shutter + lens + mirroring\ systems + light\ sensitive\ film\ (35mm)\ light\ sensitive\ cells\ (digital\ cameras) + \varepsilon)$$
(Formula 5)

$$Exposure\ f\ (shutter\ speed + aperture + \varepsilon)$$ (Formula 6)

$$Metering\ f\ (shutter\ speed\ +\ aperture +\ \varepsilon)$$ (Formula 7)

$$Lens\ f\ (aperture + focal\ length\ + \varepsilon\ )$$ (Formula 8)

$$Flash\ synch\ f\ (shutter\ speed +\ \varepsilon)$$ (Formula 9)

This research combined the research questions that emerged from the literature and the formulas that arose from the camera technology review. This research applied the twin characteristics approach (Formula 1) in order to define the hypothesis for the research, which is formulated as followed:

$$Z^1 = b^{11}y^1 + b^{12}y^2 + b^{13}y^3 + by$$ (Formula 1)

Hypothesis 1: if cameras are complex systems then they will display dependency between the technological elements.

Hypothesis 2: if cameras are complex systems then they will display a nested hierarchy structure.

Hypothesis 3: if cameras are complex systems, they will display both elements that separate complex from simple systems (Hypotheses 1–2).

Hypothesis 4: if innovation changes hierarchical formation then cameras will display different nested hierarchical formations before and after distinct rounds of innovation activities.

Hypothesis 5: if the classical view of innovation can explain innovation patterns for cameras then complex systems do not innovate differently from the classical view of innovation.

Hypothesis 6: if cameras see the emergence of more than one DD then niche, maket emerge in other to cope with heterogeneity of demand.

Hypothesis 7: if complex systems innovation explains the innovation pattern of cameras then complex systems innovate differently from classical view of innovation.

Hypothesis 8: if cameras' innovation pattern differs from classical views of innovation and resembles the innovation pattern of complex systems then complex systems innovate differently from classical views of innovation/simple systems.

The formulation of the hypotheses for this research has dictated the direction for the approach of this study. The investigation of the innovation of complex systems for this research involves the exploration/investigation for evidences that support or contradicts the the hypotheses above-mentioned (1-8), hence the adoption of a positive approach. However, this research, according to the findings, might take another direction towards the investigation of the reason behind the patterns emerging from the findings of the empirical testing.

The positivism approach suggests that the best way to arrive at the truth is the scientific method, the so-called hypothetic-deductive method (Jankowickz 2005). The hypothetic-deductive method is composed of the following elements (Jankowickz 2005). The application of the hypothetic-deductive method forms the basis for the research design:

1. The formulation of formally expressed general statements, which has the potential to explain things. Complex systems innovate differently.
2. A deduction that, if the theory were true, then you would expect to find a relationship between at least two variables A and B. The characterisation of complex systems is based the epistatic relation between the technological elements and hierarchical structure of the system. If cameras display both epistatic relations and nested hierarchy, then cameras are complex systems and if cameras are complex systems then they will innovate differently.
3. A careful definition of exactly what you need to measure, in order to observe A and B varying (Jankowickz 2005).
    a. Dependency between the technological elements of the system.
    b. Organisation of technologicalelements in a hierarchical manner.
    c. Change in hierarchical formations from period to period.
    d. Identification of camera innovation patterns or cameras innovation life cycles.
    e. Identification of possible DDs in cameras.
    f. Comparison of camera innovation patterns with both classical and complex systems innovation approaches.
4. Testing of the hypotheses.

- **Hypothesis 1:** if cameras are complex systems then they will display dependency between the technological elements.
- **Hypothesis 2**: if cameras are complex systems then they will display a nested hierarchy structure.
- **Hypothesis 3:** if cameras are complex systems, they will display both elements that separate complex from simple systems (Hypotheses 1–2)
- **Hypothesis 4:** if innovation changes hierarchical formation then cameras will display different nested hierarchical formations before and after distinct rounds of innovation activities.
- **Hypothesis 5**: if the classical view of innovation can explain innovation patterns for cameras then complex systems do not innovate differently from the classical view of innovation.
- **Hypothesis 6:** if cameras see the emergence of more than one DD then niche, maket emerge in other to cope with heterogeneity of demand.
- **Hypothesis 7:** if complex systems innovation explains the innovation pattern of cameras then complex systems innovate differently from classical view of innovation.
- **Hypothesis 8:** if cameras' innovation pattern differs from classical views of innovation and resembles the innovation pattern of complex systems then complex systems innovate differently from classical views of innovation/simple systems.

5. Drawing of the conclusions about the hypothesis.
6. The drawing of the implications back to the theory: verification.

4.3. DATA COLLECTION

This study gathered information on the following technological elements of photographic cameras:

- Year of launch in the market
- Brand
- Name of camera
- Type of camera
- RRP
- Pixels top to bottom
- Pixels right to left
- Width of camera
- Minimum ISO
- Maximum focal length
- Maximum Shutter Speed
- Total number of metering option
- Total number of flash option
- Left to right movie pixel
- Top to bottom movie pixels
- Total pixels
- Depth of camera
- Maximum ISO
- Total movie pixels
- Lenses speed
- Metering options
- Exposition options
- Shutter Speed
- Aperture of lenses
- Minimum focal Length
- Height of camera

As dummy variable:

- Automatic
- Shutter Priority
- Auto Flash
- Slow sync
- Shutter Priority AE
- Scene
- Centre Weighted
- Manual
- Aperture Priority
- Manual Flash
- Off Flash
- Aperture Priority AE
- Multi Zone
- Spot
- Programmed
- Red eye
- On flash
- Curtain Flash
- Intelligent Auto
- Honey Comb
- Partial

This research based its decision of which variable to select for the tests firstly on previous innovation research on cameras (Windrum 2005). By using the same variable as previous research on the same product, this research capitalised on the benefit of replicability and increased validity of results. Previous research only considered cameras from 1955–1975, during that period some of the technological elements of cameras only offer basic services, such as metering options or exposure options were only coded as auto or manual or metering options (yes or no) (Windrum 2005). Since this research, however, covers an increased number of years (1955–2011), it found that only including dummy variables concerning whether cameras were automatic or had metering could result in the loss of important information on whether the increased number of metering, exposure or flash options could affect either the clustering patterns or innovation life cycles of cameras. This research therefore opted to include the total number of exposure, metering and flash options.

This research also based its decision regarding the variable on the research on the linkages between the technological elements of cameras offered by the literature (Formulas 4–7). The sampling based on the literature and previous research gave the following elements for testing of the hypothesis. This research used the same variables for the entire testing for this research.

- Year launch in the market
- Total number of exposition options
- Fastest lens speed
- Shutter speed
- Total number of movie pixels
- Type of camera
- Total number of flash options
- Maximum focal length
- Total number of pixels
- Fastest lens speed

The database for the investigation of complexity in cameras consists of 4000 observations, from the years 1955 to 2009. Cameras are categorised according to their core technology into:

- Roll film
- Non-reflex – rangefinder
- 110
- 126
- SLR
- Compact
- Disc
- Instant

The reason for choosing this sample is to investigate the effect of complexity on the different core technologies. This research hypothesises that different core technologies might display different levels of dependency and association patterns (Research Questions 1–2).

This research also includes all type of cameras in order to investigate the entry, exit and possible emergence of dominant designs in the market (Research Questions 5–6).

This research primarily uses secondary data collection; secondary data is defined as data that is collected by other people (Sekaran and Bougie 2010). The nature of the data needed for this research (technological specification of cameras 1955–2011) makes it very time-consuming and very difficult to collect the necessary information, which covers the technological specifications of the 4000 cameras since 1955, hence the need for reliance on the secondary sources. This research takes into account the fact that since the information has been gathered by an outside source, factors such as reliability, validity and accuracy of the data could damage the validity of this research (Ghauri and Gronhaug 1995).

The data gathering stated using the same source as previous research on camera innovation (Windrum 2005) to capitalise on the replicability factor. Replicability increases the credibility and validity of this research’s findings (Sekaran and Bougie 2010). The primary source of information used by Windrum was *Amateur Photographer* magazine. This weekly magazine has been on the market since 1984. Information was primarily obtained from an annual book review that contains information on all the cameras that were launched into the market, with technological information as well as a short review.

This researched encountered several problems by attempting to use the same source as previous research. Firstly, information was firstly gathered from a yearly special issue on *Amateur Photographer* magazine, which compiled all cameras launch that year. This source was chosen in order to continue and test previous innovation research on cameras (Windrum 2005). Unfortunately, *Amateur Photographer* magazine stopped publishing this annual review book in 1984 and information on cameras was published instead on a weekly basis; this information, even though accurate, was not complete for the whole year. Since unlike previous research on cameras this research involved the study of cameras from 1955-2011, hence the need of another source of information. Conversation with an amateur photographer at one of the photographic clubs who was contacted for help for another source of information offered a secondary source that could complete the data set for the last two decades. *DPReview* (www.dpreview.com) is an independent website that offers reviews, news and information on technical photography. They also offer what they called a "timeline", which is a chronological review of all cameras that have been launched into the market since 1994. This research used this website to gather data on the cameras that *Amateur Photographer* did not publish. Firstly, information published by the *Amateur Photographer* after a certain period became irregular and, as later confirmed by using *DPReview*, was also incomplete year by year and biased towards certain types of cameras, mainly SLR. One of the goals of this research is to investigate the patterns of innovation during different periods in order to show changes in technological clustering and possible emergence of DDs. In the last two to three decades, *Amateur Photographer* mainly covered one type of camera (SLR); the reduction in variety of cameras used could have greatly affected the results and accuracy of this research. This research needed a reliable, unbiased source that offered information on all types of cameras in order to investigate the innovation life cycle of the camera.

A main concern arose with changing the main source of information halfway through the gathering of it. It has been seen that changing sources of data will not only reduce the validity of the research but also the consistency of the data due to the risk of having different units of measurement, variation of the definitions of terms etc. (Jankowickz 2005). Taking into account the risks of changing sources of information, this research was faces with a crutial challenge. Information on *Amateur Photographer* seemed to be incomplete and biased after 1984, hence using this source could compromise the validity and accuracy of results. Secondly, *DPReview* only provided reviews of digital cameras and *Amateur Photographer* stopped offering the yearbook in 1984, right at the start of digital cameras. This research then used *Amateur Photographer* for analogue cameras (roll film) and *DPReview* for digital cameras to ameliorate the problem of definition of terms and measurements.

The gathering process for the database on cameras also took extra measures to increase the validity of the information by crosschecking information gathered on *DPReview* with a secondary source of information, *CNET* (part of CBS interactive), another independent source on technological information about cameras, camcorders and other technological products. This cross-checking of information is with the aim of ameliorating the typical weaknesses associated with secondary data, such as possible bias of author-gathered data, possible human error in typing up data, incorrect data (Sekaran and Bougie 2010).

Information is consistent and complete for all of the period 1955–2011.

4.4. DATA ANALYSIS AND IMPLEMENTATION

The testing of the cameras as complex systems will use a multi-method approach; the reason for this approach is the different nature of the hypotheses. The basis of the multi-method analysis is the combination of different methods to investigate a phenomenon, the intention being that the combined methods complement each other (Wood, Daly et al. 1999). There are different benefits in using a multi-method analysis such as increasing understanding of results, greater robustness of conclusions, wider scope of investigation/understanding, and evolutionary hypothesis formulation (Wood, Daly et al. 1999, Gil-Garcia and Pardo 2006). The entire set of hypotheses tests distinct aspects of the complexity and innovation of cameras. This research found that even though the variables are constant for all tests, the methods to test hypotheses have to be different to get a clearer insight into the investigation of whether complex systems innovate differently.

This research chose the different methods that offered increased internal/external validity, ease of replication, potential for theory generation and potential for theory confirmation (Wood, Daly et al. 1999).

This research is going to operationalized the investigation on whether complex systens innovation differently into a two steps process, firstly the exploration of evidences consisten with the definition of complex systems and chategorisation of cameras as complex systems. This research will investigate if cameras display enough evidences that are consistent and support the two characteristics of complex systems (epistatic relation and nested hierarchy). If the testing of hypothesis 1-3 is supported by evidences given by cameras then this research will start the exploration of the innovation pattern given by cameras taking into account that cameras has offer this research evidence to support the characterisation as complex system. This research pays particular attention to the issue of DD, since there are contradictory notion in the literature about DD and heterogeneous demand. This research will investigate for the emergence of one of several DDs in the camera market (Hypothesis 6). As in the case of the classical innovation approaches, this research will also compare the innovation pattern against the complex systems innovation approach in order to test if cameras innovate as the complex systems literature suggests (Hypothesis 7).

The main and final hypothesis for this research will be tested with the investigation and combination of Hypotheses 5–7. By testing the application of both classical and complex systems innovation theories, this research will increase the understanding of the different pattern or trends displayed by cameras. This method could shed some light not only on whether complex systems innovate differently but also on the manner in which they innovate differently – is it an entirely new life cycle or is it simply a modified version of the classical innovation life cycle?

4.4.1. CHARACTERISATION OF COMPLEX SYSTEMS:

4.4.1.1. APPROACH FOR TESTING DEPENDENCY BETWEEN TECHNOLOGICAL ELEMENTS (EPISTATIC RELATIONS)

The frist step of the investigation of cameras as complex system or the characterisation of cameras as complex systems is based on the evidences in the literature of the direct relationship between the strengh of the dependency of the elements of a system and the complexity of the system. In fact the strenght of dependency of the elements of a system has been suggested as a complexity measure (Frenken 2006) or in other work the stronger the the strength of the epistatic relations the higher is the complexity.

For the investigation of the strength of the epistatic relations this research is going to use general linear regression models that measure just that, the interactions of the elements in the system – in other words the effect that a change in X will have on Y (Formula 9). The interaction regression is simply expressed by the following formula (Byrne 1998, Preacher, Curran et al. 2006, Group 2007, Preacher 2013):

$$y = a + bX \qquad \text{(Formula 10)}$$

b gives the amount of change in Y when X changes. E.g. every time that x increases by 1, Y increases by b

Frenken suggests that a way of measuring the complexity of a system is by measuring the magnitude or strength of the epistatic relation (dependency) between the technological elements of a system. The application of Formula 9 to the case of the investigation of complexity of cameras gave rise the following formula (Formula 11):

$$Complexity = TC_0 + TC_{(1)}x + TC_{(2)}y + TC_{(3)}z + TC_{(4)}xy + TC_{(5)}xz + TC_{(6)}yz + TC_{(7)}xyz + \varepsilon \quad \text{(Formula 11)}$$

Where TC is the technological characteristics of cameras

x,y,z,xy,xz,yz,xyz are the possible interactions and the effect on complexity

Previous research on complex systems has used the “cover size” measure (Page 1996, Frenken, Marengo et al. 1999, Frenken 2006). Cover size measures the complexity of difficulty of decomposing a system. Cover size models come out as an improvement of the existing methods of complexity NP and P hard. This model is used to categorise problems according to how hard they are to solve (http://mathworld.wolfram.com/ComplexityTheory.html). Page (1996) explains that weaknesses of this classical model are the over-simplification of the problems, and lack of ability to capture regularities between problems. In addition, the NP and P hard do not show the possible relations between the elements in the problem.

Cover size uses the general negative binominal regression, which shows the associations between the independent and dependent variety and the overall fit of the model (Acton and Miller 2009, Pevalin and Robson 2009). This model, however, could not be used in the case of the camera market since the number of variants within variables (high number of iterations) was too high to give accurate/conclusive results. Another problem with the application of this model in order to test Hypothesis 1 is that this model highlights/identifies the independent variables that show a level of dependency towards the dependent variable.

This research needs a model that indicates the dependency levels and association patterns amongst the independent variables, or in other words a model that analyses the interaction between the technological characteristics alone. The importance of finding a model that shows the inner workings of the systems arises from the need to specify which specific elements could have an effect on which other specific elements. This research hypothesises that changes in one element of the system might cause changes in other elements in the system.

Other authors used Poisson regression instead of negative binominal regression in order to measure the complexity of a product. This method, in the case of the testing of Hypothesis 1, encountered different problems; firstly, this method was used to measure the complexity as a whole and, as with the cover size model, there is a need for a dependent variable for the calculation.

The NK model (Kauffman 1993) is a popular model that displays the elements of a system according to their fitness to the overall system. This model is very helpful to identify areas or elements with the potential to innovate. Again, this model is not applicable for offering some light on the investigation and testing of hypothesis 1 since it does not seem to indicate possible epistatic relations between the elements of the system. This model has also been criticised for being a poor indicator or measurement of the complexity of a system (Frenken 2006).

The testing of Hypothesis 1 needs a model or models that help identify the epistatic relations between the components without the need to have a dependent variable, and, most importantly, the identification of the specific variables (technological elements) that display epistatic relations and of which other elements are affected by these epistatic relations both within and across subunits, as opposed to a model that tests complexity of products as a whole.

A model that offers the mapping of the relations and strength of these relations is the analysis of the contingency table (chi-square) (Byrne 1998). The Pearson's chi-squared test is a non-parametric binary correlation model that shows the strength and significance of the binary relations among all other variables (Sekaran and Bougie 2010). This model also shows if there are indications of association between the components of a systems and the likelihood of the results happening from chance alone (Acton and Miller 2009, Pevalin and Robson 2009). This research therefore suggests the use of the exact statistical model of Pearson's chi-squared test, due to its ability to show association (epistatic relations), in answering Hypothesis 1. This measure was complemented by Cramer’s V test, which shows how strong the relationship is between the elements or dependency levels (Acton and Miller 2009, Pevalin and Robson 2009). A weakness of this model is that it is an exploratory analysis of the data; even though its help in displaying significant associations is invaluable, the probabilities they generate cannot be relied on as an indication of generalisation of the hypothesis tested (Byrne 1998). This research has already taken into account the fact that the results of this analysis cannot be relied on as a generalisation but explores an example study for possible suggestions of new models for studying complexity. This research is presenting this analysis as exploratory research that could be further enhanced by future research on other technological products that would aid in generalisation of the results and in building a theory approach.

4.4.1.2. APPOACH FOR TESTING FOR HIERARCHICAL FORMATIONS:

For the testing of Hypothesis 2, this research firstly defines photographic cameras as the relation between the services provided by the product (service characteristics) and the technological elements involved in the provision of the service (technological characteristics). This research is going to use already existing models that have been applied to innovation studies before with successful results. What is paramount for this research is the definition of the service, and the technological characteristics that give rise to that service. This study is going to use Saviotti-Metcalfe’s (1984) model of mapping products. This model will also be widely used to define products and investigate clustering and innovation variety. On the other hand, other authors use Poisson regression for their studies of clustering patterns (Silverberg and Verspagen 2003); this research is not going to follow this regression, because it does not really reflect the relations between technological components which is an important part of this research. In Silverberg and Verspagen’s (2003) study they used innovation as such as variable rather than technological elements. This research takes into account the weaknesses of this model; the definition of a service, for one thing, is a very debatable issue since services are intangible in nature, and consumer preferences, as argued before, are very changeable and heterogeneous in nature (Saviotti and Metcalfe 1984). In addition, this research takes into account the fact that the service required by customers might change over a period. Mobile phones, as an example, started as a basic means of communications, but nowadays consumers use mobile phones as substitutes for personal stereos, laptops and more, and even to watch movies on the go. Considering those weaknesses, this research has opted for the definition of the core service as being required by customers since 1955, when this research starts. The core service for the photographic camera market, it could be argued, is enhanced quality of picture; even thought it might sound simplistic, there is an indication that this service might cover the period since 1955. This research takes into account the fact that there might be some other service characteristics offered by cameras but the service chosen by this research could be common to all periods from 1955–2009.

Investigation of the technology of cameras gave rise to some indication of possible linkages between the elements of the camera expressed in Formulas 4–8.

$$Picture\ f\ (shutter + lens + mirroring\ systems + light\ sensitive\ film\ (35mm)\ light\ sensitive\ cells\ (digital\ cameras) + \varepsilon)$$ (Formula 5)

$$Exposure\ f\ (shutter\ speed + aperture + \varepsilon)$$ (Formula 6)

$$Metering\ f\ (shutter\ speed + aperture + \varepsilon)$$ (Formula 7)

$$Lens\ f\ (aperture + focal\ length + \varepsilon)$$ (Formula 8)

$$Flash\ synch\ f\ (shutter\ speed + \varepsilon)$$ (Formula 9)

This research used the existing evidence of possible linkages of technological elements in the cameras (Formulas 4–8) in order to investigate the clustering of the technological elements and supply an enhanced service with the help of the twin characteristics approach (Saviotti-Metcalfe 1984) (formula 3). The combination of formulas 3-8 gave rise to the formulation of the service characteristics for this study on cameras (formula12)

$$Enhanced\ picture\ quality\ f\ (metering + exposure + shutter\ stops + lens\ speed + focal\ length + picture\ pixels + movie\ pixels + volume + \mathcal{E})$$ (Formula 12)

The hypothesis 2 will be tested with the help of principal component analysis. This is an easy and simple-to-apply method that has been used before with successful results (Saviotti 1985, Tether and Tajar 2008, Windrum, Diaz et al. 2009). This method shows the possible clusters of characteristics by emphasising the characteristics that correlate better with a group or communalities between the elements of a particular group (Askey 1998). PCA can be used as a way of displaying trends in the technology over a period of time and can sometimes also indicate separate clusters of products, possibly corresponding to different markets (Saviotti 1985). The analysis of the data with the help of PCA will give us a further insight into the clustering of the technologies in order to provide a service. This method will also, by showing possible clustering of technologies and dependencies, give an inside view of the type of relationships in the systems; therefore, it could also give an insight into the decomposability of the system. This hierarchical structure will also be used to chategorised the complexity of cameras as near decomoposable complex system, modular complex systems or fully integrated complex system. As explained in the previous chapter, the level of independency or decomposability of the system ultimately gives the level of complexity.

4.4.1.3. APPROACH FOR THE DEFINITION OF CAMERAS AS COMPLEX SYSTEMS:

According to the literature on complex systems theory, there are two main characteristics that separate simple from complex systems: epistatic relations and hierarchical structure. Hypotheses 1 and 2 covered the investigation of cameras for epistatic relations and nested hierarchy. The method used by this study in order to test Hypothesis 3 will be the combination and investigation of Hypotheses 1 and 2. This research will investigate if cameras display evidences that supports the possibility that cameras are complex systems, in order words cameras display evidences consisten with epistatic relation and nested hierarchy. An advantage of studying the complexity in such a manner is that this methodology, due to the identification of the distinct elements that show epistatic relations and which distinct elements cluster, offers a clearer view of the location of the epistatic relations, e.g. within the same cluster or across clusters. This combination of methods not only allows a clearer view of the inner workings of cameras but also allows classification of cameras not only as complex systems but also chategorise cameras into fully decomposable simple system, fully integrated complex system, modular complex system or near decomposable complex system. This identification is important since, as seen in the literature, innovation strategies/actions will depend on the strength or location of epistatic relations. For example, a modular structure will be more flexible for incremental innovation in the quasi-dependent unit, as opposed to near decomposable or fully integrated where incremental innovation might affect the whole system.

4.4.1.4. APPROACH FOR THE TESTING OF POSSIBLE CHANGE OF HIERARCHICAL STRUCTURE DUE TO INNOVATION ACTIVITIES:

This research is also going to include the notion in the literature that innovation in complex systems may happen by recombining the elements of the system (architectural innovation). This architectural change in the hierarchy might also happen due to innovation in one element that provokes a change in the clustering pattern due to the ill fitness of the new component. Another possible reason for this clustering change is the change of clustering due to changing consumer taste, hence changes of service being sought in the product.

The length of period covered by this research (1955–2011) allows this research to test for any architectural change in the camera market (Hypothesis 4). This research divided the period covered (1955–2011) into six ten-year periods. By dividing the period into five-year gaps, the reduced number of observations for some type of cameras did not show conclusive results; the 15-year gap runs the risk of losing any clustering pattern change due to the longer study span. There is no clear evidence in the literature that this type of investigation has been attempted before.

- 1955–1964
- 1965–1974
- 1975–1984
- 1985–1994
- 1995–2004

- 2004–2011

The testing of the complexity of the camera (Hypothesis 3) will lead to the investigation of the innovation patterns displayed by cameras in order to shed light on the notion that complex systems innovate differently.

4.4.2. INVESTIGATION ON THE INNOVATION LIFE CYCLE PATTERN OF CAMERAS (HYPOTHESIS 5-7)

The first step in the investigation of whether complex systems innovate differently is the mapping of the innovation pattern display by cameras. This research will use the Theil's entropy measure to map cameras' innovation patterns. The Theil's entropy measure is defined as a "macroscopic measure at the level of a distribution that indicated the degree of randomness in the macro-dynamics underlying a frequency distribution" (Frenken 2006, p.69). Theil's entropy measure can be used as a "variety measure of frequency distribution of technological design" (Frenken 2006, p.69). This is a non-parametric model that allows investigation of the variety (or uncertainty) in distribution; therefore, a skewed distribution will indicate that some products will dominate the product population. If variety drops to nearly zero then there could be indications that a dominant design has emerged, since all products seem to fall into the same category or product population (Frenken, 2006). The classical view of innovation suggests that at the beginning of the life cycle variety increases until it reaches a peak when variety drops and the emergence of a dominant design signifies the standardisation of the market (Abernathy and Utterback 1978). This model is a useful approach to show the mapping innovation life cycle of cameras to allow later comparison with the classical view of innovation and complex systems innovation theory. This research is going to use these same models for the testing of Hypotheses 5–7. This method has been used before to investigate innovation (Saviotti 2001, Frenken 2006, Murmann and Frenken 2006). The use of this method helped these researchers in the identification of DDs in the aircraft, refinery, helicopter, motorcycles and microcomputer industries. This method has not, however, been used in a more commercial market, such as that of the photographic camera. This research will then test the applicability of this model to the commercial market. Other research such as Windrum's (2005) has used hedonic price regression and found the emergence of two rounds of innovation and DD. Windrum (2005), in his research of innovation life cycles, used hedonic price regression; this research will not use that method at this moment in time for various reasons. The main reason is that hedonic price regression does not show technological clustering. In addition, the database covers 56 years; prices of early camera models are expressed in dimes and schillings. To use the hedonic price regression these prices would have to be converted to current prices and there are factors such as cost of life and disposable income that could make this translation of prices an inaccurate indication of willingness to pay for a product. In addition, the emergence of discount shops and websites where consumers can buy products at a discount price could also make RRP an inaccurate factor. The limitation of not being able to use the same model as previous research on cameras (Windrum 2005) not only offers a novel aspect to this research but also offers the benefits of supported validity of results if this analysis benefits from the replicability factor.

This researcher will be using the entropy measure, in particular Theil's (1975) model of variety measure (Theil 1975). This method, despite being developed for economic purposes, has also been applied to other social science studies. Theil's (1975) model of variety measure indicates the communalities or dissimilarities between the elements of a product population. Therefore, if the degree of variety is very low or close to zero, that could be an indication of a DD emerging. Not only will this model help us to identify possible DD and fall in variety but, since this research covers a period of 54 years, the comparison of Utterback-Abernathy's model (1975) against that given by Theil (1975) will also help this research to show the similarities in both cases and to show whether complex systems could be understood as innovating according to the classical view of innovation (Hypotheses 5–6).

There is evidences in the literature of entropy being used a complexity measure inparticular Aproximate Entropy (Pincus 1991) and Kolmogorov-Sinae entropy however for this research this measure are not very function; firstly because as other complexity measured investigated they measure the complexity of the product as a whole, secondly, this measures are linked to time series analysis so they will be more ideal for a situation where the fluctuation or change of complexity between period was investigated. This entropy measures after this first exploration might be taken into account for further investigation on the changes of complexity before and after innovation activites. At this moment in time the only entropy measure that will be using for this exploratory research is Theil's entropy variety measure which will help with the investigation of ILC and emergence of possible DD in complex systems.

The application of the Theil's entropy measure (1975) requested the coding of the technological elements into a set of alleles of identification numbers that revealed the specification of a particular camera (Frenken 2006), e.g. 4-0000-10-05-1-2-00. The first number refers to the core technology of the camera. Cameras were coded in chronological order of launch in the market. The second number refers to the picture's pixels. The third number concerns the shutter stops: this number refers to the stops offered by the range of shutter speeds. This translation of the range of shutter speed into stops was based on Windrum's (2005) research on amateur photographic cameras. These numbers are followed by exposure, metering and flash options and lastly the number of movie pixels. Lenses could not be included in this coding since not all cameras are sold with lenses; there is no clear evidence that consumers will buy the standards lens used for that particular camera. According to this classification, the example number would indicate, for an SLR camera with digital image (35mm film), ten shutter stops, five exposure options and one metering option, two options for the flash, and no movie pixels.

Nguyen-Saviotti suggested the Weitzman measure (Weitzman 1992) as a variety measure complementary to the Theil's entropy measure. There are evidences in the literature of entropy-Weitzman models have been used before for the investigation of variety and DD (Frenken et al. 1999, Frenken and Leydesdorff 2000). In this case, this type of measurement is used as a complementary measure for the distance between products' technological characteristics. The Weitzman (1992) model measures the distance (d) between two products, which refers to the number of discrete characteristics, which two products differ. Weitzman (1992) model clusters product's characteristics with the closest distance into groups in a manner of tree line shape. The grouping is done according to the distance between all products. This measure will not only help the research identify a possible DD but also the possible emergence of niches (Hypothesis 6). Research done by Saviotti (1996) and Levinthal (1998) also found that distribution of products might fall into two distinct groups; therefore, there might be an indication of two DDs rather than one. This model can also be useful for the indication of a possible niche market. This is a complementary model; since the Theil's entropy indicates a decrease or decrease of variety, this measurement furthers the investigation by the possible identification of DD bifurcation or emergence of niche markets.

After the comparison of the cameras' innovation pattern with the classical view of innovation, this research is going to take the cameras' innovation pattern and compare it to those illustrated in the literature of complex systems. There are several reasons for this double comparison and investigation of camera innovation pattern against both complex systems and the classical view. Firstly, the fact that there are evidences in the literature that cameras do not display trends like those of the classical view of innovation (Windrum 2005) does not mean that they will innovate as suggested in complex system theory or vice versa.

This research takes into account the fact that cameras might not display innovation patterns applicable to either the complex or the classical view. This research also takes into account the fact that cameras might display traits of both classical and complex systems. The deep investigation of innovation patterns in cameras will not be enabled by comparing the pattern against only one model of innovation, which will result in a loss of important information. This research is a firsly exploration that once a product shows consistent evidences with the definition of complex systems migh also show evidences consistent with innovation on suggested by complex system theory. This investigation at this moment in time cannot give a definite answer since it only take one example study but this investigation forms the bases for further studies in other technological markets in order to achieve confirmation of the results achieved in this research.

The testing of the final and main hypothesis of this research (Hypothesis 8) will be conducted via the combination and investigation of Hypotheses 5–7. By compering the innovation life patter display by cameras with boh classical views of innovation and complex systems theory this research could achieve a first look on which direction complex systems migh innovate, whether is the innovation life patterns on complex systems is completely different, or share similar traits.

4.5. LIMITATIONS OF THE RESEARCH

The limitations of this research started with the gathering of data for testing the research questions. This research is testing the association of the technological elements of cameras from 1955 to 2011, hence the need for the compilation of the technological specifications of cameras from that period. It would have been a very time-consuming and nearly impossible task to achieve this data on a direct basis; therefore, this research has to rely on secondary data. The reliance on secondary data is usually associated with concerns outside this author’s control, such as reliability, accuracy, typos and possible bias of people collecting that data. This research attempted to use the same source as previous research on cameras (Windrum 2005); however, after the 1980s the *Amateur Photographer* stopped publishing the annual review which listed all cameras launched in the market. Conversation with *Amateur Photographer* highlighted the risk of reliability factor for this research using this source after 1984 due to the seemingly bias of this magazine towards SLR type cameras. This research had to find another source that gave information on cameras launched into the market year by year (*DPReview*). This research again encountered the extra limitation and further weakness of changing sources. This research tried to improve the accuracy and reliability of the data gathering by crosschecking the information of the *DPReview* with a secondary source of information, *CNET Reviews*. The use of these three sources of secondary data is intended to reinforce the reliability and accuracy of the data set for this research.

The second limitation of this research was the definition of the sampling of technological elements to be used in the analysis of the data. This research tested the complexity of elements. One of the requirements that a product has to satisfy in order to be considered a complex system is the clustering of elements in order to supply a service. This research suggests that enhanced quality of picture is a service that could have been present and common for consumers since 1955. This research needed to find the elements that could be considered as improving picture quality in cameras since 1955. Informal conversations with amateur photographers could only provide the elements that could enhance the picture for digital cameras; this information was dependent on the type of photography they specialised in. This information was also biased towards high-end SLR. These informal conversations gave inconclusive results that could only be applied to the digital SLR market. This research has to rely on the association specified in the literature on camera technologies.

The identification of the technological specification again underlined the limitation of reliance on secondary data.

Another weakness of this research is that at this moment it is only presented as an exploratory study for the empirical testing of the research questions in the camera market. This research cannot make any strong generalisations on whether all complex systems innovate differently or whether cameras are a special example. There are several reasons for this limitation on generalisations or theory building. Firstly, this research only covers one case study, that of cameras; secondly, there is no clear empirical evidence of other empirical studies on complexity innovation in a commercial market, there this research cannot compare the results with any other studies in order to achieve confirmation. This limitation, however, gives this research a novel factor and the opportunity to contribute to knowledge as well as the chance to further research into other technological markets in order to achieve theory building and generalisation of the phenomena. The models used to test the research questions are easy to use and not specific to the camera market, so the hypothetic-deductive approach suggested by this research could be easily applied to other commercial markets in order to achieve a theory building strategy.

5.6. CONCLUSIONS

This research is presented as an exploratory study for the empirical testing of complex systems innovating differently. This research can only undertake an exploratory approach since this research is only investigating one case study and there is no clear evidence in the literature of other empirical studies on complex innovation in commercial markets to support the results for this research. Generalisation or theory building is not possible at this moment in time; however, this limitation opens up the possibility of further research in other technological markets in order to achieve theory building. This lack of clear empirical evidence in the literature offers this research a novel aspect and the opportunity to contribute to the knowledge base. The methodology for this research is summarised as follows (Table 2)

Table 2: Model for empirical testing of complexity and innovation life cycle

Overall aim: investigation of the possibility that: complex systems innovate differently.			
Information needed and data source	**Method used to achieve aims and objectives**	**Conceptual issues/ aims and outcomes**	
Secondary data from *Amateur Photographer/ DPReview/CNET* on technological specification. Cameras categorised according to their core technology (mirroring system). Sampling of the technological elements in the test according to the existing relations of technological elements in camera technology literature.	**Pearson chi-square test** of independence (contingency table). This test highlights pairs of technological elements that show some kind of independency. This test is complemented by **Cramer's V** test, which indicates the strength of those relationships. These two tests allow the identification of epistatic relations and	Technological elements in complex systems seem to display some kind of dependency by which changes in A result in change B. This is also the main reason why complex systems innovate differently. Identifying the particular elements that display dependency C could help innovation strategies.	**Research Question 1**: do the technological elements in cameras display indications of epistatic relations?
Secondary data from *Amateur Photographer/ DPReview/CNET* on technologic alspecification. Cameras categorised according to their core technology (mirroring system). Sampling of the technological elements in the test according to the existing relations of technological elements in camera technology literature.	Definition of cameras as the clustering of technological elements in order to supply a service using twin characteristics approach. **PCA** is used to map the clustering patterns of the technological elements in cameras. This model helps with the identification of the possible clustering of technological elements in order to supply a service.	Technological elements in complex systems seem to be organised in a nested hierarchy. The identification of the hierarchical shape not only helps with the mapping of the dependency element inside the hierarchy but also aids the development of particular innovation strategies according to the hierarchical formation and location of the dependent elements.	**Research Question 2:** do technological elements in cameras cluster in a nested hierarchical structure?
Secondary data from *Amateur Photographer/ DPReview/CNET* on technological specification. Cameras categorised according to their core technology (mirroring system). Sampling of the technological elements in the test according to the existing relations of technological elements in camera technology literature.	The results of the test for Hypotheses 1–2 will offer some light on the classification of cameras as either complex or simple systems. Hypothesis testing is complemented by hierarchical representation in order to classify complex systems according to hierarchical structure and location of epistatic relations into modular, near-	The two main elements that separate complex from simple systems are epistatic relations and nested hierarchical structure. To consider cameras as complex systems they have to satisfy BOTH requirements. The clear identification of cameras as complex systems will offer some light on complex systems innovating	**Research Question 3:** can cameras be considered complex systems?
Secondary data from *Amateur Photographer/ DPReview/CNET* on technological specification. Cameras categorised according to their core technology (mirroring system). Sampling of the technological elements in the test according to the existing relations of technological elements in	Database was divided into ten-year periods. PCA and descriptive statistics were applied to each ten-year period. The comparison of the results period by period in contrast with the innovation occurring in that period will shed light on the issue of innovation changing the clustering pattern.	The literature illustrates how technological elements are linked; this link could change over time due to innovation activities. This is directly linked to RQ1 in case of complex systems' hierarchical formations. If hierarchical changes effectiveness of innovation strategic might be affected	**Research Question 4:** does clustering of technological elements change over time due to innovation activities?

Overall aim: Investigation of the possibility that complex systems innovate differently.			
Method used to achieve aims and objectives	**Conceptual issues/ aims and outcome**		**Hypothesis to be tested**
The first step in the investigation of complex systems innovation is the mapping of the innovation life pattern displayed by cameras. The **Theil's entropy measure** helps the mapping of the communalities/ dissimilarities of the camera market, hence also helps the identification of the possible DD(s) in the camera. This model is complemented with the help of the **Weitzman measure**, which will help in the identification of the emergence of possible niche markets. This ILC on camera will be compared to both complex and classical views of innovation in order to shed some light on whether complex systems innovate differently.	The classical view/ILC illustrates a predictable process of product and process innovation. By comparing this model to the camera innovation pattern it will shed light on the issue of whether ILC can explain innovation in the camera market.	**Research Question 5**: could the ILC explain innovation in the camera market?	**Hypothesis 1:** one of the main characteristics of complex systems is dependency of technological elements. If cameras are complex systems then they will display dependency between the technological elements.
	Of the main and more debatable issues on ILC, one is the standardisation of the market with the emergence of a DD. Studying the innovation life cycle and identifying the possible DD in the camera market could offer some light on the debate of heterogeneity of demand and DD.	**Research Question 6:** does the photographic camera market see the emergence of a DD? **Research Question 6a:** does variety in the camera market give rise to one DD or the rise of different niche markets?	**Hypothesis 2:** the second characteristic of complex systems is the nested hierarchical structure. If cameras are complex systems them they will display a nested hierarchy structure.
	The stylised fact of innovation in complex systems will compare to the innovation on cameras in order to test if complex systems innovation can explain the innovation life cycle pattern for the cameras.	**Research Question 7:** can the innovation life cycle stylised facts explain innovation in the camera market?	**Hypothesis 3**: complex systems differ from simple systems by epistatic relations and nested hierarchy. If cameras are complex systems they will display BOTH elements that separate complex from simple systems.
The result of the testing of Hypotheses 5–7 will shed some light on the issue of complex systems innovating differently from simple systems. This model offers the chance to investigate how differently, and in which manner it is different.	The investigation and comparison of the results for the testing of Hypotheses 5–7 will shed some light on the possibility that complex systems innovate differently from the classical view of innovation. This method also allows distinguishing whether cameras follow treads of one, both or none of	**Research Question 8:** do complex systems innovate differently?	**Hypothesis 4:** if innovation changes hierarchical formation then cameras will display different nested hierarchical formations before and after distinct rounds of innovation activities.

Hypothesis to be tested	Information needed and data source
Hypothesis 5: if the classical view of innovation can explain innovation patterns for cameras then complex systems do not innovate differently from the classical view of innovation.	The technological elements of cameras used in previous tests (Hypotheses 1–4). Cameras in this case will be coded according to their specific technological specification with a unique number, which contains information on core and peripheral technological elements.
Hypothesis 6: if cameras see the emergence of more than one DD then niche markets emerge in order to cope with heterogeneity of demand.	The technological elements of cameras used in previous tests (Hypotheses 1–4). Cameras in this case will be coded according to their specific technological specification with a unique number, which contains information on core and peripheral technological elements.
Hypothesis 7: if complex systems innovation explains the innovation pattern of cameras then complex systems innovate differently from the classical view of innovation.	The technological elements of cameras used in previous tests (Hypotheses 1–4). Cameras in this case will be coded according to their specific technological specification with a unique number, which contains information on core and peripheral technological elements.
Hypothesis 8: if cameras' innovation pattern differs from the classical view of innovation and resembles the innovation patterns of complex systems the then complex systems innovate differently from classical view of innovation/simple systems.	Results from the test of Hypotheses 5–7.

CHAPTER 5-ANALYSIS AND RESULTS

5.1. INTRODUCTION

The focus of this research is the investigation of the possibility that complex systems innovate differently. For the testing of this phenomenon, this research firstly intends to test existence of complex systems and then investigate the innovation patterns display by these systems as opposed to classical views of innovation. Previous chapters found the gaps in the literature that gave rise to the research questions, aims and objectives and the hypothesis to test in order to investigate this phenomena (Table 2). Previous empirical research on photographic cameras (Windrum 2005) found that cameras did not seems to display innovation patterns found in the classical views of innovation. This research is taking this opportunity to test also if a possible reason for this different pattern of innovation is the complexity nature.

The investigation of the literature, in order to find a workable definition of complex systems, gave rise to a set of specification that separates and differentiates complex from simple systems. This research is going to test the possibility that cameras show signs to indicate that they are complex systems in a three stage approach.

Firstly, complex systems seem to show a non-simplistic relation between the elements of the systems. By non-simplistic, it means that the elements of the systems seems to display some kind of dependency by which actions on element A seems to affect or react on elements B or vice versa. This research starts with this phenomenon because according to the literature the dependency between the elements of is one of the main reason that hinder complex systems to innovate through normal paths. According to the literature, the level of complexity is also an accurate indicator of the complexity of the product. The first stage of the testing of cameras as complex systems is the identification of the possible epistatic relations on the cameras elements (hypothesis 1). Previous research in complexity has measure the complexity of the product as a whole, this research is going to test complexity in the way of identifying the distinct elements that carry the dependency on the systems and the elements, which affect these epistatic relations. Testing of complexity in this manner is not only filling the gap in the literature but also helps marketing and design decision to identify the risk elements that at hand when developing any innovation activity. In addition, the testing of the complexity as whole also misses information on the independent elements of the system, even the overall complexity of the systems might be relatively low, that same system might have elements that display higher levels of complexity than other does, even elements showing levels higher than the whole average. The missing of this information can have dramatic results in the overall performance of the product.

The testing of the epistatic relations of independencies between the technological elements of the cameras is reflected in formulation of hypothesis 1

Hypothesis 1: Element in complex systems show epistatic relations

$$Complexity = TC_0 + TC_{(1)}x + TC_{(2)}y + TC_{(3)}z + TC_{(4)}xy + TC_{(5)}xz + TC_{(6)}yz + TC_{(7)}xyz + \varepsilon$$ (Formula 11)

Where TC is the technological elements of cameras such as metering, exposure, shutter stops, lens speed, focal length, and picture pixels, movie pixels.

x, y, xy, xy, xz, yz, xyz are the possible interaction and the effect on complexity.

The second of the elements in the testing of cameras as complex systems is the hierarchical formation of the elements. Complex systems' elements seems to display a characteristic hierarchical formation, this nested hierarchical does not only help to manage complexity by mapping the elements into sub-levels, but also hinders innovation activities. Since elements on complex systems seems to show epistatic relations and those elements have a nested hierarchy shape, when developing any innovation activity the more elements might be affected by those changes. In addition, elements in the nested hierarchy cluster into subsystems in a synergistically manner in order to offer an enhance service.

This research shows this relationship in the testing for the possible clustering of the camera elements with the help of PCA.

There are already evidences in the literature that seems to indicate already some kind of clustering of the cameras technological elements.

$$Picture\ f\ (shutter + lens + mirroring\ systems + light\ sensitive\ film\ (35mm)\ light\ sensitive\ cells\ (digital\ cameras) + \varepsilon)$$ (Formula 5)

$$Exposure\ f\ (shutter\ speed + aperture + \varepsilon)$$ (Formula 6)

$$Metering\ f\ (shutter\ speed + aperture + \varepsilon)$$ (Formula 7)

$$Lens\ f\ (aperture + focal\ length + \varepsilon)$$ (Formula 8)

$$Flash\ synch\ f\ (shutter\ speed + \varepsilon)$$ (Formula 9)

This research is using this possible relations and the twin characteristic approach (Saviotti-Metcalfe 1984) for the formulation of hypothesis 2.

Hypothesis 2: Elements on complex systems cluster in order to supply enhance service.

Enhanced picture quality f (metering + exposure + shutter stops + lens speed + focal length + picture pixels + movie pixels + volume + Ɛ) (Formula 12)

The third part of the testing of cameras as complex systems is the investigation of the combined analysis of the hypothesis one and two and further comparison to simple systems definition. Complex systems seem to display both epistatic relation and hierarchical formation the investigation of the results of the testing of hypothesis one and two on cameras will give light to the identification of cameras as complex systems.

Hypothesis 3: if cameras display dependency between the technological elements and this technological elements cluster in a nested hierarchy then cameras are complex systems.

In addition, this research wants to offer some light on the notion of possible clustering changes in the system. There are evidences in the literature that subsystems/clusters in the nested hierarchy might also change due to innovation activities. Since innovation in one element might change other elements in the same subsystems or other subsystems, the changes in the elements might result an ill fitness in the cluster, hence the clustering change for a better-fitted elements. There is not clear empirical testing of this phenomenon in the literature give offer the opportunity for this research to test for this clustering change due to the innovation activities.

Hypothesis 4: Innovation activities can change the clustering pattern of the hierarchy.

After the testing of cameras as complex systems this research is going to focus its attention to the investigation and testing of innovation pattern display by cameras.

This research is going to map the innovation pattern displayed by cameras with the help of Theil's entropy measure, this approach help to identify possible rounds of innovation life cycle and the possible emergence of DD. Literature on complex systems illustrates that complex systems innovate differently from the classical models of innovation.

This research firstly is going to investigate that classical views of innovation are not suitable to explain the innovation on complex systems. There is already empirical evidences that seems to indicate that cameras do not follow a pattern as indicated by classical views of innovation from 1955-1974 (Windrum 2005). This research is going to use another method (theils's entropy variety measure) and added extra years from 1974-2011. This process will give some light to the notion of cameras not innovating as classical views of innovation.

Hypothesis 5: Cameras display pattern of innovation similar to those suggested by the stylised of classical views of innovation.

This research furthers the testing of classical views of innovation by focusing on the debate on the emergence of DD. There seems to be contradiction between the emergence of DD, which usually signifies the standardisation of the market, and the heterogeneity demand nature of consumer markets. In the case of complex systems, variety also seems to be the norm (Frenken 2006). There are empirical evidences in the market where demand heterogeneity seems to be satisfied by the emergence of distinct niche market. This research is going to test further the innovation pattern by the identification of one or several DD.

Hypothesis 6: Cameras see the emergence of various DD to cope with heterogeneity in the market.

The next step of this research is testing the innovation pattern displayed by cameras towards the stylised fact of complex systems innovation life cycles. Complex systems seem to displayed different pattern of innovation to those of the classical views due to the epistatic relations. This research is going to investigate if complex systems innovation can explain the innovation in cameras.

Hypothesis 7: Cameras display pattern of innovation similar to those suggested by the stylised facts on innovation for complex systems.

By testing the innovation pattern towards both the classical views and complex systems this research is attempting to offer some light on whether complex systems innovate differently. Another benefit of testing for both approaches is that this research might find that cameras even though could seems to show sign of being complex do not show innovation pattern similar to any of the approaches, or cameras might show innovations pattern from both classical and complex systems approach. Another possible scenario that is possible to test with this approach is the possibility that cameras in the early years might show a pattern closer to the classical views of innovation, but as the innovation in the product increases or technological breakthrough might trigger a change towards a more complex systems innovation life cycle.

Hypothesis 8: Complex systems innovate differently from classical view of innovation

5.2. HYPOTHESIS 1: IF CAMERAS ARE COMPLEX SYSTEMS THEN THEY WILL DISPLAY DEPENDENCY BETWEEN THE TECHNOLOGICAL ELEMENTS.

A general look at the table of association (Appendix D) shows that all cameras seem to show evidence of some kind of significant association between the technological elements. These associations vary with camera type and different periods of study. In addition, the strength of the associations (epistatic relations) also seems to vary within cameras' technological elements. These primary results seem to agree with the literature where the level of strength of dependencies might vary across the whole system (Jianmei 1993).

The camera that seems to display the highest association is the disc camera (1975–1984), where the strength of association reaches the maximum level of 1.000 in four out of the eight significant associations (Table 3 DISC CAMERAS 1975–1984. The reason for this high dependency level could be that these cameras were made, as an easy automatic snapshot camera where customers only needed to press the button and the camera would do the rest. This high level of dependency on automatic cameras also seems to be present in the association table for the instant cameras (1975–1984) (Appendix D).

Table 3 Disc cameras 1975–1984

Disc 1975–1984	Metering	Flash	Shutter speed	Focal Length	Lens speed
Exposure	P. Chi (2)=39.000 PR=0.000 LRChi(2)=9.301 Pr=0.010 Cramer V.=1.000	P. Chi(1)=0.0270 Pr=0.869 LRChi(1)=0.0526 Pr=0.819 Cramer V=0.0263	P. Chi(2)=39.000 Pr=0.000 LRChi(2)=9.3013 Pr=0.010 Cramer V.=1.000	P. Chi(9)=39.000 Pr=0.000 LRChi(9)=9.3013 Pr=0.410 Cramer V.=1.000	P. Chi(12)=0.9750 Pr=1.000 LR Chi(12)=1.3607 Pr=1.000 Cramer V.=0.1581
Metering		P. Chi(2)=0.4561 Pr=0.796 LRChi(1)=0.7471 Pr=0.688 Cramer V.=0.1081	P. Chi(4)=40.3619 Pr=0.000 LRChi(4)=11.4548 Pr=0.022 Cramer V.=0.7193	P. Chi(18)=50.0733 Pr=0.000 LRChi(18)=23.3998 Pr=0.176 Cramer V.=0.8012	P. Chi(24)=9.1131 Pr=0.997 LRChi(24)=10.957 Pr=0.989 Cramer V.=0.3418
Flash			P. Chi(2)=0.1173 Pr=0.943 LRChi(2)=0.2194 Pr=0.896 Cramer V.=-0.0548	P. Chi(9)=4.6917 Pr=0.860 LRChi(9)=3.5596 Pr=0.938 Cramer V.=0.3468	P. Chi(12)=39.000 Pr=0.000 LRChi(12)=9.301 Pr=0.677 Cramer V.=1.000
Shutter speed				P. Chi(18)=57.6588 Pr=0.000 LRChi(18)=19.9128 Pr=0.338 Cramer V.=0.8598	Pchi2(24)=14.7086 Pr=0.929 LRchi2(24)=9.5643 Pr=0.996 Cramér's V = 0.4342
Focal length					PChi(108)=1433.157 Pr=0.013 LRChi(108)=81.5397 Pr=0.973 Cramer V.=0.6386

Compact cameras (1975–1984, 1995–2004), even though they do not seem to show many significant associations between the technological elements, the significant association that are present in the tests seem to reach high levels of dependency. The lack of the presence of dependency between the technological elements on compact cameras are somewhat unexpected results since, being an automatic camera; it would somehow be expected to show a higher number of associations as in the case of the other compact cameras (TABLE 4, TABLE 5)

Table 4: Association table Compact cameras 1975-*1984*

CSLR 1995-2004	Metering	Flash	F-stop	Focal Length	Lenses Speed

CSLR 1975-1984	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposure	P. Chi(1)=1.5273 Pr=0.217 LRChi(1)=2.3309 Pr=0.127 Cramer V.=0.3303	P. Chi(1)=0.3214 Pr=0.571 L.RChi(1)=0.2981 Pr=0.585 Cramer V.=0.1515	P. Chi(6)=3.1111 Pr=0.795 LR Chi(6)=4.1375 Pr=0.658 Cramer V.=0.4714	P. Chi(4)=2.121 Pr=0.713 LRChi(4)=3.0910 Pr=0.543 Cramer V.=0.3892	P. Chi(6)=3.111 Pr=0.795 LRChi(6)=4.1375 Pr=0.658 Cramer V.=0.4714
Metering		P. Chi(1)=0.0424 Pr=0.837 LRChi(1)=0.0415 Pr=0.839 Cramer V.=0.0550	P. Chi(6)=4.2000 Pr=0.650 LRChi(6)=5.2943 Pr=0.507 Cramer V.=0.5477	P. Chi(4)=4.2000 Pr=0.380 LR Chi(4)=5.2943 Pr=0.258 Cramer V.=0.5477	P. Chi(6)=7.4667 Pr=0.280 LR Chi(6)=9.1134 Pr=0.167 Cramer V.=0.7303
Flash			P. Chi(6)=7.0707 Pr=0.314 LR Chi(6)=7.9566 Pr=0.241 Cramer V.=0.7107	P. Chi(4)=5.0909 Pr=0.278 LR Chi(4)=5.3224 Pr=0.256 Cramer V.=0.6030	P. Chi(6)=6.0808 Pr=0.414 LRChi(6)=6.3689 Pr=0.383 Cramer V.=0.6590
Shutter speed				P. Chi(36)=30.3333 Pr=0.735 LR Chi(36)=27.0723 Pr=0.859 Cramer V.=0.6009	P. Chi(24)=19.8333 Pr=0.706 LRChi(24)=19.4341 Pr=0.728 Cramer V.=0.5951
Focal Length					P. Chi(24)=42.000 Pr=0.013 LRChi(24)=27.0723 Pr=0.301 Cramer V.=0.8660

Table 5: Association Table compact camera 1995-2004

Exposition	P. Chi(8)=32.6250 Pr=0.000 LRChi(8)=19.6810 Pr=0.012 Cramer V.=0.8814	P. Chi(16)=19.7273 Pr=0.233 L.RChi(16)=17.3750 Pr=0.362 Cramer V.=0.4846	P. Chi(36)=42.8182 Pr=0.202 L.RChi(36)=29.1450 Pr=0.784 Cramer V.=0.7140	P. Chi(60)=66.2727 Pr=0.270 LR Chi(60)=38.5092 Pr=0.986 Cramer V.=0.882	P. Chi(52)=58.8545 Pr=0.239 L.RChi(52)=34.5517 Pr=0.970 Cramer V.=0.8370
Metering		P. Chi(8)=12.7969 Pr=0.119 LRChi(8)=13.5345 Pr=0.095 Cramer V.=0.5520	P. Chi(8)=27.7813 Pr=0.065 LRChi(8)=15.9199 Pr=0.598 Cramer V.=0.8133	P. Chi(30)=34.3438 Pr=0.267 LR Chi(30)=21.4651 Pr=0.873 Cramer V.=0.9043	P. Chi(26)=29.0937 Pr=0.307 LRChi(26)=16.4611 Pr=0.924 Cramer V.=0.8323
Flash			P. Chi(36)=32.229 Pr=0.649 LR Chi(36)=29.0490 Pr=0.788 Cramer V.=0.6194	P. Chi(60)=65.0417 Pr=0.306 LRChi(60)=40.1394 Pr=0.977 Cramer V.=0.8799	P. Chi(52)=40.8917 Pr=0.867 LR Chi(52)=32.3628 Pr=0.985 Cramer V.=0.6977
F-Stop				P. Chi(135)=154.5833 Pr=0.119 LR Chi(135)=83.1416 Pr=1.000 Cramer V.=0.9044	P. Chi(117)=133.7000 Pr=0.139 LR Chi(117)=75.5924 Pr=1.000 Cramer V.=0.8411
Focal Length					P. Chi(195)=439.229.250 Pr=0.047 LR Chi(197)=90.2744 Pr=1.000 Cramer V.=0.9164

Not only do the lens speed and focal lens variables seem to show the highest levels of association across all cameras studies but this result also repeats in 16 of the 18 tests done on all cameras and periods (appendix D). This repetitive association seems to agree with the association suggested by the literature of the enhanced service provided by lenses $Lens\ f\ (aperture + focal\ length + \varepsilon)$ (Formula 8).

The literature also indicates that association, even though weak, might still trigger changes in other elements (Jianmei 1993). For that reason this research is also taking the significant associations with weak strength (<0.3). The non-reflex cameras (NRSL 1955–1964) seem to show a higher number of low associations (four out of ten <0.3) with the rest of the association in the range 0.3–0.4. This research does not really find this phenomenon until the inclusion of the digital technological elements in the compact camera (Appedix D). This in itself is a phenomenon that is worth investigating; cameras (35mm) do seem to show many associations. However, the few significant associations that are displayed seem to show high levels of dependency between the technological elements. However, with the inclusion of the digital elements the number of associations rocketed to fully integrated complexity (all elements showing epistatic relations); however, the strength of the association dropped to levels in the region of 0.1 (Appendix D).

Another phenomenon that stands out in all cameras is that the association patterns seem to change from period to period. SLR cameras seem to keep the metering exposure in four out of the five periods studied (Appendix D). This change of association pattern might be due to a change of clustering due to innovation activities or ill fitness of elements. The testing of Hypothesis 2 could shed some light on this change of epistatic relations pattern year on year.

5.3. HYPOTHESIS 2: IF CAMERAS ARE COMPLEX SYSTEMS THEN THEY WILL DISPLAY A NESTED HIERARCHY STRUCTURE

On first looking at the correlation matrixes (Appendix E), this research found that not all cameras seem to show significant correlations between the technological elements of the cameras. Compact camera that seems to display low levels of dependency between the technological elements also seems to be consistent with the evidences showing seeminglyh insignificant levels of correlation (1965–1974, 1975–1984) (Appendix E). These same periods of low significant correlations seem to coincide with the only period with more epistatic relations than the previous period. This could indicate that the increased number of epistatic relations damages the correlations between the technological elements of the cameras. Another scenario could be ill fitness triggered by some innovation activity, which gives as a result the drop in significant correlation between the elements as indicated by the literature (Kaufman 1995). Further investigation on the descriptive statistics for this periods for the compact cameras (1965-1974, 1975-1984) the results are somewhat surprising since there is seems to be a drop during that year on the maximum metering, exposition, flash options, and focal length follow by a rise on innovation on those elements in following years. This could be a reason for the lack of correlation between the technological elements on those years.

Other cameras that show insignificant correlation values are roll film cameras (1965–1974) and 110 cameras (1965–1974). Roll film camera in this period (1965–1974) has a slight change of epistatic relations; again, this could be due to ill fitness of innovation activities. Study of the period after the drop of significant correlation is not possible in the roll film cameras, since there is not data available due to the exit of the market. 110 cameras, on the other hand, after a low significant correlation start, increase in correlation levels but the locations of the epistatic relations also change, as well as the reduced number of epistatic relations, which possibly shows an improvement in the fitness landscape (Appendices D–E). Study of the following years is not possible because, again, there is not data available due to the exit of the market.

Overall, SLR cameras seem to show the highest levels of adequacy KMO among all cameras studied (Appendix E).

The results of PCA seem to indicate that technological elements cluster into two or three clusters (Appendix F).

The study of the compact cameras, after the low significant correlation levels and reduced number of epistatic relations, seems to indicate a trend of starting with a clustering into three components and finishing in two clusters; all the technological elements seem to gradually move to the first component in the last period, with elements overlapping in the second component. This move of all technological elements to the first components also seems to increase the levels of significant correlations (Table 6). This could also indicate an increase towards greater fitness landscape of technological elements in the compact cameras. These results also seem to indicate that compact cameras seem to go towards a fully integrated complex system structure.

Table 6 Compact cameras CPA

Compact Camera	**1965–1974**			**1975–1984**			**1985–1994**		**1995–2004**	
	Components			**Components**			**Components**		**Components**	
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**1**	**2**
Metering	.733	.369	-.041	.764	.318	-.489	.536	-.410	.748	.543
Exposure	-.293	.274	-.661	.783	.483	-.039	.291	-.695	.813	.434
Shutter speed	.340	.613	-.338	.524	-.459	.623	.622	.265	-.743	-.194
Flash	.216	.028	.691	.464	-.486	.681	.650	.263	.571	-.189
Lens speed	-.794	.379	.189	-.854	.219	-.238	.696	.426	-.534	.726
Focal length	-.127	.816	.383	-.230	.715	.422	-.167	.523	.618	.543
Eigenvalues	1.431	1.398	1.214	2.199	1.767	1.041	2.132	1.487	2.765	1.377
% of variance	23.845	23.306	20.229	36.653	29.454	17.349	30.457	21.245	46.078	22.194
Cumulative % variance	23.845	47.151	67.280	36.653	66.107	83.456	30.457	51.702	46.078	69.032
N. Observation	35			14			121		21	

In the case of the SLR cameras, the scenario is completely opposite to the clustering displayed by compact cameras, SRL CPA starts in two clusters and, right in the last period before the introduction of digitalisation technological elements, the clustering turns into three components. The third and fourth periods (1975–1984, 1985–1994) seem to remain nearly the same (flash moves to the second component), but the clustering of metering exposure and shutter speed seem to remain for the last three periods (Table 7). In this scenario (SRL 1975-1984, 1985-1994) this results do not seem to the remain consistent with the evidences given in the literature since after further investigation of the descriptive statistic for the SRL camera (appendix F) there is seems to be incremental innovation in all the technological elements of the cameras but one (lenses speed).

Table 7 SLR PCA

SLR	**1955–1964**		**1965–1974**		**1975–1984**		**1985–1994**		**1995–2004**		
	Components		**Components**		**Components**		**Components**		**Components**		
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**3**
Metering	-	.612	.531	-.552	.639	.139	.697	-.190	.683	.251	.092

	.292										
Exposure	.570	.460	-.244	-.572	.584	.369	.849	-.176	.786	-.192	-.099
Shutter speed	.745	.373	.517	.067	.643	.401	.752	-.106	.845	.092	-.003
Flash	.525	-.169	.518	.459	.406	-.346	.353	.550	.455	-.642	-.090
Lens speed	-.595	-.326	-.622	.469	-.406	.535	.003	.741	.177	.259	.881
Focal length	.611	.191	.369	.467	-.406	.535	.211	.786	.210	.705	-.465
Eigenvalues	1.967	1.181	1.400	1.285	1.594	1.135	1.942	1.548	2.081	1.084	1.018
% Variance	32.781	19.676	23.339	21.416	26.568	18.919	32.359	25.808	34.689	18.071	16.965
Cumulative % of Variance	32.781	52.458	23.339	44.755	26.568	45.488	32.359	58.167	34.689	52.760	69.725
N. Observation	140		149		91		154		91		

In the case of the compact digital cameras, the introduction of the digital elements seems to break up the clustering pattern emerging in the last period of 35mm (all elements in component 1, Table 6) even though the digital elements do not seem to cluster with any other elements. This situation appears to come back to the phenomenon seen in the last period of compact cameras 35mm, with most elements clustering in the first component. It is not possible at this moment in time to test whether the entire component will cluster in the first component as happened in the compact cameras. In this case the radical innovation of the digitalisation of the image does not seem to make such a profund impact on the the clustering of the technological elements since four out the six technological elements seems to remain in the same clustering patern before and after the radical innovation.

Table 8 Digital compact cameras PCA

Dcompact	**1995-2004**		**2004-2011**	
	Components		**Components**	
	1	**2**	**1**	**2**
Metering	.732	-.225	.570	-.297

Exposure	.808	-.202	.628	-.490
Shutter speed	.696	-.070	.555	-.273
Flash	.319	.502	.151	-.391
Lens speed	-.007	.586	.043	.577
Focal length	.540	-.270	.503	-.084
Pixel picture	.489	.275	.592	.600
Pixel movie	.493	.480	.689	.504
Eigenvalues	2.520	1.076	2.119	1.509
% Of variance	31.469	13.444	26.482	18.862
Cumulative % variance	31.496	44.941	26.482	45.482
N. Observations	947		599	

In the case of the digital SLR (table 9), the digital elements, even though they only cluster with flash, still seem to form a cluster, as opposed to the case of the compact cameras (Table 8). In addition, the clustering of the technological elements: metering exposure and shutter speed that was the pattern for the last three periods on the SLR, even though they are retained, move position to the second component. Again radical innovation on the SRL cameras does not seem to make such a radical changes as the ones displayed by incremental innovation on other periods, however in the SRL seem to make an stronger effect than in the compact cameras.

Table 9 DSLR PCA

DSLR	**1995-2004**			**2005-2011**		
	Components			**Components**		
	1	**2**	**3**	**1**	**2**	**3**
Metering	.105	.799	.095	.347	-.400	.459
Exposure	-.094	.771	.057	.677	.307	.098
Shutter speed	.077	.656	-.063	.714	-.142	.126
Flash	-.102	-.375	.579	.548	.450	.131
Lens speed	.975	-.001	.080	.610	-.314	-.114
Focal length	.972	-.048	.159	-.386	.597	.314
Pixel picture	-.215	.257	.653	.219	.068	-.821
Pixel movie	-.055	-.034	.596	.244	.789	-.069
Eigenvalues	1.980	1.873	1.165	2.019	1.560	1.043
% of variance	24.754	23.411	14.559	25.234	19.498	13.043
Cumulative % variance	24.754	48.165	62.724	25.234	44.732	57.775
N. observation	156			49		

The testing of the association suggested by the literature seems to indicate that not all cameras offer evidence to support these associations apart from the period in the compact cameras where all elements seem to cluster in the first component (Table 6).

In the SLR cameras the technological elements seems to cluster for:

$$Exposure\ f\ (shutter\ speed\ +\ aperture+\ \varepsilon)$$ (Formula 6)

$$Metering\ f\ (shutter\ speed\ +\ aperture+\ \varepsilon)$$ (Formula 7)

$$Lens\ f\ (aperture\ +focal\ length\ +\varepsilon\ )$$ (Formula 8)

In the first period and then move to only Formula 8. 110 cameras also seem to suggest Formula 8 in the first period and Formulas 6 and 7 in the last period.

Overall, cameras seem to indicate significant evidence of possible clustering of the technological elements.

5.4. HYPOTHESIS 3: IF CAMERAS ARE COMPLEX SYSTEMS THEY WILL DISPLAY BOTH ELEMENTS THAT SEPARATE COMPLEX FROM SIMPLE SYSTEMS (HYPOTHESES 1–2)

The investigation of the combined results of both Hypotheses 1 and 2 seems to indicate that most cameras display epistatic relations both across and within clustering elements as indicated by the literature (Appendix F). This result seems to increase the importance of knowing the inner workings of the system, as it seems innovation activities might not only affect the subunits but also other subunits of the system.

All cameras seems to display both a clustering of the elements and epistatic relations (appendix F); compact cameras are the one type that seems to show weaker evidence in the independencies testing (Hypothesis 1) and the clustering seems to move towards all the elements in one component. However, the introduction of the digital elements seems to change this picture and increase the number of epistatic relations to the maximum level of fully integrated complex system (appendix D).

The hierarchical distribution of the elements, however, still seems to show signs of some hierarchical shape of the technological elements (Appendix G). There is an element to highlight in the testing of this type of camera; in the period (1985–1994) (increased number of epistatic relations), the hierarchical formation is nearly flat. These results could support the indication in the testing of Hypotheses 1 and 2 that this period could have been affected by an ill fitness of innovation in one of the elements. This change not only affected the hierarchical formation but also the epistatic relations (Frenken 2006, Zhang and Gao 2010, Zhou 2013).

The investigation of the hierarchical representation seems to show clearly cameras displaying signs of modular complexity in NSLR (1955–1964) (Figure 22), SLR (1955–1964) (Figure 23), and 126 (1965–1974) (Figure 24).

Figure 22: NSLR hierarchical formation (1955–1964)

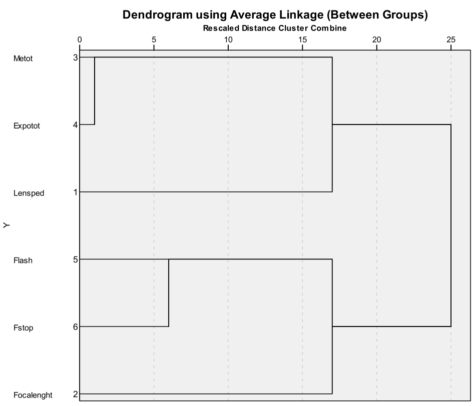


Figure 23: SLR hierarchical formation (1955–1964)

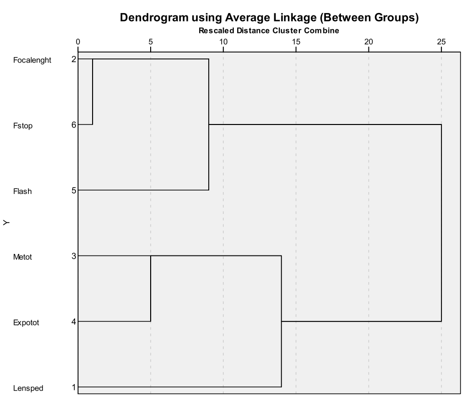
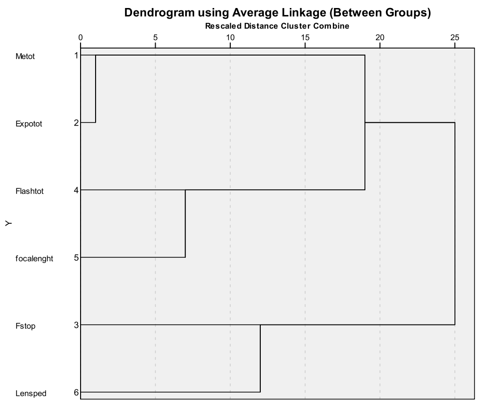
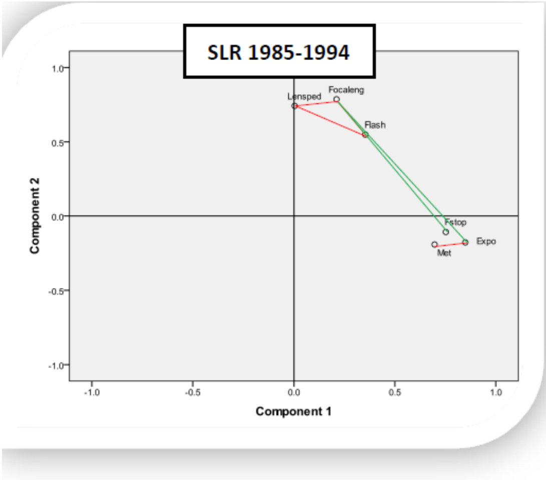


Figure 24: 126 hierarchical formation (1965–1974)



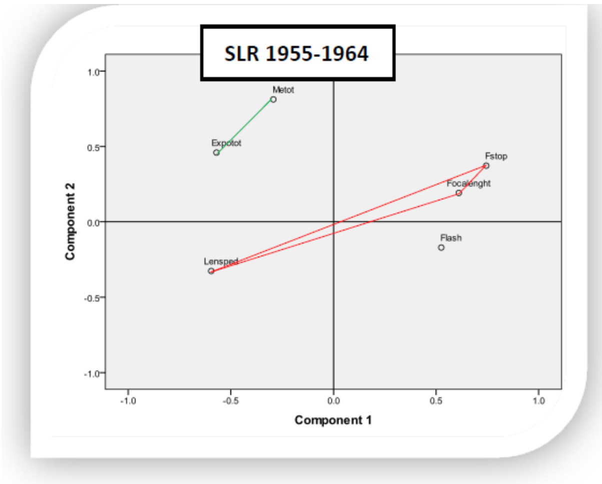
The combination of these results with the investigation of the epistatic relations (Hypothesis 2) (Appendix G) shows that, even though it seems to show a modular complexity structure, the dependencies between the elements do not seem reduced to the elements in the distinct modules but also across modules, as indicated by the literature on quasi-modular structures (Brusoni et at 2007, Yayavaram and Ahuja 2008). As in the case of SRL camera (1985-1994) where even though it seem to show a modular structure with 2 distinct units, the investigation of the epistatic relations revaled epistatic relations both within the units (red connecting line) and across units (green connecting line)(FIGURE 25). This is relevant and suggests caution in using this approach to managing complexity since modules are not completely independent from one another as suggested by the literature.

Figure 25: Representation of epistatic relations SLR 1985-1994



The only camera that seems to display a modular complxity with independent units is the SRL camera in the period 1995 (Figure 26).

Figure 26 Representation of epistatic relations SLR 1955-1964



The level of strength between, across and within clusters seems to vary from camera to camera and from period to period.

In the case of the digital cameras, the DSLR seems to show a hierarchical formation of a modular structure with three units as opposed to two in previous periods (Figure 27). Cameras also seem to change from modular complexity to near decomposable complexity from one period to the next, as in the case of the digital compact cameras (Figure 28).

Figure 27: DSLR hierarchical formation 1995–2004

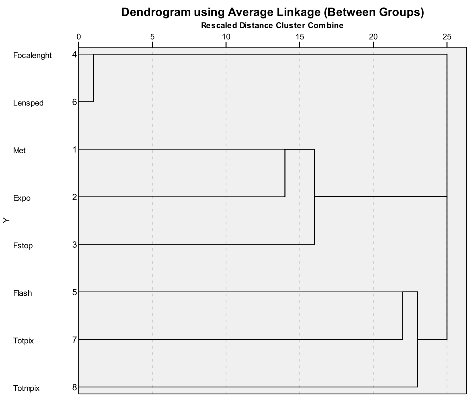
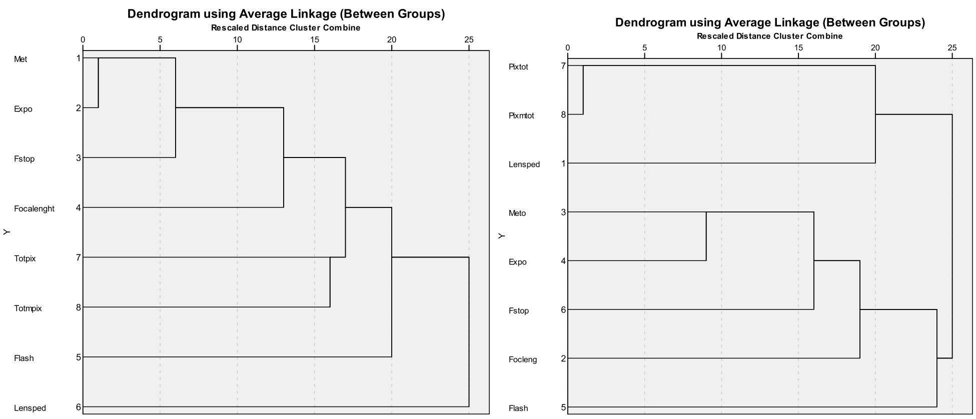


FIGURE 28: Compact digital hierarchical formation (1995–2004) (2005–2011)



The combined investigation of the epistatic relation and nested hierarchy also reveled that as the literature points closest in distant do not necessarily need to represent the highest epistatic relations or independence levels or even show not epistatic relation at all.

FIGURE 29 *Representation of epistatic relations NSLR 1965-1974*

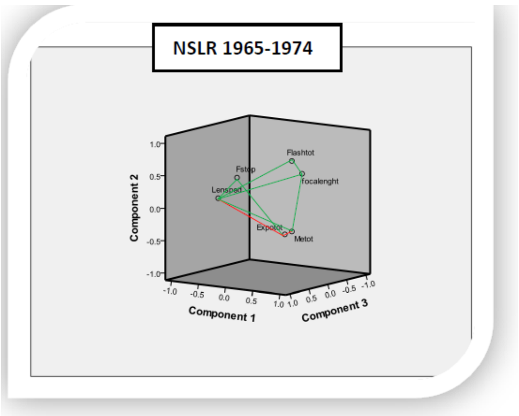
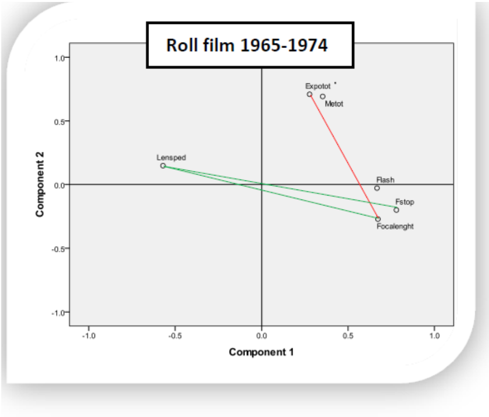


FIGURE 30



The test of Hypothesis 3 seems to show evidence that cameras show hierarchical formations and dependencies between the elements of the clusters. In addition, the testing of Hypothesis 3 seems to display an array of different types of complex systems as being near decomposable complex systems, modular complex system and fully integrated complex system (Appendix G).

5.5. HYPOTHESIS 4: IF INNOVATION CHANGES HIERARCHICAL FORMATION THEN CAMERAS WILL DISPLAY DIFFERENT NESTED HIERARCHICAL FORMATIONS BEFORE AND AFTER DISTINCT ROUNDS OF INNOVATION ACTIVITIES

All cameras seem to show somewhat different clustering patterns, from period to period. Some cameras have more drastic changes (Table 10) and some other cameras keep a degree of clustering, with changes developing around that cluster. SLR cameras (Table 7) seem to keep some clustering pattern in the last three periods of the test. The clustering of metering–exposure–shutter seems to become a pattern. The further examination of this phenomenon and the descriptive statistic of the SLR incremental innovation in those three technological elements show that, apart from the increase of the maximum metering of 3 to 7 in the 1975–1984 period, all other technological elements even small seems to show some kind of incremental innovation.

Table 10: Roll film PCA

Roll film	1955–1964		1964–1974	
	Components		Components	
	1	2	1	2
Metering	.353	.691	-.044	-.769
Exposure	.277	.708	.795	-.182
Shutter speed	.780	-.199	.366	.355
Flash	.668	-.028	.180	.566
Lens speed	-.570	.146	.091	.581
Focal length	.673	-.270	.839	-.202
Eigenvalues	2.034	1.114	1.514	1.394
% of variance	33.895	18.574	25.231	23.234
Cumulative % variance	33.895	52.469	25.231	48.465
No. of observation	80		14	

Not only might innovation activities seem to change to different degrees of magnitude the clustering pattern but they also seem to change the hierarchical formation of the systems. Further analysis of the hierarchical shape of the cameras seems to indicate that cameras change from near decomposable complex system to modular complex system from one period to another.

The testing of Hypothesis 4 seems to indicate that in fact innovation or changes in any of the technological innovations could not only change the clustering elements but also the shape of the hierarchy (appendix G). It is important to highlight this hierarchical change from period to period since the literature indicated the hierarchy of the product not only dictates the organisational goals but also the innovation/marketing strategies that would be most cost efficient for that that type of product.

PHOTOGRAPHIC CAMERAS' INNOVATION PATTERNS

The previous section's results seem to indicate that in general cameras seems to show indication or evidences consistent witht the definition of complex systems since most cameras show indications of some type of hierarchical clustering and epistatic relations between the technological elements of the camera. The evidence that seems to support Hypothesis 3 allows this research to further investigate the notion that complex systems innovate differently. The investigation of the innovation of the complex system is going to be operationalized, firstly, with the application of the Theil's entropy measure to the coded cameras from 1955. The representation of Theil's entropy measure will help this research to shed some light on the testing of appropriateness and applicability of stylised facts to the classical view on innovation (Hypothesis 5) and the emergence of the possible dominant design and/or drop in variety (Hypothesis 6).

The Weitzman measure is used as complementary measure to Theil's entropy measure and will help this research to answer Hypothesis 6 on the possible emergence of niche markets.

The combination of the results of the entropy and the Weitzman measure compared to the stylised facts on complexity innovation and their application to camera innovation will shed some light on Hypothesis 6. The final and main question for this research on whether complex systems innovate differently (Hypothesis 8) will be addressed by testing Hypotheses 5–7.

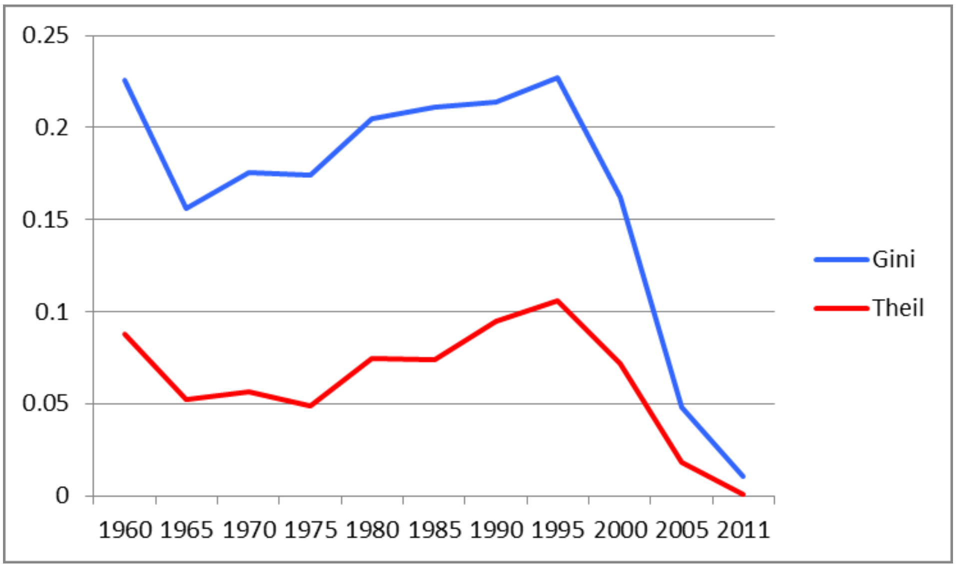
5.6. HYPOTHESIS 5: IF THE CLASSICAL VIEW OF INNOVATION CAN EXPLAIN INNOVATION PATTERNS FOR CAMERAS THEN COMPLEX SYSTEMS DO NOT INNOVATE DIFFERENTLY FROM THE CLASSICAL VIEW OF INNOVATION

According to the theory of the innovation life cycle as illustrated in Chapter 2, variety will experience a high peak at the beginning of the life cycle, then after the emergence of a DD variety drops and innovation shifts to process innovation. After the application of the Theil's entropy measure (Figure 31) it seems that cameras seems to see an increase on variety at the beginning of the ILC (1955) and dropped round about 1965 as indicated by the stylised fact on classical views of innovation; however, variety after this period (1955-1965) rose slightly again and then experienced another drop around 1975. These results are also confirmed by Windrum's (1995) study on the amateur photographer. This research seeks to highlight the possible increase of validity of these results: since this author used a different method of analysis (hedonic price regression), results are supported by this research using the entropy measure, hence the possible increase in validity of these results. Variety rose once again after 1975 until 1980, and then seemed to stay stagnant until about 1990 when variety once again rose dramatically until nearly 2000, when it dropped completely (Figure 31).

Literature on the classical view of innovation seems to indicate that, after an initial drop in variety and standardisation of the market, innovation will shift to process innovation. The results on camera innovation patterns seem to contradict this notion since, after an initial round of innovation and drop in variety, variety seems to increase repeatedly to a total of four distinct rounds of innovation (Figure 31).

So far the investigation of the applicability of the classical model of innovation life cycles seems to offer unconlcusive results in order to offer any light on the hypothesis 5. If only taking into account the suggestion of the ILC offered by Abbernathy-Utterback (1975) where variety increase to a peak where a DD emerges and variety drops and innovation activies swift their focus to process innovation, the results of cameras seems to offer evidences consistent to the Widrum (2005) where cameras do not seems to follow that ILC pattern. However, if takng into account the suggestion by other authors where the innovation is a iterate process (Fosters 1986) then innovation in cameras could support at this moment in the investigation that suggestion.

Figure 31: Theil's Entropy measure cameras 1955–2011



5.7. HYPOTHESIS 6: IF CAMERAS SEE THE EMERGENCE OF MORE THAN ONE DD THEN NICHE MARKETS EMERGE IN ORDER TO COPE WITH HETEROGENEITY OF DEMAND

The drop in variety also seems to indicate the emergence of a dominant design in the market; however, it seems even clearer after 2005, when variety drops to near the zero value. This result seems to be consistant with hypothesis 5 (only in the instance of taking the fall in variety on its own) but also of Hypothesis 6 on the emergence of a dominant design.

According to the representation of innovation patterns of cameras, it seems that variety falls four times as opposed to one, more remarkably after 2000. Analysis of the frequencies table (Table 11) shows that non-reflex (rangefinder) cameras seemed to dominate the market followed by SLR just before 1965; these results seems to supported by Windrum's (2005) results. This dominance changed just before 1980, when SLR and 126 dominated the market; these results also supported by Windrum's (2005) results. Only a decade later, compact cameras supplanted 126; these two types stayed dominant in the market, and were only supplanted by the digital version, which dominated the market after 2000. This results suggests that camera market sees the emergence of a dominant design, as suggested by the literature (Abernathy and Utterback 1978, Anderson and Tushman 1990, Tushman and Murmann 1998). Regarding hypothesis 6, this research should highlight several specifications. The camera market sees a fall in variety, which on its own seems to be consistant with Hypothesis 6. However, the camera market seems to display evidences for t two dominant design in all periods where the variety drops (Table 11); this seems to disagree with the idea of the standardisation of the market as indicated by the literature (Abernathy and Utterback 1978) – on the other hand, these results seems to offer some light into the issue of manage the heterogeneous nature of demand and emergence of dominant design.

Table 11: Camera frequencies % 1955–2011

	Roll film	**NSLR**	**SLR**	**110**	**126**	**Compact**	**Instant**	**Disc**	**DSLR**	**DCompact**
1960	58.82	3	11.1							
1965	12.16	48.63	30.04							
1970	11.95	38.35	28.76	2.39	15.75	2.73				
1975		3	26.92	10.39	18.07	11.53				
1980		2.23	26.49	37.32	4.60	2.53	3.22			
1985		20.35	31.78	3.07	0.07		2.1	13.92		
1990			48.85			51.14				
1995			64.10			34.61			1.28	
2000			26.08			9.56			5.21	58.26
2005			8.16			1.66			7	82.83
2011									13.69	86.30

Regarding the representation of the Theil's entropy complementary measure, Weitzman shows this trend in a more graphic way. During the first period (1955–1965) it seems that cameras follow the same innovation trajectory (Figure 32). The next period (1965–1974) shows indications towards a with a blur emergence of two groups, possibly indicating the emergence of two niche markets

Figure 32: Weitzman measure 1955–1964

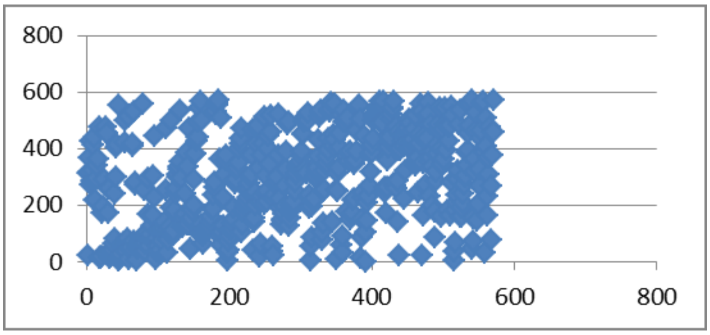
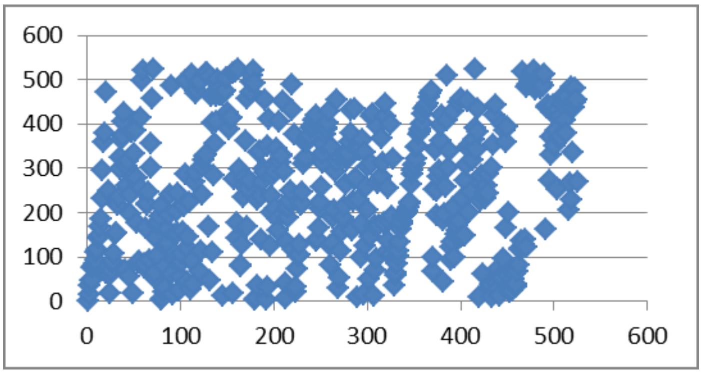
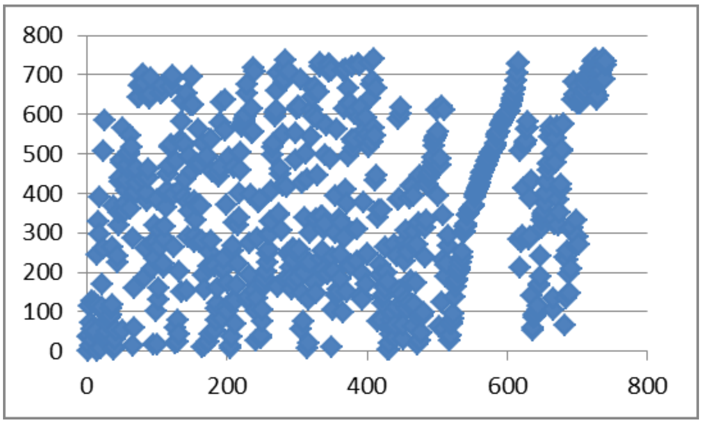


Figure 33: Weitzman measure 1965–1974



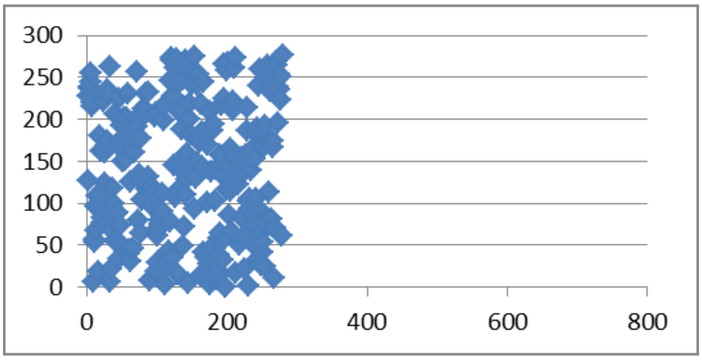
This separation becomes clearer in the next period (1975–1984) where there seems to be a distinct group separating from the rest (Figure 34).

Figure 34: Weitzman measure 1975–1984



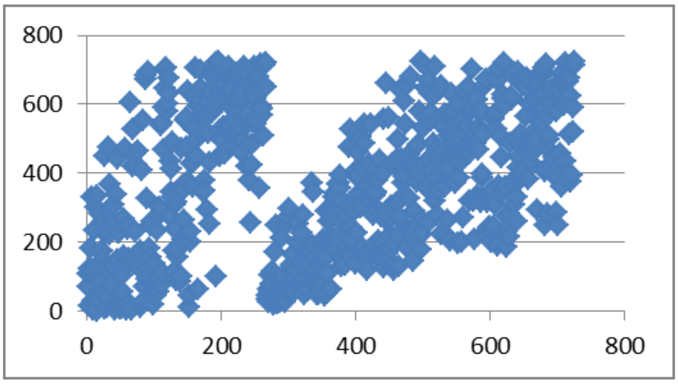
The results showing for the next period (period 1985–1994) are very puzzling: after a pattern that seems to indicate the formation of niche markets, all cameras group on one side of the graph. This could be due to similarity of specifications even though frequencies show a distinct emergence of SLR and compact cameras as the dominant designs (Figure 35).

Figure 35: Weitzman measure 1984–1994



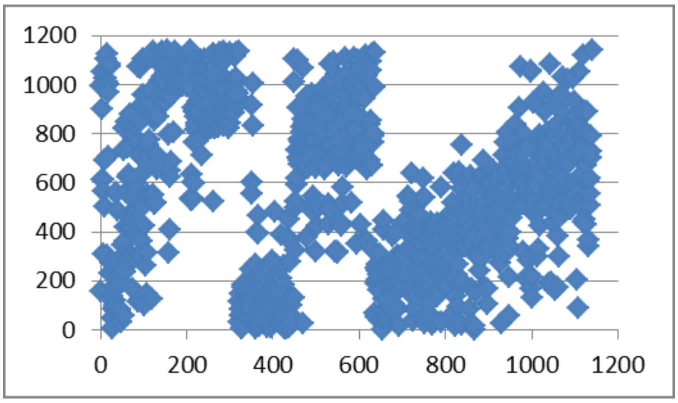
With the appearance of the digital cameras during the period 1995–2005, the representation of the distance between the models shows a very clear bifurcation of cameras into two distinct niches (Figure 36).

Figure 36: Weitzman measure 1994–2004



What is more surprising is that the exit of non-digital cameras gives rise to not two but three distinct groups (Figure 37). This could be due to the emergence or the so-called "SLR-type" cameras, which offer the easiness of use of compact cameras but with the high technological specification of SLR.

Figure 37: Weitzman measure 2005–2011



This supports the idea that dominant design could bifurcate into two dominant designs (Frenken, Saviotti et al. 1999); in the case of the amateur cameras we found there are indications of three possible niche markets. First, the traditional snap-shooter: this consumer is likely to use the camera on special occasions. Their level of knowledge of photography or cameras is relatively low, hence the need for an easy, simple camera. Second: any snap-shooters that have a higher knowledge of cameras, despite possibly only using them for special occasions. They might regard picture quality more highly than the previous group. And the last group is that of the amateur photographer.

The analysis of the Weitzman measure seems to suggest that the conbined results of Theil's entropy-Weitzzman analysis seems to display evidences that support hypothesis 6 regarding dominant designs and niche markets. A dominant design might emerge but this dominant design might then bifurcate into distinct niches in order to handle heterogeneity of demand.

The analysis of the Theil's entropy measure and Weitzman measure forms a picture of camera innovation. At the beginning of the innovation life cycle it seems that variety reaches a peak, offering different solutions to a technological problem. The emergence of the rangefinder and SLR cameras as possible dominant designs seems to have had an effect on the variety, which later drops. This same cycle seems to be repeated four times during the period studied in this research. During periods of low variety, incremental innovation in products only seems to be disrupted by another technological breakthrough until it drops almost to zero at the end of the innovation life cycle studied here. This pattern almost seems to indicate that dominant designs emerge as the best solutions for given periods but not as global solutions; no ultimate solution appears to arrive after three rounds of innovation and 54 years of different incremental and radical trial and error offered by cameras firms.

5.8. Hypothesis 7: If complex systems innovation explains the innovation pattern of cameras then complex systems innovate differently from the classical view of innovation

The information on the stylised facts on complex systems innovation (Table 1) formed the basis for the testing of Hypothesis 7.

Complex systems seem to see the emergence of a DD in the core technology of the systems; once these core dominant designs are established in the market, innovation activity seems to be focused on the peripheral elements. The camera market seems to also display a dominant design in the core technology (SLR, compact) and after the definition of the DD core technology; innovation seems to focus on the peripheral elements (metering, exposure, increased flash options, lens and shutter increase speed and so on). Cameras even display the emergence of dominant design in one of the peripheral elements of the hierarchy – 35mm film and digital capture.

Another factor that seems to agree with the innovation pattern displayed by cameras is that of variety and niche creation. Cameras seem to display more than one DD in order to satisfy heterogeneous demand. As the literature indicated, in complex systems variety is the norm (Frenken 2006).

The ILC pattern display by the cameras seems to show evidences that seems to resemble more the suggestion of ILC offered by complex systems. Cameras innovation evidences seems to support hypothesis 7.

5.9. HYPOTHESIS 8: IF CAMERAS' INNOVATION PATTERN DIFFERS FROM THE CLASSICAL VIEW OF INNOVATION AND RESEMBLES THE INNOVATION PATTERN OF COMPLEX SYSTEMS THEN COMPLEX SYSTEMS INNOVATE DIFFERENTLY FROM THE CLASSICAL VIEW OF INNOVATION/SIMPLE SYSTEMS

The camera market seems to display the stylised facts found in both the classical view and complex systems view. Cameras seem to display the stylised facts of the classical view in that, after a period of ferment, increased variety, this variety drops, and a possible dominant design seems to emerge. In the case of the camera market, the dominant design came in the case of the core technology of the camera, as illustrated by complex systems theory. Innovation after the emergence of the core dominant design moves to the peripheral elements. The camera market also sees the emergence of a possible dominant design in the peripheral elements in the shape of 35mm and then in the digitalisation of the image. These peripheral element dominant designs seem to agree with the literature on complex systems innovation (Murmann and Frenken 2006). Cameras seem to innovate differently in that, after the emergence of a core technology as the dominant design (SLR/compact cameras), innovation does not seem to focus on process innovation but on the peripheral elements with the emergence of their own dominant design (35mm/digital image). Variety in the cameras does not seem to drop as drastically as suggested by the classical view: variety does not markedly drop until the fourth round of innovation.

In general terms, camera innovation patterns seem to rather display a ILC that resembles more complex systems innovation stylised facts; however, they still share the same classical view stylised facts, such as the initial drop of variety and emergence of the DD. In the case of the cameras, it is only found at the beginning of the innovation life cycle. Either way, it seems that cameras seem to show indications of complexity and the innovation of cameras seems to show evidence that differs from or contradicts the classical view of innovation.

5.10. Conclusion

This chapter has been dedicated to the analysis and investigation of the possibility of the amateur camera being considered as a complex system. The second part of this research moved towards the investigation of the innovation pattern. These results were later compared to the classical view of innovation in order to offer some clarity on the issue of complex systems innovating differently.

This research focused on the idea that changes or innovation activites in the components of systems might change the clustering pattern. This research focuses its attention on the introduction of metering systems, and shift of 35mm film for digitalisation of the image. Other activities that could change the clustering pattern are incremental innovation in any of the elements.

Hypothesis 1's results gave an indication that all cameras seem to display evidences for some kind of epistatic relations between the technological elements of the cameras. These epistatic relations change with number and strength from camera to camera so this research could hypothesise that the type of core technology of the cameras could have some effect on the number of epistatic relations of the camera and the way they are shaped. The highest strength of epistatic relations seems to be displayed by the snapshot cameras. There is a point to highlight in this case and it is that compact cameras, although seeming to display high levels of dependency strength, are also the cameras with a lower number of epistatic relations.

This research also took levels of strength <0.3 since the literature suggested that weak independence levels could also affect other elements in the system. This research found that cameras seem to display lower levels of dependency at the beginning of the life cycle or after a technological breakthrough, as in the case of roll fill and non-reflex cameras, which seem to show lower levels of dependency. In addition, after the introduction of the digital technological elements, epistatic relations seem to weaken but the number of epistatic relations in both compact cameras and SLR is doubled (in the case of compact cameras, making them fully integrated complex system).

This research found signs that seem to be consistant with Hypothesis 1, where technological elements display epistatic relations.

Hypothesis 2 tested for the second condition for considering technological artefacts as complex systems. All cameras seem to display some kind of clustering. Technological elements seem to cluster mainly into two or, rarely, three components, which could indicate two or three services. These services could be identified with the association suggested by the literature as metering, exposure and lenses. Lens service characteristics seem to be the most common in the results of Hypothesis 2. The hierarchical formation seems to display various forms of near-decomposable complex systems and modular complex systems. The identification of the shape of the hierarchies is important for the management of innovation activities, since, as suggested by the literature, hierarchical structure not only dictates the most efficient innovation strategies to follow but also the main goal or objective that a company might pursue (Zhan and Gao 2010).

This research found evidence that seems to support Hypothesis 2 since cameras display some hierarchical formation. There is only one case in the compact cameras where this hierarchical formation is rather flat.

The results of the testing seem to support Hypotheses 1 and 2 hence being consistent with the support by evidences of hypothesis 3 of cameras show indication to support complex system definition. All types of cameras seem to display both epistatic relations and hierarchical formation of the technological elements.

The evidences that seem to support hypothesis 3, considering cameras as complex systems, allow this research to follow on with the investigation of whether complex systems innovate differently.

An extra element that this research included was the testing of whether innovation activities could change the way in which elements cluster in order to offer an enhanced service (Hypothesis 4). According to the results of the investigation, all cameras seem to have some clustering change period by period to variant degrees of magnitude. These results were compared with the descriptive statistics of the cameras in order to confirm that innovation (incremental, radical) took place in that particular period, and the results confirmed that even in cases with small incremental innovation in the technological elements, the clustering changed.

There are different points to highlight in the testing of this hypothesis; for the SLR there seem to be changes until the clustering of metering/exposure/shutter speed becomes established in the clustering pattern and remains for the last three periods of the study. This stable clustering might indicate signs for a maximum fit of these elements.

In the case of the compact cameras, all the technological elements seem to change clustering patterns until they all cluster in the first component. This could be an indication of the automation of the camera, where all elements are interconnected so that consumers only need to press a button and take a picture.

The changes in the clustering also affect the hierarchical formation; cameras seem to change from near decomposable complex system to modular complex system from period to period.

These results seem to indicate that innovation activities not only change the clustering elements of cameras but also the hierarchical formation of the system.

After the mapping of the innovation life cycle of cameras, this research was ready for the investigation of whether complex systems innovate differently.

There are several points to highlight from this analysis:

6. Technological elements seem to cluster in order to offer a service.
7. Incremental innovation seems to change the way elements cluster to offer a service.
8. Elements that form a cluster do not necessarily need to show a significant level of association or dependency.
9. Dependency cannot only be found within elements that cluster together; association and dependency levels can also spread across other elements in other clusters.
10. Incremental innovation might not only change the clustering pattern; there is indication that these incremental innovations can also increase the relations between the elements and level of dependency.
11. Innovation activities could also change the hierarchical shape of the system.
12. The inclusion of new elements shows indications towards an increase in complexity and relations between elements, even though this might not have such a deep effect on the clustering pattern.
13. Even elements that show indications of modularity, such as lenses and flashes, can show indications of higher dependency.

14. Elements that cluster together do not necessarily need to show high levels of association of dependency.
15. Modularity structures, which are characterised as having independent modules, also display dependency between elements in different modules; this awareness is crucial for any innovation activity in this structures.
16. Points closest on the clustering map might not show the highest levels of dependency.

Most of these results are confirmed by the literature review in previous chapters; however, what it is interesting is the dependency: it is not reduced to the elements that cluster together but can spread across the whole system. This is very important for marketing activities and design decisions. Changes within a cluster might affect functioning of other elements in other clusters, hence risking the performance of the other cluster. This raises the importance of knowing the inner workings of the system.

The investigation of the life cycle also discovered that variety indeed increases at the beginning of the market and this variety falls after the emergence of a possible dominant design, which seems to support Hypothesis 5. However, in the case of photographic cameras there is an indication of this cycle repeating four times since 1955; this repeated cycle of innovation give inconclusive results for Hypothesis 5. Abbernathy-Utterback (1976) suggests only one round of innovation and DD; on the other hand, other authors (Foster 1986) suggest innovation as a cycle that could repeat itself. In the case of the amateur photographer, there is indication of a bifurcation of the dominant design into two distinct niches: amateur photographer and casual snap-shooter. In the last period, there is evidence of the emergence of three distinct niche markets.

The testing of Hypothesis 7 on complex systems innovation, on the other hand, gives a clearer picture of the pattern displayed by cameras. Cameras, after an initial drop in innovation, eventually have two DDs, as opposed to one as suggested in the classical view of innovation. These DDs are found in the core technology of the systems, as indicated by complex systems theory, as opposed to the entire product. This core technology facilitates the variety and satisfaction of heterogeneous demand. These results seem to agree on the stylised fact of complex systems that variety is the norm (Frenken 2006).

Once the core technology DD is established, innovation focuses on the peripheral elements of the systems, which also display their own DD as in the case of the 35mm and in the digitalisation of the camera. These phenomena are illustrated by complex systems innovation. The evidence on whether cameras innovate as complex systems theory seems stronger than the evidence for the classical view of innovation, hence the suggesting the support Hypothesis 7.

The inconclusive and somewhat blurred illustration of cameras by the classical view of innovation but the indication that cameras innovation seems to follow a pattern towards the complex systems innovation since to indicate that the classical view of innovation are not very efficient or applicable in the case of complex system.

These results seem to indicate that, even though complex systems might show signs that could be related to the classical view of innovation, in fact they seem to display a pattern of innovation distinct from those suggested by the classical view of innovations, hence the acceptance of Hypothesis 8.

The results of the hypothesis testing and their relation to the aims and objectives of this research is summarised in table 12.

TABLE 12 Hypothesis testing results

Hypothesis	Aims and objectives	Methodology	Results
Hypothesis 1: one of the main characteristics of complex systems is dependency of technological elements. If cameras are complex systems then they will display dependency between the technological elements. **Supported by evidences**	Technological elements in complex systems seem to display some kind of dependency by which changes in A result in change B. This is also the main reason why complex systems innovate differently. Identifying the particular elements that display dependency could help effectively develop innovation strategies.	Pearson's chi-square test of independence (contingency table). This test highlights pairs of technological elements that show some kind of independency. This test is complemented by Cramer's V test, which indicates the strength of those relationships. These two tests allow the identification of the epistatic relations and strength of those relations.	All cameras seem to show some technological elements that show dependency on other elements in the system. Different cameras show different patterns of dependency between elements Dependency levels not only vary between different cameras but also within different subunits (clusters) of the same camera. These varying levels of strength raise caution in innovation activities since the effect on other elements of the systems might vary from one element to another in the same system according to the strength of the dependency.
Hypothesis 2: the second characteristic of complex systems is the nested hierarchical structure. If cameras are complex systems them they will display a nested hierarchy structure. **Supported by evidences**	Technological elements in complex systems seem to be organised in a nested hierarchy. The identification of the hierarchical shape not only helps with the mapping of the dependency elements inside the hierarchy but also aids the development of particular innovation strategies according to the hierarchical formation and location of the dependent elements.	Definition of cameras as the clustering of technological elements in order to supply a service using the twin characteristics approach. PCA is used to map the clustering patterns of the technological elements in cameras. This model helps with the identification of the possible clustering of technological elements in order to supply a service.	Technological elements in cameras seem to cluster into two and three components that seem to indicate the provision of two/three services by cameras. Technological elements also seem to overlap into two distinct components or cluster. This component overlap gives rise to caution since changes in these particular elements, depending on the strength of the epistatic relations, might affect not only one but two clusters at the same time.
Hypothesis 3: complex systems differ from simple systems by epistatic relations and nested hierarchy. If cameras are complex systems they will display BOTH elements that separate complex from simple systems. **Supported by evidences**	The two main elements that separate complex from simple systems are epistatic relations and nested hierarchical structure. To consider cameras as complex systems they have to satisfy BOTH requirements. The clear identification of cameras as complex systems will shed some light on complex systems innovating differently from simple systems.	The results of the test for Hypotheses 1–2 will shed some light on the classification of cameras as either complex or simple systems. Hypothesis testing is complemented by hierarchical representation in order to classify complex systems according to hierarchical structure and location of epistatic relations into modular complex system, near-decomposable complex system, fully integrated complex system etc.	All cameras to different degrees and magnitudes displayed both epistatic relations and clustering of the elements; hence, the results of Hypotheses 1–2 seem to indicate that cameras could be considered complex systems. However, the results of clustering and dependency combined seem to disagree with the suggestion in the literature that the closest points show the highest levels of dependency in the hierarchy. The hierarchical representation seems to indicate that cameras display hierarchical structures, both modular complex system and near decomposable comlex system. It is important to highlight that in the case of cameras, as also suggested by the literature, modular structures' units are not as independent as suggested by some authors but in fact levels of dependency are found across other units.
Hypothesis 4: if innovation changes hierarchical formation then cameras will display different nested hierarchical	The literature illustrates that technological elements are linked; this link could change over time due to innovation	Database was divided into ten-year periods. PCA and descriptive statistics were applied to each ten-year period.	There seems to be indication of clustering changes in all periods studied for all cameras; further comparison with the descriptive

formations before and after distinct rounds of innovation activities. **Supported by evidences**	activities. This is directly linked to RQ1 in case of complex systems hierarchical formations. If hierarchical changes effectiveness of innovation strategy might be affected RQ2.	The comparison of the results period by period in contrast with the innovation occurring in that given year will shed light on the issue of innovation changing the clustering pattern.	statistics revealed that all those periods showed some kind of innovation activities, whether it was just incremental or more radical. At this moment in time this research cannot ensure this clustering change is due to innovation activities alone, since this study unfortunately does not offer a period where no innovation was present to test whether clustering still changed. These results seems to indicate that not only did the clustering change but also the hierarchical formation, with some cameras going from modular to near-decomposable from one period to another. These findings are not only relevant but also crucial for the implementation and effectiveness of innovation activities.
Hypothesis 5: if the classical view of innovation can explain innovation patterns for cameras then complex systems do not innovate differently from the classical view of innovation. **Inconclusive Results**	The classical view/ILC illustrates a predictable process of product and process innovation. Comparing this model to the camera innovation pattern will shed light on the issue of whether ILC can explain innovation in the camera market.	The first step in the investigation of complex systems innovation is the mapping of the innovation life pattern displayed by cameras. The entropy measure helps the mapping of the communalities/dissimilarities of the camera market, hence also helps the identification of the possible DD(s) in the camera. This model is complemented with the Weitzman measure, which will help the identification of the emergence of possible niche markets. This ILC of cameras will be compared to both complex and classical views of innovation in order to offer some light on whether complex systems innovate differently.	Cameras seem to display a period at the beginning of the ILC where variety increases to a large degree; after this period of increase, variety decreases once again as indicated by the classical view of innovation. However, in the case of cameras the decrease in variety sees two DDs as opposed to one. After the DDs emerged, innovation did not completely shift to processes; instead; cameras seemed to display another three other rounds of innovation with another two DDs in each round.
Hypothesis 6: if cameras see the emergence of more than one DD then niche markets emerge in order to cope with heterogeneity of demand. **Supported by evidences**	One of the main and more debatable issues on ILC is the standardisation of the market with the emergence of a DD. Studying the innovation life cycle and identifying the possible DD in the camera market could offer some light on the debate on heterogeneity of demand and DD.		Cameras see the emergence of two DDs in each round of innovation, Further investigation seems to indicate that in all periods there seem to be markets (amateur, snapshot); in the last period studied there seems to be the creation of a extra niche market (automatic cameras with the high specs of amateurs). These results seem to indicate that in the case of cameras DDs have to bifurcate into niche markets in order to cope with heterogeneity of demand.
Hypothesis 7: if complex systems innovation explains the innovation pattern of cameras then complex systems innovate differently from the classical view of innovation.	The stylized facts of innovation in complex systems will be compared to the innovation in cameras in order to test if complex systems innovation can explain the innovation life cycle pattern for the cameras.		This model seems to explain better the innovation pattern displayed by cameras. Cameras have several DDs, as variety is the norm for complex systems. They see the emergence of a DD in the core technology (mirroring system); after the establishments of these DDs, innovation moves to the peripheral elements, which, in the camera case, also show the emergence of DDs (35mm,

Support by evidences			digitalization of image).
Hypothesis 8: if camera innovation patterns differ from the classical view of innovation and resemble the innovation patterns of complex systems then complex systems innovate differently from the classical view of innovation/simple systems. **Supported by evidences**	The investigation and comparison of the results for the testing of Hypotheses 5–7 will shed some light on the possibility that complex systems innovate differently from the classical view of innovation. This method also allows it to be distinguished whether cameras follow treads of one, both of none of the models illustrated.	The result of the testing of Hypotheses 5–7 will offer some light on the issue of complex systems innovating differently from simple systems. This model offers the possibility of investigating how differently they do so, and what the differences are.	In the case of cameras, at the beginning of the ILC (1955-1965) seems to initially resemble the classical view of innovation; however, this situation changes when cameras see the emergence of two DDs, as indicated by complex systems innovation theory. Overall, cameras seem to innovate as indicated by complex systems innovation theory with the only commonality with the classical view of innovation being the initial increase of variety at the beginning of the ILC. Cameras give potential evidence to indicate that complex systems innovate differently from the classical view of innovation/simple systems.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

This research was exploratory investigation on the notion in the literature that complex systems innovate differently (Frenken 2006). This research took the example study of photographic cameras since previous research on innovation ILC for this case already seems to give evidences of not following a pattern as suggested by classical views of innovation. The added 26 years gave light to some of the issues regarding the ILC for cameras. For the investigation of this phenomenon, this research first investigated the literature on complex systems theory in order to achieve a workable definition for later comparison to a definition of simple systems. The identification of a complex systems definition not only helped for the identification of this research example study (cameras) as complex systems but, also, the comparison with simple systems offered a clear determination of whether cameras display traits similar to complex or simple systems or both or even neither of the definitions.

The investigation of the literature on complex systems suggested that one of the main factors that separate complex from simple systems is the dependency between the elements. This dependency is also the main reason for complex systems to innovate differently. Technological elements in complex systems relate in a non-simplistic manner where the sum of the parts is more than the whole (Simon 1962). Further investigation of the complex systems literature found that complex systems not only display epistatic relations but also the elements in complex systems form a nested hierarchy structure. Hierarchical structure is defined as "a system that is composed of interrelated subsystems, each of the latter, in turn, hierarchic structure until we reach the lower level of elementary components" (Simon 1968, p.87). Technological elements in cluster systems cluster in order to offer an enhanced service or synergy effect.

The investigation of complex systems theory gave rise to the emergence of a workable set of characteristics for complex systems that separated complex and simple systems. Complex systems for this research are systems that show evidences of dependency betweent the technologicale elments (epistatic relations) AND these technological elements are structurilised in a hierarchical manner.

Consistent with the definition of complex systems this research also suggested a further chategorisation of complex systems according to the magnitude of the epistatic relations and the hiercharchical structure into:

- Fully integrated complex system: All the elements of this product show a certain level of dependency.
- Fully decomposable: None of the elements show any type of relations of dependency or simple system.
- Near decomposable complex systems: elements might show weak (but not negligible) dependency.
- Modular complex system: this system takes the shape of a hierarchy formed of units that are highly connected between the elements within the distinct units but loosely connected within other units.

The results of the investigation of the literature and the link to the main aims and objective and the process and models suggested to achieve those aims is summarise in (TABLE 2).

Table 2: Model for empirical testing of complexity and innovation life cycle

Overall aim: investigation of the possibility that: complex systems innovate differently.				
Hypothesis to be tested	**Information needed and data source**	**Method used to achieve aims and objectives**	**Conceptual issues/ aims and outcomes**	
Hypothesis 1: one of the main characteristics of complex systems is dependency of technological elements. If cameras are complex systems then they will display dependency between the technological elements.	Secondary data from *Amateur Photographer*/ *DPReview*/*CNET* on technological specification. Cameras categorised according to their core technology (mirroring system). Sampling of the technological elements in the test according to the existing relations of technological elements in camera technology literature.	**Pearson chi-square test** of independence (contingency table). This test highlights pairs of technological elements that show some kind of independency. This test is complemented by **Cramer's V** test, which indicates the strength of those relationships. These two tests allow the identification of epistatic relations and	Technological elements in complex systems seem to display some kind of dependency by which changes in A result in change B. This is also the main reason why complex systems innovate differently. Identifying the particular elements that display dependency C could help innovation strategies.	**Research Question 1**: do the technological elements in cameras display indications of epistatic relations?
Hypothesis 2: the second characteristic of complex systems is the nested hierarchical structure. If cameras are complex systems them they will display a nested hierarchy structure.	Secondary data from *Amateur Photographer*/ *DPReview*/*CNET* on technologic alspecification. Cameras categorised according to their core technology (mirroring system). Sampling of the technological elements in the test according to the existing relations of technological elements in camera technology literature.	Definition of cameras as the clustering of technological elements in order to supply a service using twin characteristics approach. **PCA** is used to map the clustering patterns of the technological elements in cameras. This model helps with the identification of the possible clustering of technological elements in order to supply a service.	Technological elements in complex systems seem to be organised in a nested hierarchy. The identification of the hierarchical shape not only helps with the mapping of the dependency element inside the hierarchy but also aids the development of particular innovation strategies according to the hierarchical formation and location of the dependent elements.	**Research Question 2:** do technological elements in cameras cluster in a nested hierarchical structure?
Hypothesis 3: complex systems differ from simple systems by epistatic relations and nested hierarchy. If cameras are complex systems they will display BOTH elements that separate complex from simple systems.	Secondary data from *Amateur Photographer*/ *DPReview*/*CNET* on technological specification. Cameras categorised according to their core technology (mirroring system). Sampling of the technological elements in the test according to the existing relations of technological elements in camera technology literature.	The results of the test for Hypotheses 1–2 will offer some light on the classification of cameras as either complex or simple systems. Hypothesis testing is complemented by hierarchical representation in order to classify complex systems according to hierarchical structure and location of epistatic relations into modular, near-	The two main elements that separate complex from simple systems are epistatic relations and nested hierarchical structure. To consider cameras as complex systems they have to satisfy BOTH requirements. The clear identification of cameras as complex systems will offer some light on complex systems innovating	**Research Question 3:** can cameras be considered complex systems?
Hypothesis 4: if innovation changes hierarchical formation then cameras will display different nested hierarchical formations before and after distinct rounds of innovation activities.	Secondary data from *Amateur Photographer*/ *DPReview*/*CNET* on technological specification. Cameras categorised according to their core technology (mirroring system). Sampling of the technological elements in the test according to the existing relations of technological elements in	Database was divided into ten-year periods. PCA and descriptive statistics were applied to each ten-year period. The comparison of the results period by period in contrast with the innovation occurring in that period will shed light on the issue of innovation changing the clustering pattern.	The literature illustrates how technological elements are linked; this link could change over time due to innovation activities. This is directly linked to RQ1 in case of complex systems' hierarchical formations. If hierarchical changes effectiveness of innovation strategic might be affected	**Research Question 4:** does clustering of technological elements change over time due to innovation activities?

Overall aim: Investigation of the possibility that complex systems innovate differently.

Hypothesis to be tested	Information needed and data source	Method used to achieve aims and objectives	Conceptual issues/ aims and outcome	
Hypothesis 5: if the classical view of innovation can explain innovation patterns for cameras then complex systems do not innovate differently from the classical view of innovation.	The technological elements of cameras used in previous tests (Hypotheses 1–4). Cameras in this case will be coded according to their specific technological specification with a unique number, which contains information on core and peripheral technological elements.	The first step in the investigation of complex systems innovation is the mapping of the innovation life pattern displayed by cameras. The **Theil's entropy measure** helps the mapping of the communalities/ dissimilarities of the camera market, hence also helps the identification of the possible DD(s) in the camera. This model is complemented with the help of the **Weitzman measure**, which will help in the identification of the emergence of possible niche markets. This ILC on camera will be compared to both complex and classical views of innovation in order to shed some light on whether complex systems innovate differently.	The classical view/ILC illustrates a predictable process of product and process innovation. By comparing this model to the camera innovation pattern it will shed light on the issue of whether ILC can explain innovation in the camera market.	**Research Question 5**: could the ILC explain innovation in the camera market?
Hypothesis 6: if cameras see the emergence of more than one DD then niche markets emerge in order to cope with heterogeneity of demand.	The technological elements of cameras used in previous tests (Hypotheses 1–4). Cameras in this case will be coded according to their specific technological specification with a unique number, which contains information on core and peripheral technological elements.		Of the main and more debatable issues on ILC, one is the standardisation of the market with the emergence of a DD. Studying the innovation life cycle and identifying the possible DD in the camera market could offer some light on the debate of heterogeneity of demand and DD.	**Research Question 6:** does the photographic camera market see the emergence of a DD? **Research Question 6a:** does variety in the camera market give rise to one DD or the rise of different niche markets?
Hypothesis 7: if complex systems innovation explains the innovation pattern of cameras then complex systems innovate differently from the classical view of innovation.	The technological elements of cameras used in previous tests (Hypotheses 1–4). Cameras in this case will be coded according to their specific technological specification with a unique number, which contains information on core and peripheral technological elements.		The stylised fact of innovation in complex systems will compare to the innovation on cameras in order to test if complex systems innovation can explain the innovation life cycle pattern for the cameras.	**Research Question 7:** can the innovation life cycle stylised facts explain innovation in the camera market?
Hypothesis 8: if cameras' innovation pattern differs from the classical view of innovation and resembles the innovation patterns of complex systems the then complex systems innovate differently from classical view of innovation/simple systems.	Results from the test of Hypotheses 5–7.	The result of the testing of Hypotheses 5–7 will shed some light on the issue of complex systems innovating differently from simple systems. This model offers the chance to investigate how differently, and in which manner it is different.	The investigation and comparison of the results for the testing of Hypotheses 5–7 will shed some light on the possibility that complex systems innovate differently from the classical view of innovation. This method also allows distinguishing whether cameras follow treads of one, both or none of	**Research Question 8:** do complex systems innovate differently?

The results of the test for both epistatic relations for cameras gave evidences consisten with the definition of complex system. Cameras seemed to display both epistatic relations to varying magnitude and hierarchical formations. This research found evidences consistent with fully integrated complex systems, near decomposable complex system and modular complex system. There is however several point to hightlight on the testing of cameras as complex systems.

a. Technological elements seem to cluster in order to offer a service (Simon 1962, Saviotti-Metcalfe 1984, Frenken 2006). The most repeted clustering amongst all the cameras types seems to be the lens service (formula 8), followed by service of metering and exposition (formula 6-7).
b. The elements that form a cluster do not necessarily need to display the highest levels of dependency on the hierarchy. Magnitude of dependency or strength of epistatic relations might vary across and within cluster on a same system (Freken, Marengo et al. 1999, Frenken 2006).
c. Units on modular complex systems might not be as independent as suggested by the literature (Schilling 2000, Langlois 2002). This research found that technological elements that seems to direct towarch modular complexity still seems to diplay high levels of dependency with other elements of the hierarchy.

This research took the opportunity to test the effect of innovation activites on the change of clustering of tehnological elements. This is a novel investigation since there is not clear evidence in the literature of an investigation of this kind. This research found that the clustering of the technological elements seemed to changes to varying degrees (move of one technological element to another cluster or complete new clustering pattern) this results where compare to the descriptive statistics and resulted on the a possible link betweent he incremental innovation occurring on that period and the changes on the clustering pattern. Further investigation of this phenomena found evidences that seem to indicate that innovation activities not only migh change the clustering pattern but also the strength/ magnitude of the complexity of the individual technological elements and the over system. In the case of the compact cameras, the introduction of the digital technological elements result from insignificant/inconclusive evidences for complexity to a hierarchy where all elements show a distinct level of dependency, or in other words the introduction of new elements results in the transition of compact cameras from fully disintegrated (possibly a simple system) to a fully integrated complex system (all elements show epistatic relations). These findings offer the filling of a gap in knowledge since there is no clear evidence in the literature that shows empirical results of the type found in this research.

Another phenomena that seemed to occur is that innovation not only seems to change the clustering pattern but with that also change the hierarchical formation of the technological elements. This research found evidence of cameras going from being near decomposable complex system to modular complex system.

The investigation of the cameras ILC gave rise to the following pattern:

a. The camera market seems to show the pattern offered by the classical view of innovation in the increased variety of technological solutions at the beginning of the market (Utterback and Abernathy 1975). The camera market on the other hand contradicts this classical view by displaying the emergence of two DD as opposed to one DD as suggested by the literature (Utterback and Abernathy 1975). These results support the idea of complex systems innovation where variety is the norm and one dominant design cannot satisfy all consumer demand (Frenken 2006). These results also support the idea of the dominant design's bifurcation into distinct niche markets (Frenken, Saviotti et al. 1999).

b. Cameras seem to show evidences that follows the complex systems theory on dominant design, by the emergence of a core technology dominant design (SLR, compact cameras) as opposed to a product dominant design, and, following the establishment of the core technological dominant design, innovation focuses on the peripheral elements which also seem to display their own dominant design (35mm, digital image) (Frenken 2006). Variety on those periphery elements is the ones that seem to help complex systems to manage the heterogeneity of demand.

c. The camera market also seems to contradict the classical view in that the innovation life cycle is repeated four times as opposed to once (Utterback and Abernathy 1975). This result, however, supports the views of innovation as an iterative process (Foster 1986, Anderson and Tushman 1990, Tushman and Murmann 1998). Cameras on the on othe hand seems to suggest evidences that contradict the classical views of ILC in the manner that innovation activities does not change focus to the process innovation once a DD emerges but camera seems that once DD emerges the focus of innovation swifts to the periphery elements of the product as well as the process innovation.

d. The camera market also sees the bifurcation of the market into distinct niche markets. The representation of the Weitzman measure shows two distinct groups in the periods 1975–1984 and 1995–2004, and in the period 2004–2011 there seems to be the emergence of three distinct groups.

These results seem to be confirmed by the literature and empirical studies (Frenken, Saviotti et al. 1999, Murmann and Frenken 2006).

Even though cameras might display some trait on their ILC that may resemble the classical views of innovation, the theory of the classical views of ILC does not seem to offer any light on the innovation pattern offered by cameras, neither seems to be applicable in the case of cameras. Since this is only a primary exploratory study this research cannot give a defite answer on whether cameras seems to innovate differently from ILC due to evidences that seems to suggest their complexity nature or if cameras it is an special exception of the rule.

This research proposes the investigation of other technological product that could also offer evidences supporting the complexity definition in order to offer some light on the phenomena of complex systems innovating differently.

CONTRIBUTION TO KNOWLEDGE

This research has attempted to contribute to knowledge by the empirical testing of a product to see if it can be considered a complex system and if indeed it innovates differently. This research suggested the use of a two-step model to test complexity of products, which ameliorated the weaknesses of existing complexity models, such as limited explanation of which elements show epistatic relations and the individual levels of dependency between the elements. These models aim to make marketing and design managers aware of the high-risk elements when undertaking innovation activities.

In the process of testing the research questions, this research encountered further phenomena that have not been illustrated or investigated by the literature, such as the results on the complexity level of the introduction of new elements in the system. The findings of this research are particularly relevant not only for their contribution to knowledge but also to marketing and design activities. The epistatic relations between elements indeed seem to limit the innovation activities in complex systems. This research has indicated that both incremental and radical innovation could increase the complexity of the systems to the extreme of making a product fully integrated. The repercussion of this transition to fully integrated systems will mean that even changes on a small scale could affect the rest of the hierarchy (all other elements). This brings an awareness to marketing and design managers of the in-depth knowledge of the inner workings of the system as suggested by the literature (Ulrich 1995, Tushman and Murmann 1998, Frenken 2006) These results could not have been possible using the existing models of complexity measures which are limited to the measurement of the overall complexity of the product.

This research also suggested the use of the entropy measure as an indicator of innovation life cycles in order to ameliorate the weaknesses of the existing models of innovation (Windrum 2005). The results of this study, however, seem to indicate the same results as the previous investigation, hence increasing the validity of this research. Entropy measurement helps this research to identify the innovation life cycles of cameras and possible emergence of dominant designs. This research proposes the use of the entropy measure in the investigation of innovation life cycles in cases such as that of cameras, where hedonic price regression cannot be used, due to currency change or where willingness to pay for a product might be limited by the emergence of other discounted products that might put at risk the accuracy of the RRP.

The results seem to indicate that there is evidence of complex systems displaying a somewhat different pattern of innovation than that suggested by the classical view. This result seems to increase the importance of the gap in the literature concerning a model that could explain and/or aid the investigation of complex systems innovation. This research suggested the inclusion of the Weitzman entropy measure in order to investigate this innovation in the complex systems case. The identification of a model that will explain the pattern of innovation that complex systems might take will aid marketing and design managers in the identification of the elements that could limit innovation activities. The identification of such a model is important because it seems to indicate, judging by the results of this research, that in complex systems every innovation, even if small, might increase the complexity of the product as well as the possible clustering pattern and epistatic relations. This research found clear examples in the digitalisation of compact cameras changing from nearly decomposable systems to fully integrated complex systems. This has profound repercussions on marketing and design activities since, due to the transition of epistatic relations showed by all elements in compact cameras with the digitalisation of the image, innovation in any element might affect all the elements in the systems, as opposed to the compact cameras (35mm), where innovation activities might affect a maximum of two elements in the whole system. This result indeed seems to support the idea of the limitation of trial and error strategies in complex systems. The identification of the elements that might limit innovation brings back the relevance of the model suggested by this research to test the complexity of technological products.

This research has been portrayed as an exploratory case study for the empirical testing of the research question. The case study has been suggested as a theory building method (Eisenhardt 1989); however, at this moment in time this research cannot offer conclusive evidence that the patterns displayed by cameras can be generalised for complex systems. These limitations, however, open up the opportunity for further research on other technological commercial products in order to test whether patterns displayed by cameras could be considered the norm to a rule (theory building) or just a special case influenced by technological constraints, consumer demand or any other elements not included in this research.

APPENDIX A-WINDRUM, DIAZ, FILIOU (2009)

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Exploring the relationship between technical and service characteristics

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Abstract the paper explores the complex relationship between technical and service characteristics discussed by the Saviotti-Metcalfe model of innovation. It is proposed that principal components analysis (PCA) is a more appropriate method of analysing this relationship than approaches previously used. A PCA is performed on a dataset of mobile phone handsets for the period 2003 to 2008. In addition to the relationship between technical and service characteristics, the analysis explores the existence of clusters of ergonomic characteristics within mobile phone handsets. The findings indicate that a limited set of core technology components underpin the large set of service characteristics offered by mobile phone handsets, and that the mapping between technical and service characteristics can be highly complex.

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JEL Classification D12 ∑ O33

1 Introduction

The Saviotti and Metcalfe (1984) model of product innovation is well-established within modern innovation theory. The authors' stated aim was to advance empirical research through the development of a framework that brings together output indicators of innovation and stimulates the development of new, improved indicators. The framework is underpinned by Lancaster's work on characteristics (Lancaster 1966, 1971). Differences in the prices charged for rival products reflect differences in the quality of the 'services characteristics' that are offered to consumers. Further, the quality of service characteristics depends on an underpinning set of technologies that are embodied in a product. Hence, variation in price and the quality of 'service characteristics' can be directly tied to the 'technical characteristics' of a set of competing technologies. Saviotti and Metcalfe highlight complex relationships between clusters of technical and service characteristics, and the fluidity of these relationships over time.

This paper addresses an important limitation within the existing empirical work on characteristics; namely, the relationship between technical and service characteristics that lies at the heart of the Saviotti-Metcalfe model. This has not been critically examined within the existing body of empirical research. In their 1984 paper, Saviotti and Metcalfe propose the application of the hedonic price method to empirically explore the relationship between price and technical characteristics (or, alternatively, between price and service characteristics).[1] A number of papers using this method followed. Saviotti applied the hedonic method to a study of automobiles (Saviotti 1985) and helicopters (Saviotti and Tricket 1993); Trajtenberg (1989) applied it to data on computed axial tomography (CAT) scanners; and Grupp (1998) to data on bio-diagnostic kits and capital goods. Estimating the shadow prices of technical characteristics does not provide insight into the relationship between service characteristics and technical characteristics. The same limitation applies to work by Frenken and colleagues (Frenken et al. 1999; Frenken and Leydesdorff 2000) who apply entropy and Weitzman techniques to examine variety within service characteristics space or, alternatively, within technical characteristics space. They did

[1]The hedonic approach to the measurement of technological change has its origins in the work of Court (1939), Stone (1956), Lancaster (1966), and Griliches (1957, 1971).

not analyse the correspondence between variety in service characteristics and variety in technical characteristics.[2]

In order to open up a discussion of the complex relationship between technical and service characteristics, we apply the method of principal components analysis (PCA). PCA is attractive because it is a well-established statistical procedure for examining complex, relationships, and is simple to implement (Dunteman 1994; Stevens 1992). In this paper we apply PCA to a dataset of technical and service characteristics of mobile phone handsets, collected for the period 2003 to 2008. There are two striking aspects of this technology. First, there is the portability of the design. Consumers require a handset that is relatively compact and lightweight but which can offer a variety of services. There is therefore both an ergonomic component in the aesthetic look and feel of this manufactured artefact, and a technological component with ever more sophisticated features and service characteristics offered within the same basic design configuration. This is very much within Lancaster's original discussion of consumer demand for service characteristics, which formed the starting point of the Saviotti and Metcalfe model.

The remainder of the paper is organised as follows. "Section 2" reviews the Saviotti-Metcalfe model of innovation. This highlights their discussion of the importance of overlapping clusters of technical characteristics that support a set of distinct service characteristics. It is argued that a set of core technologies underpin a larger number of service characteristics. What is more, there can be multiple, complex links between technical and service characteristics. This argument is derived from Dosi's work on technological paradigms, which Saviotti and Metcalfe used to operationalise their model.

"Section 3" provides a detailed discussion of the technical and the service characteristics of the modern mobile phone. There are three core technologies that underpin this design: battery, screen, and microchip technologies. We take three service characteristics that are popular on modern phones: cameras, for taking and transmitting still images; video facilities for recording, downloading and watching (short) video clips; and music facilities for playing and storing songs. Sets of research hypotheses are derived. Three of these hypotheses consider correlations between an individual service characteristic (i.e. photographs, video, and music services, respectively) and the set of underpinning battery, screen, and microchip technical characteristics. The fourth hypotheses considers the existence of correlations between the physical/ergonomic features of mobile phone handsets.

"Section 4" discuses the method of principal components analysis and describes the characteristics dataset that is used to test the research hypothesis.

[2]The Weitzman variety measure is only applied to technical characteristics, which are assumed to be discrete and orthogonal to one another in Hamming distance. A separate analysis, using

the entropy measure on Euclidean space, is applied to service characteristics. These service characteristics are once again assumed to be discrete and orthogonal to one another

"Section 5" reports results of the PCA on mobile phone service and technical characteristics. As we shall see, these strongly support the Saviotti-Metcalfe model of the relationship between technical and service characteristics. "Section 6" concludes by pulling together the findings of the paper and considers future research opportunities.

2 Empirical applications of the Saviotti-Metcalfe model

The Saviotti-Metcalfe model (1984) was seminal in establishing a 'characteristics approach' to modelling innovation. It developed Lancaster's work on demand (Lancaster 1966, 1971). Lancaster observed that all types of products (both manufactured goods and immaterial services) can be described by the bundle of 'intrinsic characteristics' (or attributes) that they embody. These characteristics are the stream of services, provided by a good/service, which the purchaser consumes over the lifetime of the purchased product. Lancaster observed that consumers choose between alternative bundles of service characteristics and prices that are offered on the market by producers. Lancaster used the example of the electric kettle to illustrate his point. Different designs offer different quality and price points in terms of the volume of water that can be boiled and the time taken. Their designs also offer alternative aesthetic and ergonomic (touch and feel) characteristics that are valued by consumers.

Saviotti and Metcalfe (1984) took Lancaster's insight and translated it into a model of innovation (also see Saviotti 1985, 1996). 'Service characteristics' are equivalent to what Lancaster called the intrinsic characteristics from which consumers derive utility through consumption. Saviotti and Metcalfe link these service characteristics to a set of underpinning technical characteristics. Each product has a set of core technologies whose performance can be described by a vector of 'technical characteristics'. Improvements in technical characteristics, achieved through R&D, enhance the quality of the associated service characteristics that are of interest to consumers.

The relationship between service and technical characteristics is presented in Fig. 1.[3] For example, an automobile's service characteristics of speed and fuel efficiency clearly depend on the physical, technical characteristics of its engine. Given the underpinning technologies, one will expect to see cumulativeness in innovation and specific trajectories within which service characteristics can be improved.

'Process characteristics' are governed by capital equipment and by their underpinning process technologies (Saviotti and Metcalfe 1984, p. 144). Saviotti (1985,1996) subsequently expanded this to include tangible assets (such as plant and equipment), intangible assets (such as brand name, copyright, and

[3]These are clearly defined for manufactured goods, though possibly less so for services (see Gallouj and Weinstein 1997; and Windrum and GarcÌa-GoÒi 2008

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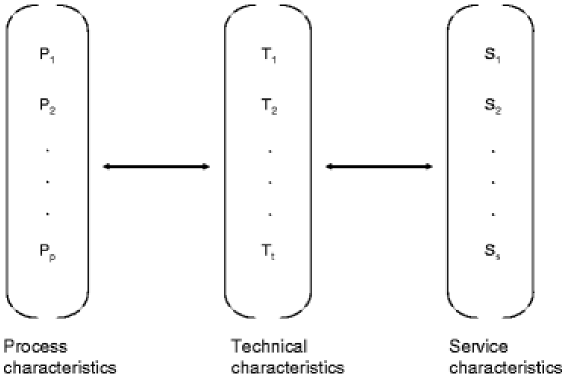

Fig. 1

patents), human resources (such as education, training, experience, and skills of individual staff), and organisational resources (such as corporate culture, organisational structure, rules, and the procedures of the firm) that range from the design to production to marketing.

As noted in "Section 1," a key aspect of the Saviotti-Metcalfe model is the relationship between technical and service characteristics. In the simplest case, a service characteristic may depend on a single technical component. However, Saviotti and Metcalfe highlight the possible existence of complex relationships between clusters of technical and service characteristics, and the fluidity of relationships over time. An innovation in one technical component may affect a number of co-related technical components and a number of service characteristics.

Saviotti (1996) makes clear that Dosi's theory of technological paradigms and trajectories (Dosi 1982) is essential to operationalising the model; structuring the discussion of the relationship between technical and service characteristics, and a discussion of how technological change alters technical and service characteristics over time. Drawing on T.S. Kuhn's work on scientific paradigms and the development of science (Kuhn 1962), Dosi defines a technological paradigm as a "'model' and a 'pattern' of solution of selected technological problems based on selected principles derived from natural science and selected material technologies" (Dosi 1982, p. 152).

Dosi states that one should think of a product as a cluster of technologies rather than a single, independent technology. For Dosi, a technology is "a set of pieces of knowledge both directly 'practical' (related to concrete problems and devices) and theoretical (but practically applicable although not necessarily already applied), know-how, methods, procedures, experience of success and failure and also, of course, physical devices and equipment" (Dosi 1982,

p. 151). A 'technological trajectory' is the pattern of 'normal' problem solving activity (the parallel of 'normal science') that seeks incremental performance improvements based on the existing set of accepted technical frames and solutions. By contrast, a radical innovation is founded on the creation of a new set of technology frames and solutions, and results in a new trajectory that is qualitatively different to the old technology trajectory. This may initially be sparked by the incremental development of a technology. As engineers seek to improve the performance of a product, they realise the need to engage in a radical redesign of the core technologies and/or the sets of core technologies that are used in the product. This can lead to a new set of conceptual models and solutions, thereby establishing a new paradigm with a new technological trajectory.

Implementing these ideas into their model of technical and service characteristics, Saviotti and Metcalfe proposed that complex relationships can exist between the clusters of technologies that underpin different products. What is more, the relationship between technical and service characteristics can change over time (Saviotti and Metcalfe 1984, pp. 142-143). Multiple connections may exist between the technical characteristics and the set of final service characteristics within a single product, as illustrated in Fig. 2.

The purpose of this paper is to empirically explore the existence of clusters of service and technical characteristics, such as those indicated in Fig. 2. This has not been directly examined in previous empirical studies. The core research proposition which we wish to empirically explore in this paper is the following:

Proposition 1 Service characteristics are produced by overlapping clusters of technical characteristics.

In addition to clusters of technical and service characteristics, a product may contain service characteristics that are determined by non-technological

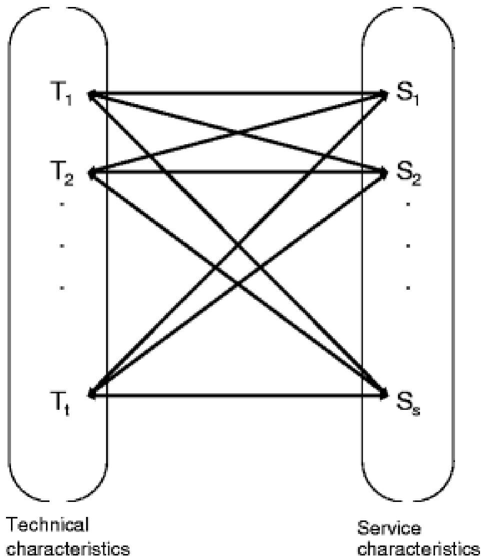

Fig 2. Fig. 2 Mapping between

technical and service

characteristics

clusters. There may be, as Lancaster proposed, non-technical, ergonomic features of a product that provide service characteristics which are attractive to the consumer. This provides our second research proposition:

Proposition 2 A product can contain one or more non-technological clusters.

In order to conduct the analysis, we will apply principal components analysis (PCA) to a dataset of mobile phone characteristics. PCA is a method that is used to analyse patterns of correlations among a set of original variables. While PCA is commonly used as a technique for reducing data for regression analysis, it can also be used to identify patterns of behaviours or actions which are shared by a particular group of variables - here clusters of service and technical characteristics, or to differentiate one cluster of characteristics from another. In this paper we conduct a principal components analysis on a dataset of mobile phone characteristics that has been collected for the period September 2003 to January 2008. Prior to conducting this analysis, we first need to consider the core technologies that underpin the key features and service characteristics of a modern mobile phone. This is the focus of the next section.

3 Technical and service characteristics of mobile phones

The construction of indices of key service characteristics and core technical characteristics is non-trivial. It requires an availability of good quality data, and knowledge of the technology and the industry on the part of the researcher (Saviotti and Metcalfe 1984; Saviotti 1985; Grupp 1998). The collection and assessment of characteristics data can be time intensive, even for a single product or technology. Additionally, and in contrast to patent statistics for instance, there is not a standard classification of characteristics (Gambardella 2001). This opens up issues of omission and consistency. For example, Saviotti (1985) describes how researchers in three studies used different characteristics to describe agricultural tractors sold in the UK market, rendering void any attempt to compare their research findings.

Given the lack of agreed standards, the researcher needs to be clear about decisions taken in the selection of data sources (i.e. the strengths and weaknesses of the sources used, the completeness and consistency of those sources), and decisions taken in the construction of the dataset. Take, as an example of the latter, the battery life of a mobile phone. Should this be treated as a technical characteristic or a service characteristic? It could be argued that battery life is a service characteristic. We treat battery technology as a technical characteristic because it is core to portable technologies such as mobile phones. Different battery technologies are available, each with their strengths and weaknesses in terms of average life times, cost, and weight. Given estimates of the energy demands of the different services offered by a particular phone design, and knowing the technical characteristics of the alternative battery technologies that are available, designers choose an appropriate battery option. Determining the maximum portability (in hours) of the phone design in this way ensures that users do not need to recharge on a daily basis. Certainly, if users faced such an inconvenience, then one might well expect battery type to enter into their purchasing considerations. As such, it would need to be treated as a service characteristic in its own right. This may occur in the future if, for instance, real time video and music services grow in popularity and improvements in battery technology are unable to keep up with the rate of increase in energy requirements. This example highlights the contingency of decisions made by researchers in defining technical and service characteristics, and the contestability of decisions. Good practice requires that researchers are explicit about the basis or their decisions.

3.1 Technical characteristics

One can identify three core technologies that determine the 'technical characteristics' of the modern mobile phone. In addition to battery technology, there is screen technology and microchip technology**.**

3.1.1 Battery technology

As noted, the underpinning battery technology determines the maximum portability (in hours) of a mobile phone. Three alternative types of batteries are currently available for use in mobile phones: nickel-metal-hydride (Nimh); lithium-ion (Li-ion); and lithium-ion-polymer (Li-Po). Of these, Li-ion is currently predominant in mobile phones. First launched in early 1991, Li-ion technology offers higher electrochemical potential and has the largest density for weight of all currently available options (van Schalwijk and Scrosati 2002). What is more, the Li-ion battery is a low maintenance design, i.e. there is no memory discharge and has a low self-discharge rate, and does not require prolonged priming when new.

Current Li-ion technology does have its drawbacks, however. A major issue is the relatively high cost of production compared to the other battery types. There were well documented problems of early versions exploding. This was due to the instability of lithium metal. Temperatures, particularly during charging, can quickly rise to the melting point of metallic lithium, resulting in a violent reaction. The problem was solved by substituting non-metallic elements, and today Li-ion is possibly the safest battery on the market. A potential disadvantage that remains is that of battery ageing. However, this is less of an issue for consumers who regularly change their phone. Network companies offer their contract customers the possibility to upgrade their phones every year, and, hence, the batteries contained therein.

Nickel-metal-hydride (Nimh) was launched at the end of the 1980s. It quickly replaced the nickel-cadmium batteries used in the earliest mobile phones. Nimh offered 30-40% higher capacity than nickel-cadmium, was less prone to battery memory loss, offered simple storage and transportation, and was more environmentally friendly compared than nickel-cadmium, which is a highly toxic metal (Linden and Reddy 2001). Nimh batteries have largely been replaced by Li-ion batteries. Nimh batteries have a number of weaknesses compared with Li-ion batteries. Nihm has a relatively limited service life: performance starts to deteriorate after 200-300 charge/discharge cycles. Nimh also has a relatively short storage life of 3 years. As noted previously, this may not necessarily be a major disadvantage, given the frequent replacement of phones, and their batteries, by customers. A definite limitation is the limited discharge current of Nimh batteries. While they are capable of delivering high discharge currents, heavy load reduces the battery's cycle life. Finally, the technology suffers from high self-discharge.

The third and final type of battery that can be found in modern mobile phones is the Li-lithium-ion-polymer (Po) battery. Sony-Ericsson is currently the main advocate of the Po battery. What differentiates Po from other battery technologies is the electrolyte that is used. Unfortunately, the dry lithium polymer suffers from poor conductivity. To ameliorate this problem, a gelled electrolyte is added. Po batteries have a number of advantages over current Li-ion technology. First, one can produce very low profile batteries; batteries with the profile of a credit card are feasible. Second, there is a flexibility of battery form. Po batteries can be produced in almost any form, freeing battery manufacturers and phone designers from standard cell formats. Third, the technology can be produced in high volumes, so any reasonably sized battery can be produced economically. Fourth, Po batteries are very lightweight. Gelled electrolytes enable simplified packaging by eliminating the need for a metal shell. Fifth, Po batteries offer improved safety. They are more resistant to overcharge than Li-ion batteries, with less chance of electrolyte leakages.

Compared to Li-ion technology, Po technology has three main weaknesses. The first is a lower energy density and decreased cycle count compared to Li-ion. Second, due to lower production levels, they are currently more expensive to manufacture. Third, they have a higher cost-to-energy ratio than Li-ion.

3.1.2 Microchip technology

Microchip technology determines the maximum memory (in bytes) of a mobile phone and, hence, the quality of features such photos, video, and music storage. Two alternative forms of memory technology underpin the current generation of mobile phones: internal memory and removable memory. Until recently, internal memory exploited two microchips; one dedicated to operating system software and application software; the other dedicated to pictures, video, and music storage. Recently, there has been experimentation with a single chip set to perform all functions. The key attraction here is the saving of space within the mobile phone.

'Flash memory' is used for both internal and removable memory in mobile phones. Flash memory is non-volatile computer memory that can be electrically erased and reprogrammed. The key advantage of non-volatile memory is that it does not require energy in order to store information on a chipset

Besides mobile phones, non-volatile memory is used in PDAs and digital cameras. By contrast, PCs use volatile DRAM memory.

There are two alternative types of flash memory used in the current gen-eration of mobile phones: NOR and NAND.[4] NOR flash was first introduced by Intel in 1988 as an alternative to EPROM and EEPROM based devices. In 1989 Toshiba introduced NAND flash architecture. This addressed the need for lower cost per bit, higher performance, and disk-like memory. Technically, NOR and NAND flash differ in two important ways: the connections of the individual memory cells are different, and the interface provided for reading and writing the memory is different (NOR allows random-access for reading, NAND only allows page access). The NOR configuration consists of individual memory cells that are connected in parallel. This facilitates random access and provides a fast response time. NOR is typically used for fast response rate/low density applications, such as code storage. Within mobile phones, it is most effective for application storage.

NAND is a serial memory cell that has 1 less contact per pair of cells than NOR memory, making NAND less expensive to produce. NAND is popular because it is a cost-effective means of producing high density storage devices with fast response rates. Indeed, NAND was specifically developed as a high density storage alternative to NOR (the endurance of a typical NAND flash is 1,000,000 cycles compared with a typical NOR flash of 100,000 cycles). In mobile phones, NAND is typically used for high density storage and high speed programme/erase applications such as music, video, picture data storage.

3.1.3 Screen technology

Screen technology is the third core technology underpinning the modern mobile phone. The quality of a screen is governed by the number of pixels per square centimetre. This is directly related to the quality of the Liquid Crystal Display (LCD) of the phone. The type of LCD screen determines the resolu-tion. This is particularly important for the quality (service characteristics) of its camera and video facilities. An LCD is a thin, flat display device, made up of a certain number of colours or monochrome pixel arrays, taking the form of a light source or reflector. An LCD is usually utilised in battery powered electronic devices because it requires very small amounts of electric power.[5]

LCD displays are divided into two groups: passive-matrix and active-matrix (Polymers and Liquid Crystals 2008). Passive matrix types include super twisted nematic (STN) and the colour version STN (CSTN). In a passive

[4]NOR stands for Not 'OR'. A NOR gate is a basic logic gate similar to an OR gate, but with the output inverted. NAND stands for Not 'AND'. A NAND gate is a basic logic gate similar to an AND gate but with an inverted output.

[5]For an informed and clearly written introduction to LCDs, the reader is referred to the website of the Liquid Crystal Technology Group (http://plc.cwru.edu/tutorial)

matrix, each row or column of the display has a single electrical circuit. The pixels are addressed one at a time, by row and column address. It is called 'passive' because a pixel must retain its state between refreshes, without the benefit of a steady electrical charge. Due to the low total pixel number and low response times, screen resolution of passive matrix types is poor. As the number of pixels increase, this type of display becomes increasingly less feasible. Hence, it is mainly found in older mobile phones and in low-end mobile phones. Active matrix, thin-film transistor (TFT), LCDs contain a greater number of pixels and offer far better colour resolution. Each pixel has its own dedicated transistor, allowing each column line to access one pixel. Almost all new mobile phone models have TFT displays.

3.2 Service characteristics

In order to research Proposition 1, we consider the relationship between the core technologies just discussed and three key service characteristics that are popular on modern phones: cameras for taking and transmitting still images, video facilities for recording, downloading and watching (short) video clips, and music facilities for playing and storing songs. In order to research the second of our research proposals, we also consider the factors determining the ergonomic comfort of a mobile phone. Let us take each of these in turn.

3.2.1 Camera quality

The quality of a still image that is viewed on a mobile phone is directly governed by the pixel resolution of the phone's camera software. One would expect a correlation to exist between the quality of this service characteristic and the quality of the core technologies, i.e. the technical characteristics, which underpin the mobile phone. Perhaps the most obvious is the resolution of the LCD screen. Memory is another important factor, as better quality images with higher pixel content require more memory. Finally, larger and better LCD displays require more power, placing greater demands on battery efficiency. This provides us with the first of our test hypotheses.

Hypothesis 1: There is a positive correlation between the pixel resolution of camera software, LCD pixel resolution, phone memory, and battery life.

3.2.2 Video quality

Perhaps not surprisingly, the factors governing video quality are not too dissimilar to those governing the quality of a still image—given that video is essentially a stream of still images combined with a sound recording. The key determinant of video quality is the software that governs the pixel resolution of the image and the sound resolution. As with still images, one expects a positive correlation to exist between the quality of this service characteristic and the technical characteristics of the core battery, memory and screen technologies.

Hypothesis 2: There is a positive correlation between the pixel resolution of video software, LCD pixel resolution, phone memory, and battery life.

3.2.3 Music quality

The quality of digital music playback depends on the sampling bit rate of the recording. Further, it is heavily dependent on the memory and the battery life of the phone. The higher the sampling rate of a recording, the better its quality. A number of different formats are currently available. These include ATRAC, AAC, MP3, and MP4. In terms of sound quality what matters is the sampling rate, not the particular format that is used. The major downside with higher sampling rates is that they require more memory per track. As with video, playing continuous music is very demanding in terms of energy, and so the battery life of a phone becomes an important technological factor.

Hypothesis 3: There is a positive correlation between sampling rates of the music software, phone memory, and battery life.

3.3 Non-technological service characteristics

Finally, we will examine the existence of a correlation between the ergonomic comfort of using a mobile phone and its size (volume) and weight. One consequence of the focus on technical characteristics in past empirical research has been an ignoring of design ergonomics. Yet, as discussed in "Section 1" and "Section 2," the ergonomic characteristics of product designs play a prominent role in Lancaster's theoretical work (Lancaster 1966, 1971).

Ergonomic characteristics provide a set of non-technologically determined service characteristics. The 'ideal' size and weight of a mobile phone is determined by the human anatomy, with which the device interacts. In this case, the ideal size is governed by the size of human fingers that operate the phone and the palm of the hand in which a phone rests, while ideal weight is governed by the strength of the human wrist and arm that must hold and carry the device.

There may well be an ideal range of size and range of weight that consumers demand. A very large and heavy phone is cumbersome to carry and cannot be stored easily. At the other end of the scale, a phone that is very small cannot by operated effectively by human fingers, increasing the probability of typing errors.

There is a further ergonomic characteristic to consider: the resolution power of the human eye determines a minimum effective size for an LCD screen. Increasing screen size and resolution has a direct impact on the overall size of a mobile phone. The trend towards camera phones offering picture taking, picture sharing, and retrieval of online data from websites requires higher screen image quality. Imagequality has thus become an important service characteristic in its own right. The larger the screen, the greater the number of screen pixels, and the better the quality of image resolution that can be displayed. Given the increased demand for picture and video services, and the fact that larger screens are easier to view than smaller screens, one might reasonably expect phone sizes and weights to be at the upper limit of the ergonomically comfortable range. Recent examples of this trend include the Nokia N series and the Blackberry models. These larger sized handsets offer more internet and camera features than smaller sized phones.

There is, however, a downside to larger screens. To maintain a given level of image resolution, larger screens require a larger number of pixels. This necessitates a commensurate increase in the overall dimensions of the phone (its volume) and an increase in weight. The negative correlation between battery life (hours), on the one hand; and screen size, volume, and weight, on the other, reflects the current limits of battery technology discussed above. The larger the size of screen, the greater the power required to produce a given level of brightness, and, hence, the greater the drain on battery life.

Taken together, one would expect a positive correlation between screen size, phone volume, and phone weight. A limiting factor is the battery power needed to operate a larger screen. One would expect a negative correlation between battery life and the other ergonomic characteristics of screen size, phone volume, and phone weight.

Hypothesis 4: There is a positive correlation between screen size and the volume and weight of a mobile phone,and a negative correlation between battery life and screen size, phone volume, and phone weight.

If this set of expected correlations exists, it will be identifiable as a separate and distinct principal component within the estimated models that are developed to test Hypotheses 1, 2 and 3. One of the advantages of the PCA method is that one can conduct joint hypothesis testing such as this (Ahamad 1967). For example, when testing technical and service characteristics governing camera quality (Hypothesis 1), we can additionally test the relationship between battery life and the ergonomic variables of overall handset size (volume), screen size, weight. If a distinct set of ergonomic correlations do exist, then this will show up as a separate estimated principal component containing these four variables. Further, we have argued that the expected sign for battery life within this estimated component is negative.

To summarise, we have identified a set of four testable hypotheses. Three of these investigate the relationship between specific service characteristics and the technical characteristics of the core technologies that underpin mobile phones. The service characteristics that we test are camera quality, video quality, and music quality. The fourth hypothesis investigates the existence of a distinct set of ergonomic characteristics, determined by the physical proportions of a mobile phone and how these proportions relate to the human body.

4 Principal component analysis and mobile phone dataset

Principal components analysis (PCA) is a method that is used to analyse patterns of correlations among a set of original variables. It generates a number of 'principal components' that capture interrelationships between the original variables and their tendency for these variables to co-appear (Dunteman 1994).

PCA tends to be used as data reduction technique, i.e. for grouping a number of independent variables for regression purposes. However, PCA can be used as an exploratory statistical technique to analyse correlations between groups of distinct variables as they appear in the principal components. This use of PCA is more common amongst non-economists, and there is a well documented literature stretching back to Ahamad (1967, 1968). There are some previous examples of this use of PCA in the innovation literature, where researchers have explored patterns of interrelationships among variables to shed light on associations and links for which little knowledge exists (Tether and Tajar 2008). For example, Coombs and Tomlinson (1998) used PCA to explore whether distinct styles of innovative behaviour can be identified between service and manufacturing firms. Filiou and Windrum (2007) used PCA to examine the behaviour of biotech and pharma firms in cooperation agreements and their underlying tendencies to systematically interrelate exploration and exploitation via these cooperation agreements. The benefit of PCA, compared to other exploratory statistical techniques, such as factor analysis, is that it does not make prior assumptions regarding the extent and the structure of interdependencies among the original variables (Stevens 1992). In terms of the current paper, the attraction of PCA is that it provides us with a relatively simple and effective tool with which to undertake an exploratory analysis of the relationship between service characteristics and technical characteristics within a mobile phone dataset.

In order to apply PCA, we must assess the number of composite variables required to achieve a sound representation of the original set of variables. This is assessed using a combination of statistical criteria. These include the Kaiser and Joliffe criteria, which only retain components with eigenvalues greater than 1 or 0.7, respectively. It also includes Cattell's Scree Plot. In order to simplify the discussion, we present the estimated PCA for each test in the "Section 5". The correlation matrix that underpins each of these estimated PCAs is placed in the "Appendix." Information on the level of model significance and the estimated KMO statistic of sampling adequacy are also provided, along with each respective correlation matrix, in the "Appendix."

With regards to the estimated PCA, only those original variables with contributions (or weights) that are greater than (±) 0.4 are considered to make a meaningful contribution to the construction of a component. We will indicate these with an asterisk (*) in the tables presented in "Section 5". The principal components are interpreted on the information that these variables carry (Stevens 1992)

Note that, in order to deal with overlapping clusters of technical and service characteristics, we need to estimate separate PCAs for each of the key service characteristics that we are interested in. Turning to the dataset, this was constructed using information published in a well known, reputable, and publicly available source: the UK consumer magazine 'What Mobile Phone'. The use of a source such as this provides a dataset that is consistent and complete. The information has been cross-checked using the GSM Arena website. This website specialises in second hand mobile phones, and produces detailed product specifications for a very large list of models. Use of these independent, publicly available sources ensures other researchers can readily access and analyse the same information, allowing replicability of the results.

Information has been gathered on the characteristics for 319 mobile phones, produced and marketed during the period September 2003 to January 2008. The dataset includes handsets produced by 36 different manufactures. These include well known manufacturers such Nokia, Motorola and Sony-Ericsson, and less well known producers such as Fly, Lobster, and Primus. Data is available prior to September 2003, but information on internal and external memory only started to be published for all models from this date, as memory cards stated to be included as a standard feature. Hence, the information required to test hypotheses 1 to 3 is complete for the period September 2003 to January 2008.

Data was collected for eight variables: total volume of the handset (millimeters), weight of the phone handset (grams), total memory of the phone including card memory (megabytes), maximum lifetime of battery (hours), screen size (pixels), camera picture resolution (pixels), video picture resolution (pixels), and music playing facility (binary dummy variable).

5 Results

5.1 Camera quality and ergonomics

As discussed in "Section 3", PCA enables us to jointly test our hypotheses regarding camera quality and ergonomics. In order to test Hypothesis 1 we include the variables total memory, battery life, LCD screen pixels, and camera pixels (see "Section 3.2"). To test Hypothesis 4, the existence of a correlation between ergonomic characteristics, we additionally include the variables Physical Dimensions (volume) and Weight (see "Section 3.3").

The diagnostic statistics show that all components have eigenvalues greater than 1, and cumulatively interpret just over 56% of the original variance across all characteristics. The estimated correlation matrix, on which the PCA is constructed, is presented in "Appendix" Table 4. It indicates that the level of model significance is within the 1% level, with an estimated KMO statistic of sampling adequacy of 0.576. This is reasonable

Table 1
Estimated principal components for camera quality and ergonomics

Variables	**Retained components**	
	1	**2**
Physical dimensions (volume)	0.764*	− 0.091
Weight	0.849*	0.187
Total memory	0.067	0.473*
Battery life	−0.423*	0.560*
LCD screen pixels	0.580*	0.628*
Camera pixels	0.045	0.767*
Number of observations	319	319
Eigenvalues		
Total	2.007	1.383
Percent of variance	33.452	23.046
Cumulative percent of variance	33.452	56.498

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization. Rotation

converged in three iterations

Examining Table 1, we find there are two estimated principal components for this set of variables. The second of the estimated principal components indicates a positive correlation exists between camera pixels, LCD screen pixels, total memory, and battery life. The estimated principal component thus supports Hypothesis 1.

The first estimated principal component indicates an interaction between the physical features of a mobile phone handset: its physical dimensions (volume), weight, and screen size (measured in pixels), and, thus, battery life. These support Hypothesis 4 and have the expected signs. That is to say, the physical proportions of screen size, volume, weight, are positively correlated, while battery life is negatively related to these three variables. What is interesting is that this is the first estimated principal component, i.e. the physical /ergonomic properties of the mobile phone explain the largest percentage of variance across all characteristics. This, as we shall see, is a finding common to all the tests. In this particular case, the non-technological characteristics account for almost 34% of variance, while the service and technical characteristics account for 23% of variance.

5.2 Video quality and ergonomics

To test Hypothesis 2 regarding the determinants of video quality we consider the variables total memory, battery life, LCD screen pixels, and video image size. Once again, in order to jointly test Hypothesis 4 regarding the ergonomic characteristics, we also include the variables physical dimensions (volume) and weight.

The diagnostic statistics for the PCA comprising these characteristic variables indicates that all components have eigenvalues greater than 1, and cumulatively interpret around 72% of the original variance across all characteristics. “Appendix” Table 5 presents the estimatedcorrelation matrix on which this PCA is constructed. This indicates that the level of model significance is within

Table 2
Estimated principal components for video quality and ergonomics

Variables	**Retained components**		
	1	**2**	**3**
Physical dimensions (volume)	0.783*	0.012	− 0.233
Weight	0.836*	− 0.102	0.180
Total memory	0.005	0.008	0.927*
Battery life	− 0.294	0.756*	0.058
LCD screen pixels	0.643*	0.310	0.442*
Video image size	0.323	0.761*	− 0.05
Number of observations	319	319	319
Eigenvalues			
Total	2.030	1.278	1.012
Percent of variance	33.841	21.294	16.869
Cumulative percent of variance	33.841	55.136	72.004

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization. Rotation converged in five iterations

the 1% level, with an estimated KMO statistic of sampling adequacy of 0.532. Since this is greater than 0.5, it is acceptable.

The estimated PCA, shown in Table 2, contains three estimated principal components for this particular set of variables. The second estimated component indicates a positive correlation between video image size (pixels) and battery life. The third estimated component indicates a positive correlation between LCD screen pixels and total memory.

Together, these offer partial support of Hypothesis 2. Clearly, the pair-wise correlation between image size and battery life is particularly strong in the case of video recording and playback. Certainly, video is far more demanding on battery life than still pictures. The recording and playback of even a short, 2-3 min video clip, requires a large and constant draw of power. The strong, pair-wise correlation between LCD screen pixels and memory can be explained by the fact that a mobile phone (like a PC) requires RAM memory in order to temporarily display a picture on a screen. The amount of RAM required for a short, 2-3 min video recording is therefore large, certainly in comparison to a single frame photograph.

Once again, the first estimated principal component supports Hypothesis 4 concerning an interaction between the physical/ergonomic features of a mobile phone handset: its physical dimensions (volume), weight, and screen size (measured in pixels), and battery life. Each estimated variable has the expected sign. That is to say, the physical proportions of screen size, volume, and weight are positively correlated, while battery life is negatively related to these three variables.

5.3 Music quality and ergonomics

Our final test examines the determinants of music quality. To test Hypothesis 3 we include the variables total memory, battery life, LCD screen pixels, and music play and storage. Once again, to jointly test Hypothesis 4 regarding ergonomic characteristics we include physical dimensions (volume) and weight.

Table 3
Estimated principal components for music quality and ergonomics

Variables	**Retained components**	
	1	**2**
Physical dimensions (volume)	0.786*	− 0.003
Weight	0.785*	0.371
Total memory	− 0.117	0.611*
Battery life	− 0.505 *	0.421*
LCD screen pixels	0.452*	0.701*
Music play and storage	0.102	0.569*
Number of observations	319	319
Eigenvalues		
Total	2.005	1.217
Percent of variance	33.420	20.284
Cumulative percent of variance	33.420	53.704

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization. Rotation converged in three iterations

The diagnostic statistics for the PCA comprising these characteristic vari-ables indicates that all components have eigenvalues greater than 1. In this case, the selected variables cumulatively interpret almost 54% of the original variance across all characteristics. "Appendix" Table 6 presents the estimated correlation matrix on which this particular PCA is constructed. The level of model significance is, once again, within the 1% level. The estimated KMO statistic of sampling adequacy for the correlation matrix is 0.603, which is good.

The estimated PCA, shown in Table 3, contains two estimated principal components. Again, the first estimated principal component contains the physical/ergonomic features of a mobile phone handset: its volume, weight, screen size, and battery life. This first principal component explains around 33% of total variance across all variables. Each variable has the expected sign, supporting Hypothesis 4.

The second estimated principal component indicates a positive correlation exists between music play and storage, total memory, battery life, and LCD screen pixels. This principal component explains around 20% of total variance across all variables. Each variable has the expected sign, supporting Hypothesis 3.

6 Conclusions

The goal of the paper was to empirically test the relationship between technical and service characteristics, as expounded by the Saviotti and Metcalfe model. The model posits that complex relationships exist between the service characteristics which consumers value, and a core set of underpinning technologies with particular technical characteristics. Rather than there being a simple one-to-one mapping between individual technical characteristics and individual service characteristics, overlapping clusters of technical characteristics can exist which produce a larger number of service characteristics. This relationship between technical and service characteristics has not been explored in past empirical research.

In order to address this gap in the empirical literature, the paper applied principal components analysis (PCA) to a dataset of technical and service characteristics collected on mobile phone handsets. Using PCA as an exploratory research method, the findings clearly indicate that a limited set of underpinning technologies support a set of key service characteristics that are demanded by consumers.

In addition to testing correlations between technical and service characteristics, the paper explored the existence of a cluster of ergonomic characteristics. Ergonomic design and its influence on consumer preferences was a key part of Lancaster's original theory of consumer demand. Yet this has been ignored in prior empirical research, which has preferred to concentrate on technical characteristics. Not only was this non-technological cluster consistently identified in the tests, but it was consistently the first estimated principal component, accounting for around one-third of the explained variance in each of the estimated models. Meanwhile, correlated technical and service characteristics accounted for 20% to 23% of the explained variance in our estimated models.

These research findings have a number of implications for future research. Further empirical research is required to improve our understanding of clusters of technical and service characteristics, and how these clusters develop over time. This would directly feed into current debates surrounding, for example, the work of Henderson and Clark (1990) on product architectures and the dynamics of architectural and modular innovation; and debates concerning the work of Baldwin and Clark (1997), Brusoni et al. (2001), and Langlois (2003) on the implications of modularity for organisational structures and supply chain relationships.

Another area requiring attention is the role of demand in determining the direction in which clusters of service characteristics develop over time. As one of the authors has argued elsewhere, heterogeneous consumer preferences is an important factor affecting the development of multiple niches containing products with distinct technical and service characteristics or, alternatively, dominant designs (Windrum and Birchenhall 1998; Windrum 2005). Further, the way in which heterogeneous consumer preferences evolve over time is a key factor affecting the timing of new technological products and the probability of new technologies displacing older technology products in sequential technology competitions and substitutions (Windrum and Birchenhall 2005; Windrum et al. 2009a, b). Given the findings of the current paper, future research needs to consider the empirical relationship between distributions of consumer preferences and clusters of technical and service characteristics, and how clusters change over time. As we approach the 25th anniversary of the publication of the Saviotti and Metcalfe model, it is testament to the authors that their work continues to provoke debate and to stimulate new empirical research.

Appendix

Table 4

Estimated correlation matrix for camera quality

		Physical dimensions (volume)	**Weight**	**Total memory**	**Battery life**	**Screen pixels**	**Camera pixels**
Correlation	Physical dimensions (volume)	1.000					
	Weight	0.487 (0.000)	1.000				
	Total memory	−0.033 (0.281)	0.103 (0.033)	1.000			
	Battery life	−0.129 (0.011)	−0.144 (0.005)	0.050 (0.189)	1.000		
	Screen pixels	0.240 (0.000)	0.532 (0.000)	0.247 (0.000)	0.030 (0.299)	1.000	
	Camera pixels	0.015 (0.397)	0.114 (0.021)	0.105 (0.030)	0.221 (0.000)	0.400 (0.299)	1.000

Figures in brackets indicate sig. (one-tailed); determinant 0.384; Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy 0.576; Bartlett's test of sphericity, approximate chi-square 305.568; df 15, sig. 0.000

Table 5

Estimated correlation matrix for video quality

		Physical dimensions (volume)	**Weight**	**Total memory**	**Battery life**	**Screen pixels**	**Video image size**
Correlation	Physical dimensions (volume)	1.000					
	Weight	0.487 (0.000)	1.000				
	Total memory	−0.032 (0.283)	0.103 (0.033)	1.000			
	Battery life	−0.130 (0.010)	−0.144 (0.005)	0.049 (0.190)	1.000		
	Screen pixels	0.239 (0.000)	0.532 (0.000)	0.247 (0.000)	0.030 (0.294)	1.000	
	Video image size	0.203 (0.000)	0.084 (0.067)	0.069 (0.110)	0.182 (0.001)	0.360 (0.000)	1.000

Figures in brackets indicate sig. (one-tailed); determinant 0.384; Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy 0.532; Bartlett's test of sphericity, approximate chi-square 301.388; df 15, sig. 0.000

Table 6

Estimated correlation matrix for music play and storage

		Physical dimensions (volume)	Weight	Total memory	Battery life	Screen pixels	Music play and storage
Correlation	Physical dimensions (volume)	1.000					
	Weight	0.487 (0.000)	1.000				
	Total memory	−0.032 (0.283)	0.103 (0.033)	1.000			
	Battery life	−0.130 (0.010)	−0.144 (0.005)	0.049 (0.190)	1.000		
	Screen pixels	0.239 (0.000)	0.532 (0.000)	0.247 (0.000)	0.030 (0.294)	1.000	
	Music play and storage	0.240 (0.236)	0.194 (0.000)	0.055 (0.162)	0.039 (0.243)	0.290 (0.000)	1.000

Figures in brackets indicate sig. (one-tailed); determinant 0.443; Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy 0.603; Bartlett's test of sphericity, approximate chi-squared 256.940; df 15, sig. 0.000

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APPENDIX B- HORAS AND TEMPUS EXAMPLE (SIMON 1962)

The Architecture of ComplexityAuthor(s): Herbert A. Simon

Source: Proceedings of the American Philosophical Society, Vol. 106, No. 6 (Dec. 12, 1962), pp.467-482

"THE EVOLUTION OF COMPLEX SYSTEMS; Let me introduce the topic of evolution with a parable. There once were two watchmakers, named Hora and Tempus, who manufactured very fine watches. Both of them were highly regarded, and the phones in their workshops rang frequently -new customers were constantly calling them. However, Hora prospered, while Tempus became poorer and poorer and finally lost his shop. What was the reason? The watches the men made consisted of about 1,000 parts each. Tempus had so constructed his that if he had one partly assembled and had to put it down-to answer the phone say-it immediately fell to pieces and had to be reassembled from the elements. The better the customers liked his watches, the more they phoned him, the more difficult it became for him to find enough uninterrupted time to finish a watch. The watches that Hora made were no less complex than those of Tempus. But he had designed them so that he could put together subassemblies of about ten elements each. Ten of these subassemblies, again, could be put together into a larger subassembly; and a system of ten of the latter sub- assemblies constituted the whole watch. Hence, when Hora had to put down a partly assembled watch in order to answer the phone, he lost only a small part of his work, and he assembled his watches in only a fraction of the man-hours it took Tempus. It is rather easy to make a quantitative analysis of the relative difficulty of the tasks of Tempus and Hora: Suppose the probability that an interruption will occur while a part is being added to an incomplete assembly is p. Then the probability that Tempus can complete a watch he has started without interruption is (1-p) 100-a very small number unless p is .001 or less. Each interruption will cost, on the average, the time to assemble 1/p parts (the expected number assembled before interruption). On the other hand, Hora has to complete one hundred eleven sub-assemblies of ten parts each. The probability that he will not be interrupted while completing any one of these is (1-p) 10, and each interruption will cost only about the time required to assemble five parts.7 Now if p is about .01-that is, there is one chance in a hundred that either watchmaker will be interrupted while adding any one part to an assembly then a straightforward calculation shows that it will take Tempus, on the average, about four thousand times as long to assemble a watch as Hora. We arrive at the estimate as follows: 1. Hora must make 111 times as many complete assemblies per watch as Tempus; but' 2. Tempus will lose on the average 20 times as much work for each interrupted assembly as Hora [100 parts, on the average, as against 51; and, 3. Tempus will complete an assembly only 44 times per million attempts (.991(0(= 44 X 10-6), while Hora will complete nine out of ten (.9910 = 9 x 10-1). Hence Temppus will have to make 20,000 as many attempts per completed assembly as Hora. (9 x 10-1) /(44 x 10-6) = 2x 104. Multiplying these three ratios, we get: 1/111 x 100/5 x 9910/ 991000 = 1/111 x 20 x 20,000 - 4,000. 7 The speculations on speed of evolution were first sug- gested by H. Jacobson's application of information theory to estimating the time required for biological evolution. See his paper, Information, reproduction, and the origin of life, in American Scientist 43: 119-127, January, 1955. From thermodynamic considerations it is possible to estimate the amount of increase in entropy that occurs when a complex system decomposes into its elements. (See, for example, R. B. Setlow and E. C. Pollard, illeoccildar biophysics, 63-65, Reading, Mass., Addison-Wesley Publishing Co., 1962, and references cited there.) But entropy is the logarithm of a probability, hence information, the negative of entropy, can be interpreted as the logarithm of the reciprocal of the probability-the "improbability," so to speak. The essential idea in Jacobson's model is that the expected time required for the system to reach a particular state is inversely proportional to the probability of the state-hence increases exponentially with the amount of information (negentropy) of the state. Following this line of argument, but not introducing the notion of levels and stable subassemblies, Jacobson arrived at estimates of the time required for evolution so large as to make the event rather improbable" Simon (1962, p. 470)

APPENDIX C- TIMELIME MAJOR INNOVATION IN PHOTOGRAPHY

1814	Joseph Niepce achieves first photographic image with camera obscura - however, the image required eight hours of light exposure and later faded.
1837	Louis Daguerre's first daguerreotype - the first image that was fixed and did not fade and needed under thirty minutes of light exposure.
1840	First American patent issued in photography to Alexander Wolcott for his camera.
1841	William Henry Talbot patents the Calotype process - the first negative-positive process making possible the first multiple copies.
1851	Frederick Scott Archer invented the Collodion process - images required only two or three seconds of light exposure.
1859	Panoramic camera patented - the Sutton
1861	Oliver Wendell Holmes invents stereoscope viewer.
1871	Richard Leach Maddox invented the gelatin dry plate silver bromide process - negatives no longer had to be developed immediately.
1880	Eastman Dry Plate Company founded.
1884	George Eastman invents flexible, paper-based photographic film.
1888	Eastman patents Kodak roll-film camera.
1900	First mass-marketed camera—the Brownie.
1913/1914	First 35mm still camera developed. The first 35mm still camera (also called candid camera) developed by Oskar Barnack of German Leica Camera. Later it became the standard for all film cameras.
1927	General Electric invents the modern flash bulb
1932	First light meter with photoelectric cell introduced.
1935	Eastman Kodak markets Kodachrome film
1941	Eastman Kodak introduces Kodacolor negative film.
1942	Chester Carlson receives patent for electric photography (xerography).
1948	Edwin Land markets the Polaroid camera.
1949	East German Zeiss develops the Contax S, first SLR with an unreversed image in a pentaprism viewfinder
1954	Eastman Kodak introduces high speed Tri-X film
1963	Polaroid introduces instant color film.
1972	110-format cameras introduced by Kodak with a 13x17mm frame
1973	Polaroid introduces one-step instant photography with the SX-70 camera.
1978	Konica introduces the first point-and-shoot, autofocus camera Konica C35 AF. It was named "Jasupin".
1981	Sony demonstrates the Sony Mavica – the world's first digital electronic still camera. Digital photography and television images are related to the same technology, so this camera recorded images into a mini disk and then put them into a video reader. Images could be displayed to a television monitor or color printer.
1983	Kodak introduces disk camera, using an 8x11mm frame (the same as in the Minox spy camera)

1984	Canon demonstrates first digital electronic still camera.
1985	Pixar introduces digital imaging processor Minolta markets the world's first autofocus SLR system (called "Maxxum" in the US);
1986	Fuji introduced the disposable camera. The inventors also call this device "single-use cameras".
1987	The popular Canon EOS system introduced, with new all-electronic lens mount
1990	Eastman Kodak announces Photo CD as a digital image storage medium.
1991	Kodak released the first professional digital camera system (DCS) which was of a great use for photojournalists. It was a modified Nikon F-3 camera with a 1.3 megapixel sensor.
1994/1996	The first digital cameras for the consumer-level market that worked with a home computer via a serial cable were the Apple QuickTake 100 camera (February 17 , 1994), the Kodak DC40 camera (March 28, 1995), the Casio QV-11 (with LCD monitor, late 1995), and Sony's Cyber-Shot Digital Still Camera (1996).
2001	**The Easy Share camera comes into play** Kodak put out their Easy Share digital camera, which made it easy to snap pictures and download them to the computer.
2004	Kodak ceases production of film cameras
2005	The Canon EOS 5D is launched. This is first consumer-priced full-frame digital SLR with a 24x36mm CMOS sensor.

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APPENDIX D-ASSOCIATION TABLES ALL CAMERAS

1. ASSOCIATION TABLES ROLL FILM CAMERAS

Roll film 1955-1964	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	Pchi2(1) = 9.2391 Pr = 0.002 LRchi2(1)=4.7482 Pr = 0.029 Cramér'sV=0.3377	Pchi2(2) = 0.3544 Pr = 0.838 LRchi2(2) = 0.6046 Pr = 0.739 Cramér's V= 0.0661	Pchi2(9) = 3.8118 Pr = 0.923 LRchi2(9) = 3.1701 Pr = 0.957 Cramér's V =0.2169	Pchi2(14) = 2.586 Pr = 1.000 LR chi2(14) =2.5706 Pr=1.000 Cramér's V =0.1909	Pchi2(15) = 0.9872 Pr = 1.000 LRchi2(15) = 1.3733 Pr = 1.000 Cramér's V = 0.1132
Metering		Pchi2(2) = 10.4093 Pr = 0.005 LR chi2(2) =5.9227 Pr = 0.052 Cramér's V =0.3585	Pchi2(9) = 9.6063 Pr = 0.383 LR chi2(9)=11.5313 Pr = 0.241 Cramér's V = 0.3444	Pchi2(14) = 6.5158 Pr = 0.952 LR chi2(14) =7.8210 Pr = 0.898 Cramér's V = 0.3029	Pchi2(15) = 5.9101 Pr = 0.981 LR chi2(15) = 8.6320 Pr = 0.896 Cramér's V = 0.2770
Flash			Pchi2(18) =19.0440 Pr = 0.389 LRchi2(18)=23.177 Pr=0.184 Cramér's V =0.3429	Pchi2(28) = 13.3693 Pr = 0.991 LR chi2(28) =15.8877 Pr=0.967 Cramér's V =0.3068	Pchi2(30) = 16.7459 Pr = 0.975 LR chi2(30)=22.9101 Pr = 0.819 Cramér's V = 0.3298
Shutter speed				Pchi2(112)=105.7020 Pr = 0.650 LRchi2(112)=74.7166 Pr = 0.997 Cramér's V = 0.4314	Pchi2(135) =218.47 Pr = 0.000 LRchi2(135)=112.09 Pr=0.925 Cramér's V =0.5615
Focal Length					Pchi2(154=287.8195 Pr = 0.000 LRchi2(154)=93.812 Pr=1.000 Cramér's V =0.6071
Average Association: 0.4662					

Roll film 1965-1974	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	Pchi2(1)=9.007 Pr = 0.966 LR chi2(1)=4.146 Pr = 0.929 Cramér's V=0.042	Pchi2(6) = 9.1000 Pr = 0.168 LRchi2(6)=11.2064 Pr = 0.082 Cramér's V=0.8062	Pchi2(4) =3.7917 Pr = 0.435 LRchi2(4)= 4.6147 Pr = 0.329 Cramér's V=0.5204	Pchi2(16)=29.158 Pr = 0.021 LR chi2(16)=15.773 Pr=0.472 Cramér's V=0.829	Pchi2(13)=4.392 Pr = 0.977 LRchi2(13)=5.917 Pr = 0.949 Cramér's V=0.339
Metering		Pchi2(1) =2.2400 Pr = 0.134 LRchi2(1)= 3.2913 Pr = 0.070 Cramér's V=0.4000	Pchi2(4) =3.7917 Pr = 0.435 LRchi2(4)= 4.6147 Pr = 0.329 Cramér's V=0.5204	Pchi2(6)= 9.1000 Pr = 0.168 LR chi2(6) = 11.2064 Pr = 0.082 Cramér's V=0.8062	Pchi2(5) =4.2000 Pr = 0.521 LRchi2(5) = 5.2943 Pr = 0.381 Cramér's V = 0.5477
Flash			Pchi2(4) =2.5667 Pr = 0.633 LRchi2(4) = 3.5682 Pr = 0.468 Cramér's V=0.4282	Pchi2(6) = 9.1000 Pr = 0.168 LRchi2(6) = 11.2064 Pr = 0.082 Cramér's V = 0.8062	Pchi2(5) = 4.2000 Pr = 0.521 LRchi2(5) = 5.2943 Pr = 0.381 Cramér's V = 0.5477
Shutter speed				Pchi2(24) = 23.0417 Pr = 0.517 LRchi2(24) =21.8940 Pr = 0.586 Cramér's V = 0.6415	Pchi2(20) = 31.6944 Pr = 0.047 LRchi2(20) =23.6201 Pr = 0.259 Cramér's V = 0.7523
Focal Length					Pchi2(30) = 49.5833 Pr = 0.014 LRchi2(30) =35.7570

					Pr = 0.216 Cramér's V = 0.8416
Average association: 0.8056					

2. Association tables Non Reflex Cameras

NSLR 1955-1964	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	Pchi2(1) = 8.4935 Pr =0.004 LRchi2(1)=8.6533 Pr = 0.003 Cramér'sV=0.1858	P chi2(3) =7.6833 Pr = 0.053 LRchi2(3)=9.1925 Pr = 0.027 Cramér's V=0.1767	Pchi2(10)=17.6789 Pr=0.061 LRchi2(10)=19.254 Pr=0.037 Cramér's V=0.2681	Pchi2(16) = 37.3133 Pr =0.002 LRchi2(16)=22.5220 Pr = 0.127 Cramér's V = 0.3927	Pchi2(16) = 37.6583 Pr = 0.002 LRchi2(16)=26.7992 Pr =0.044 Cramér's V=0.3929
Metering		Pchi2(3)=7.8740 Pr = 0.049 LRchi2(3)=8.2550 Pr = 0.041 Cramér's V=0.1789	Pchi2(10)=10.0582 Pr = 0.435 LRchi2(10)=11.014 Pr = 0.356 Cramér's V=0.2022	Pchi2(16)=13.3134 Pr = 0.650 LR chi2(16)=16.8772 Pr = 0.394 Cramér's V=0.2346	Pchi2(16)=38.6547 Pr = 0.001 LRchi2(16)=46.8650 Pr = 0.000 Cramér's V=0.3980
Flash			Pchi2(30)=47.6013 Pr = 0.022 LRchi2(30)=51.712 Pr = 0.008 Cramér's V=0.2540	Pchi2(48)=123.0326 Pr =0.000 LR chi2(48)=52.5784 Pr = 0.301 Cramér's V = 0.4117	Pchi2(48)=37.3610 Pr = 0.866 LRchi2(48)=34.6716 Pr = 0.925 Cramér's V=0.2259
Shutter speed				Pchi2(160)=236.559 Pr = 0.000 LRchi2(160)=107.16 Pr = 1.000 Cramér's V = 0.3127	Pchi2(160)= 206.1813 Pr = 0.008 LRchi2(160)=118.678 Pr = 0.994 Cramér's V =0.2907
Focal Length					Pchi2(208)=576.6472 Pr = 0.000 LRchi2(208)=109.928 Pr = 1.000 Cramér's V = 0.4290
Average association: 0.3246					

NSLR 1965-1974	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	Pchi2(9) = 61.0511 Pr = 0.000 LRchi2(9)=26.5618 Pr = 0.002 Cramér'sV=0.3372	Pchi2(6)= 0.7860 Pr = 0.992 LRchi2(6)=1.0834 Pr = 0.982 Cramér'sV=0.0469	Pchi2(45)=93.5324 Pr = 0.000 LRchi2(45)=40.295 Pr = 0.671 Cramér's V=0.4173	Pchi2(60)= 41.2634 Pr = 0.969 LR chi2(60)=27.6563 Pr = 1.000 Cramér's V=0.2812	Pchi2(48)= 84.1737 Pr = 0.001 LRchi2(48)=43.1350 Pr = 0.672 Cramér's V = 0.4004
Metering		Pchi2(6) = 4.5368 Pr = 0.604 LRchi2(6)=4.2578 Pr = 0.642 Cramér'sV=0.1126	Pchi2(45)=61.5657 Pr = 0.051 LRchi2(45)=55.405 Pr = 0.138 Cramér's V=0.3386	Pchi2(60) =91.0321 Pr = 0.006 LRchi2(60)=64.6752 Pr = 0.317 Cramér's V= 0.4176	Pchi2(48)=113.5494 Pr = 0.000 LRchi2(48)=70.7596 Pr = 0.018 Cramér's V=0.4651
Flash			Pchi2(30)=29.4618 Pr = 0.493 LRchi2(30)=29.845 Pr = 0.474 Cramér's V=0.2869	Pchi2(40) = 55.8503 Pr = 0.049 LRchi2(40)= 44.3041 Pr = 0.295 Cramér's V=0.4006	Pchi2(32) = 68.3953 Pr = 0.000 LRchi2(32)=36.1718 Pr = 0.280 Cramér's V=0.4421
Shutter speed				Pchi2(280)=305.1054 Pr = 0.145 LRchi2(280)=200.1443 Pr = 1.000 Cramér's V=0.3539	Pchi2(240)=331.513 Pr = 0.000 LRchi2(240)=174.13 Pr = 1.000 Cramér's V =0.3554
Focal Length					Pchi2(320)=534.540 Pr = 0.000 LRchi2(320)=193.60 Pr = 1.000

					Cramér's V = 0.4382
Average Association: 0.4082					

3. Association tables SRL

SRL 1955-1964	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	P. Chi(4)=17.0801 Pr=0.000 LRChi(4)=16.7433 Pr=0.000 Cramer V.=0.349	Pchi2(4)=4.6640 Pr = 0.324 LRchi2(4)=5.3124 Pr = 0.257 Cramér V=0.1291	P. Chi(22)=33.4689 Pr=0.056 LRChi(22)=31.6627 Pr=0.083 Cramer V.=0.3457	P. Chi(34)=41.000 Pr=0.168 LR Chi(34)=31.7329 Pr=0.579 Cramer V.=0.3891	P. Chi(36)=30.9935 Pr=0.705 LRChi(36)=28.6583 Pr=0.803 Cramer V.=0.3351
Metering		P. Chi(2)=2.8026 Pr=0.246 LRChi(2)=3.1385 Pr=0.208 Cramer V.=0.1415	P. Chi(11)=12.6749 Pr=0.315 LRChi(11)=15.4274 Pr=0.164 Cramer V.=0.3009	P. Chi(17)=21.3735 Pr=0.210 LR Chi(17)=25.2546 Pr=0.089 Cramer V.=0.3935	P. Chi(18)=25.4923 Pr=0.112 LRChi(18)=30.4424 Pr=0.033 Cramer V.=0.4298
Flash			P. Chi(22)=16.9377 Pr=0.767 LRChi(22)=17.901 Pr=0.712 Cramer V=0.2460	P. Chi(34)=21.3239 Pr=0.956 LRChi(34)=26.9168 Pr=0.801 Cramer V=0.278	P. Chi(36)=17.7883 Pr=0.995 LR Chi(36)=24.1063 Pr=0.935 Cramer V.=0.2539
Shutter speed				Pchi2(187)=322.6623 Pr = 0.000 LRchi2(187)=129.285 Pr = 1.000 Cramér's V=0.4610	Pchi2(198)=350.831 Pr=0.000 LRchi2(198)=174.653 Pr = 0.883 Cramér's V=0.4807
Focal Length					P. Chi(272)=557.3898 Pr=0.000 LRChi(272)=218.411 Pr=0.993 Cramer V.=0.5043
Average Association: 0.4487					

SRL 1965-1974	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	Pchi2(3)=2.2902 Pr = 0.514 LRchi2(3)=2.7355 Pr = 0.434 Cramér's V=0.1244	Pchi2(2) =3.2161 Pr = 0.200 LRchi2(2) =4.2827 Pr = 0.117 Cramér'sV=0.1474	Pchi2(12) =29.6892 Pr = 0.003 LRchi2(12)=23.2110 Pr = 0.026 Cramér's V =0.4479	Pchi2(12) =17.3775 Pr = 0.136 LRchi2(12) =13.8483 Pr = 0.311 Cramér's V =0.3486	Pchi2(12) = 9.0916 Pr = 0.695 LRchi2(12)=12.3179 Pr = 0.420 Cramér's V =0.2513
Metering		Pchi2(6)= 4.8908 Pr = 0.558 LRchi2(6)=5.2816 Pr = 0.508 Cramér'sV=0.1285	Pchi2(36) =42.5972 Pr = 0.208 LRchi2(36)=47.0918 Pr = 0.102 Cramér's V=0.3097	Pchi2(36)=50.8028 Pr = 0.052 LRchi2(36)=45.8642 Pr = 0.126 Cramér's V =0.3441	Pchi2(36) =46.3109 Pr = 0.117 LRchi2(36) =46.3008 Pr = 0.117 Cramér's V = 0.3274
Flash			Pchi2(24) =17.8952 Pr = 0.808 LRchi2(24)=23.0863 Pr = 0.515 Cramér's V = 0.2459	Pchi2(24) =27.7912 Pr = 0.269 LRchi2(24) =36.1884 Pr = 0.053 Cramér's V =0.3117	Pchi2(24) =14.8811 Pr = 0.924 LRchi2(24) =17.9707 Pr = 0.804 Cramér's V= 0.2273
Shutter speed				Pchi2(132)=182.3986 Pr = 0.002 LRchi2(132)=88.8949 Pr = 0.999 Cramér's V =0.3405	Pchi2(144) =375.4896 Pr = 0.000 LRchi2(144)=128.2056 Pr = 0.823 Cramér's V = 0.4662

Focal Length					Pchi2(132) = 351.7692 Pr = 0.000 LRchi2(132)=122.8296 Pr = 0.704 Cramér's V =0.4729
Average Association: 0.4318					

SRL 1975-1984	**Metering**	**Flash**	**Shutter speed**	**Focal Length**	**Lenses Speed**
Exposition	PChi(15)=30.770 Pr=0.009 LRChi(15)=38.996 Pr=0.009 Cramer V.=0.2215	P. Chi(15)=11.9562 Pr=0.682 LRChi(15)=11.1557 Pr=0.741 Cramer V.=0.1381	P. Chi(70)=89.8294 Pr=0.055 LRChi(70)=65.0150 Pr=0646 Cramer V.=0.2932	P. Chi(100)=41.9837 Pr=1.000 L.RChi(100)=49.2896 Pr=1.000 Cramer V.=0.2019	P. Chi(110)=72.6417 Pr=0.998 L.RChi(110)=63.532 Pr=0.1.000 Cramer V.=0.2643
Metering		P. Chi(9)=14.8005 Pr=0.097 LRChi(9)=11.9664 Pr=0.215 Cramer V.=0.1536	P. Chi(42)=71.3893 Pr=0.003 LRChi(42)=63.1797 Pr=0.019 Cramer V.=0.3374	P. Chi(60)=158.5408 Pr=0.000 LR Chi(60)=127.739 Pr=0.000 Cramer V.=0.5065	P. Chi(66)=124.9020 Pr=0.000 LRChi(66)=104.495 Pr=0.002 Cramer V.=0.4474
Flash			P. Chi(42)=42.5946 Pr=0.325 LRChi(42)=31.2611 Pr=0.888 Cramer V.=-0.2697	P. Chi(34)=21.3239 Pr=0.956 L.RChi(34)=26.9168 Pr=0.801 Cramer V.=0.2780	P. Chi(60)=230.2836 Pr=0.000 LRChi(60)=42.6896 Pr=0.956 Cramer V.=0.6104
Shutter speed				P.Chi(280)=340.1801 Pr=0.008 LRChi(280)=162.118 Pr=1.000 Cramer V.=0.3434	P. Chi(308)=415.227 Pr=0.000 LRChi(308)=186.845 Pr=1.000 Cramer V.=0.3776
Focal Length					P. Chi(418)=1.7e+03 Pr=0.000 LRChi(418)=367.811 Pr=0.963 Cramer V.=0.6604
Average Association: 0.4380					

SRL 1985-1994	**Metering**	**Flash**	**Shutter speed**	**Focal Length**	**Lenses Speed**
Exposition	PChi(36)=86.1541 Pr=0.000 LRChi(36)=71.241 Pr=0.000 Cramer V.=0.3054	PChi(30)=20.8671 Pr=0.892 LRChi(30)=20.715 Pr=0.897 Cramer V.=0.1646	PChi(70)=89.8294 Pr=0.055 LRChi(70)=65.015 Pr=0646 Cramer V.=0.2932	PChi(90)=123.0437 Pr=0.012 L.RChi(90)=135.207 Pr=0.001 Cramer V.=0.3649	PChi(132)=98.3652 Pr=0.987 L.RChi(132)=82.707 Pr=1.000 Cramer V.=0.3273
Metering		PChi(30)=89.7392 Pr=0.000 L.RChi(30)=23.6166 Pr=0.789 Cramer V.=0.0314	PChi(90)=100.1629 Pr=0.218 LRChi(90)=98.074 Pr=0.263 Cramer V.=0.3292	PChi(132)=68.5711 Pr=1.000 LRChi(132)=68.9125 Pr=1.000 Cramer V.=0.2733	PChi(144)=78.0894 Pr=0.996 LRChi(144)=72.453 Pr=0.999 Cramer V.=0.2917
Flash			PChi(75)=73.3798 Pr=0.0531 L.RChi(75)=57.4765 Pr=0.934 Cramer V.=0.3087	PChi(110)=183.1212 Pr=0.000 LR Chi(110)=99.3964 Pr=0.756 Cramer V.=0.4893	PChi(90)=142.9087 Pr=0.001 LRChi(90)=92.8126 Pr=0.544 Cramer V.=0.4322
Shutter speed				PChi(330)=527.7087 Pr=0.000 LRChi(330)=177.74 Pr=1.000 Cramer V.=0.4795	PChi(285)=295.0549 Pr=0.328 LRChi(285)=183.795 Pr=1.000 Cramer V.=0.3586
Focal Length					PChi(418)=893.9089 Pr=0.000 LRChi(418)=302.747

					Pr=1.000 Cramer V.=0.5545
Average Association: 0.3796					

SRL 1995-2004	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	PChi(49)=152.345 Pr=0.000 LRChi(49)=72.022 Pr=0.018 Cramer V.=0.4918	PChi(35)=40.8293 Pr=0.230 LRChi(35)=47.5443 Pr=0.077 Cramer V.=0.3012	PChi(70)=100.9225 Pr=0.009 LRChi(70)=91.1805 Pr=0.045 Cramer V.=0.4002	PChi(119)=110.2286 Pr=0.705 L.RChi(119)=85.7062 Pr=0.991 Cramer V.=0.4206	PChi(77)=79.6671 Pr=0.395 L.RChi(77)=65.510 Pr=0.822 Cramer V.=0.3576
Metering		PChi(35)=51.0227 Pr=0.039 LRChi(35)=49.4044 Pr=0.054 Cramer V.=0.3367	PChi(70)=181.8206 Pr=0.000 LRChi(70)=96.989 Pr=0.018 Cramer V.=0.5372	PChi(119)=191.4704 Pr=0.000 LRChi(119)=75.5261 Pr=0.999 Cramer V.=0.5544	PChi(77)=64.7814 Pr=0.838 LRChi(77)=58.128 Pr=0.946 Cramer V.=0.3255
Flash			PChi(50)=47.1978 Pr=0.587 L.RChi(50)=50.0299 Pr=0.472 Cramer V.0.3239	PChi(85)=94.9370 Pr=0.216 L.RChi(85)=82.0535 Pr=0.570 Cramer V.=0.4619	PChi(55)=70.9594 Pr=0.072 L.RChi(55)=60.6395 Pr=0.280 Cramer V.=0.3993
Shutter speed				PChi(170)=277.2052 Pr=0.000 LRChi(170)=119.2323 Pr=0.999 Cramer V.=0.5581	PChi(285)=295.0549 Pr=0.328 LRChi(285)=183.7954 Pr=1.000 Cramer V.=0.3586
Focal Length					PChi(187)=397.7210 Pr=0.000 LRChi(187)=138.4090 Pr=0.997 Cramer V.=0.6374
Average Association: 0.5022					

4. ASSOCIATION TABLES 110 CAMERAS

110 1965-1974	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	Pchi2(2)=2.8718 Pr = 0.238 LRchi2(2)=3.5964 Pr = 0.166 Cramér'sV=0.320	P chi2(1)=0.1657 Pr = 0.684 LRchi2(1)=0.3080 Pr = 0.579 Cramér's V=0.076	Pchi2(5)=3.8769 Pr = 0.567 LR chi2(5)=4.4018 Pr = 0.493 Cramér's V=0.3721	Pchi2(12)=10.5778 Pr = 0.565 LR chi2(12)=8.4961 Pr = 0.745 Cramér's V=0.7888	Pchi2(11)=9.5694 Pr = 0.569 LR chi2(11)=7.5102 Pr = 0.756 Cramér's V=0.6067
Metering		Pchi2(2)=2.8718 Pr = 0.238 LR chi2(2)=3.596 Pr = 0.166 Cramér'sV=0.320	Pchi2(10)=24.4533 Pr = 0.006 LR chi2(10)=19.1706 Pr = 0.038 Cramér's V=0.6608	Pchi2(24)=30.9778 Pr = 0.154 LRchi2(24)=24.9574 Pr = 0.408 Cramér's V=0.9545	Pchi2(22)=42.8550 Pr = 0.005 LR chi2(22)=30.6369 Pr = 0.104 Cramér's V=0.9078
Flash			Pchi2(11)=16.6111 Pr = 0.120 LRchi2(11)=10.2828 Pr=0.505 Cramér's V=0.7993	Pchi2(5)=9.1538 Pr = 0.103 LR chi2(5)=7.1386 Pr = 0.211 Cramér's V=0.5718	Pchi2(12)=17.0000 Pr = 0.150 LRchi2(12)=12.3152 Pr = 0.421 Cramér's V=1.0000
Shutter speed				P chi2(60)=75.5556 Pr = 0.085 LR chi2(60)=53.1886 Pr = 0.721 Cramér's V=0.9428	Pchi2(55)=80.6000 Pr = 0.014 LR chi2(55)=67.9175 Pr = 0.113 Cramér's V= 0.7874
Focal Length					Pchi2(108)=130.333 Pr = 0.071

					LRchi2(108)=68.236 Pr = 0.999 Cramér's V= 0.9230
Average Association: 0.7833					

110 1975-1984	**Metering**	**Flash**	**Shutter speed**	**Focal Length**	**Lenses Speed**
Exposition	Pchi2(6)=40.351 Pr = 0.000 LRchi2(6)=33.77 Pr = 0.000 Cramér'sV=0.281	Pchi2(4)=0.2876 Pr = 0.991 LR chi2(4)=0.550 Pr = 0.968 Cramér's V=0.023	Pchi2(30)=277.897 Pr = 0.000 LR chi2(30)=29.514 Pr = 0.491 Cramér's V=0.739	Pchi2(68)= 65.940 Pr = 0.548 LRchi2(68)=47.461 Pr = 0.973 Cramér's V=0.374	Pchi2(50)= 53.031 Pr = 0.358 LRchi2(50)=41.006 Pr = 0.814 Cramér's V0.328
Metering		Pchi2(6)=23.998 Pr = 0.001 LRchi2(6)=11.884 Pr = 0.065 Cramér's V=0.217	Pchi2(45)=123.625 Pr = 0.000 LRchi2(45)=66.136 Pr = 0.022 Cramér's V=0.402	Pchi2(102)=314.811 Pr = 0.000 LR chi2(102)=112.338 Pr = 0.228 Cramér's V=0.6682	Pchi2(75)=353.715 Pr = 0.000 LR chi2(75)=125.265 Pr = 0.000 Cramér's V= 0.692
Flash			Pchi2(30)=36.214 Pr = 0.201 LRchi2(30)=24.483 Pr = 0.751 Cramér's V=0.267	Pchi2(68)=225.4474 Pr = 0.000 LR chi2(68)=61.832 Pr = 0.687 Cramér's V=0.6926	Pchi2(50) = 139.966 Pr = 0.000 LR chi2(50)=69.054 Pr=0.038 Cramér's V=0.5334
Shutter speed				Pchi2(510)=691.335 Pr = 0.000 LRchi2(510)=256.189 Pr = 1.000 Cramér's V=0.442	Pchi2(375)=811.221 Pr = 0.000 LR chi2(375)=234.248 Pr = 1.000 Cramér's V=0.4689
Focal Length					Pchi2(850)=2.3e+03 Pr = 0.000 LRchi2(850)=586.170 Pr = 1.000 Cramér's V = 0.6238
Average Association: 0.5236					

5. ASSOCIATION TABLES 126 CAMERAS

126 1965-1974	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	PChi(4)=0.7782 Pr=0.941 LRChi(4)=1.2582 Pr=0.8668 CramerV.=0.0582	PChi(4)=4.2555 Pr=0.373 LR Chi(4)=3.0517 Pr=0.549 Cramer V.=0.1360	PChi(16)=35.6832 Pr=0.003 LRChi(16)=19.4128 Pr=0.248 Cramer V.=0.3939	P Chi(36)=49.6244 Pr=0.065 LR Chi(24)= 2.0151 Pr=0.7333 Cramer V.=0.0780	PChi(24)=47.4598 Pr=0.003 LR Chi(24)=25.2757 Pr=0.391 Cramer V.=0.4645
Metering		PChi(16)=62.0349 Pr=0.000 LRChi(16)=56.3921 Pr=0.00 Cramer V.=0.5193	PChi(24)=40.1646 Pr=0.291 LR Chi(24)=33.1439 Pr=0.605 Cramer V.=0.3489	PChi(24)=131.8012 Pr=0.000 LRChi(24)=22.0459 Pr=0.009 Cramer V.=0.6320	PChi(24)=84.222 Pr=0.021 LRChi(24)=34.7188 PR=0.996 Cramer V.=0.5146
Flash			Pchi2(16) =19.0766 Pr = 0.265 LRchi2(16)=14.4920 Pr = 0.562 Cramér's V=0.2888	PChi(18)=28.068 Pr=0.061 LR Chi(16)=25.8823 Pr=0.102 Cramer V.=0.6074	Pchi2(15) = 35.5158 Pr = 0.00 LRchi2(15)=28.5095 Pr = 0.019 Cramér's V = 0.6147
Shutter speed				Pchi2(144)=166.9945 Pr = 0.095 LRchi2(144)=105.224 Pr = 0.994 Cramér's V = 0.5241	P chi2(120) = 164.1433 Pr = 0.005 LRchi2(120)=114.2613 Pr=0.631 Cramér's V =0.4672

Focal Length					PChi(24)=461.1710 Pr=0.000 LRChi(24)=200.3116 Pr=0.441 Cramer V.=0.7427
Average Association: 0.5436					

6. ASSOCIATION TABLE COMPACT CAMERAS

CSLR 1965-1974	**Metering**	**Flash**	**Shutter speed**	**Focal Length**	**Lenses Speed**
Exposition	P. Chi(6)=1.5066 Pr=0.959 LR Chi(6)=2.1897 Pr=0.901 Cramer V.=0.1467	P. Chi(4)=1.2069 Pr=0.877 LR Chi(4)=2.0459 Pr=0.727 Cramer V.=0.1313	P. Chi(16)=9.1300 Pr=0.908 LR Chi(16)=8.6299 Pr=0.928 Cramer V.=0.3611	P. Chi(10)=4.7168 Pr=0.909 LRChi(10)=6.4506 Pr=0.776 Cramer V.=0.2715	P. Chi(12)=3.0583 Pr=0.995 LR Chi(12)=4.3087 Pr=0.977 Cramer V.=0.2153
Metering		P. Chi(6)=6.2293 Pr=0.398 LRChi(6)=5.0421 Pr=0.538 Cramer V.=0.2983	P. Chi(24)=43.3779 Pr=0.002 LRChi(24)=23.3478 Pr=0.499 Cramer V.=0.6858	P. Chi(15)=23.9010 Pr=0.067 LRChi(15)=21.4479 Pr=0.123 Cramer V.=0.4990	P. Chi(18)=27.7735 Pr=0.066 LRChi(18)=18.3466 Pr=0.433 Cramer V.=0.5397
Flash			P. Chi(16)=15.3275 Pr=0.501 LRChi(16)=10.5005 Pr=0.839 Cramer V.=0.4679	P. Chi(10)=6.4000 Pr=0.781 LRChi(10)=7.1803 Pr=0.708 Cramer V.=0.3162	P. Chi(12)=8.5381 Pr=0.0742 LRChi(12)=7.1959 Pr=0.844 Cramer V.=0.3597
Shutter speed				P. Chi(35)=35.2813 Pr=0.455 LR Chi(35)=34.5770 Pr=0.488 Cramer V.=0.4699	P. Chi(30)=43.1712 Pr=0.057 LR Chi(30)=36.4261 Pr=0.194 Cramer V.=0.5194
Focal Length					P. Chi(42)=50.7956 Pr=0.166 LRChi(42)=39.1694 Pr=0.596 Cramer V.=0.5065

CSLR 1975-1984	**Metering**	**Flash**	**Shutter speed**	**Focal Length**	**Lenses Speed**
Exposition	P. Chi(1)=1.5273 Pr=0.217 LRChi(1)=2.3309 Pr=0.127 Cramer V.=0.3303	P. Chi(1)=0.3214 Pr=0.571 L.RChi(1)=0.2981 Pr=0.585 Cramer V.=0.1515	P. Chi(6)=3.1111 Pr=0.795 LR Chi(6)=4.1375 Pr=0.658 Cramer V.=0.4714	P. Chi(4)=2.121 Pr=0.713 LRChi(4)=3.0910 Pr=0.543 Cramer V.=0.3892	P. Chi(6)=3.111 Pr=0.795 LRChi(6)=4.1375 Pr=0.658 Cramer V.=0.4714
Metering		P. Chi(1)=0.0424 Pr=0.837 LRChi(1)=0.0415 Pr=0.839 Cramer V.=0.0550	P. Chi(6)=4.2000 Pr=0.650 LRChi(6)=5.2943 Pr=0.507 Cramer V.=0.5477	P. Chi(4)=4.2000 Pr=0.380 LR Chi(4)=5.2943 Pr=0.258 Cramer V.=0.5477	P. Chi(6)=7.4667 Pr=0.280 LR Chi(6)=9.1134 Pr=0.167 Cramer V.=0.7303
Flash			P. Chi(6)=7.0707 Pr=0.314 LR Chi(6)=7.9566 Pr=0.241 Cramer V.=0.7107	P. Chi(4)=5.0909 Pr=0.278 LR Chi(4)=5.3224 Pr=0.256 Cramer V.=0.6030	P. Chi(6)=6.0808 Pr=0.414 LRChi(6)=6.3689 Pr=0.383 Cramer V.=0.6590
Shutter speed				P. Chi(36)=30.3333 Pr=0.735 LR Chi(36)=27.0723 Pr=0.859 Cramer V.=0.6009	P. Chi(24)=19.8333 Pr=0.706 LRChi(24)=19.4341 Pr=0.728 Cramer V.=0.5951

Focal Length					P. Chi(24)=42.000 Pr=0.013 LRChi(24)=27.0723 Pr=0.301 Cramer V.=0.8660

CSLR 1985-1994	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	PChi(12)=83.114 Pr=0.000 LRChi(12)=22.88 Pr=0.029 CramerV.=0.4785	PChi(16)=12.6742 Pr=0.696 L.RChi(16)=13.5768 Pr=0.630 Cramer V.=0.1618	PChi(60)=182.2166 Pr=0.000 L.RChi(60)=49.7104 Pr=0.826 Cramer V.=0.6136	PChi(80)=76.3566 Pr=0.595 LR Chi(80)=40.2095 Pr=1.000 Cramer V.=0.3988	PChi(60)=70.9888 Pr=0.157 LRChi(60)=44.6867 Pr=0.930 Cramer V.=0.3830
Metering		PChi(12)=25.8337 Pr=0.011 LRChi(12)=18.9023 Pr=0.091 Cramer V=0.2668	PChi(45)=158.2173 Pr=0.000 L.RChi(45)=53.6557 Pr=0.176 Cramer V.=0.6602	PChi(60)=112.5662 Pr=0.000 L.RChi(60)=59.877 Pr=0.480 Cramer V.=0.5592	PChi(45)=29.4816 Pr=0.964 LRChi(45)=26.1090 Pr=0.989 Cramer V.=0.2850
Flash			P. Chi(6)=7.0707 Pr=0.314 L.RChi(6)=7.9566 Pr=0.241 Cramer V.=0.7107	P. Chi(80)=131.8707 Pr=0.000 L.RChi(80)=93.7315 Pr=0.140 Cramer V.=0.5241	P. Chi(60)=67.3373 Pr=0.241 L.RChi(60)=53.3083 Pr=0.717 Cramer V.=0.3730
Shutter speed				P. Chi(300)=408.7729 Pr=0.000 LRChi(300)=195.0998 Pr=1.000 Cramer V.=0.4765	P. Chi(225)=247.1816 Pr=0.148 LRChi(225)=145.4144 Pr=1.000 Cramer V.=0.3690
Focal Length					P. Chi(300)=439.6420 Pr=0.000 LRChi(300)=177.6772 Pr=1.000 Cramer V.=0.4942
Average Association: 0.5091					

CSLR 1995-2004	Metering	Flash	Shutter speed	Focal Length	Lenses Speed
Exposition	PChi(8)=32.6250 Pr=0.000 LRChi(8)=19.6810 Pr=0.012 Cramer V.=0.8814	PChi(16)=19.7273 Pr=0.233 L.RChi(16)=17.3750 Pr=0.362 Cramer V.=0.4846	PChi(36)=42.8182 Pr=0.202 L.RChi(36)=29.1450 Pr=0.784 Cramer V.=0.7140	PChi(60)=66.2727 Pr=0.270 LR Chi(60)=38.5092 Pr=0.986 Cramer V.=0.882	PChi(52)=58.8545 Pr=0.239 L.RChi(52)=34.5517 Pr=0.970 Cramer V.=0.8370
Metering		PChi(8)=12.7969 Pr=0.119 LRChi(8)=13.5345 Pr=0.095 Cramer V.=0.5520	PChi(8)=27.7813 Pr=0.065 LRChi(8)=15.9199 Pr=0.598 Cramer V.=0.8133	PChi(30)=34.3438 Pr=0.267 LR Chi(30)=21.4651 Pr=0.873 Cramer V.=0.9043	PChi(26)=29.0937 Pr=0.307 LRChi(26)=16.4611 Pr=0.924 Cramer V.=0.8323
Flash			PChi(36)=32.229 Pr=0.649 LRChi(36)=29.0490 Pr=0.788 Cramer V.=0.6194	PChi(60)=65.0417 Pr=0.306 LRChi(60)=40.1394 Pr=0.977 Cramer V.=0.8799	PChi(52)=40.8917 Pr=0.867 LR Chi(52)=32.3628 Pr=0.985 Cramer V.=0.6977
Shutter speed				PChi(135)=154.583 Pr=0.119 LRChi(135)=83.141 Pr=1.000 Cramer V.=0.9044	PChi(117)=133.7000 Pr=0.139 LR Chi(117)=75.5924 Pr=1.000 Cramer V.=0.8411

Focal Length					P.Chi(195)=439.229 Pr=0.047 LR Chi(197)=90.2744 Pr=1.000 Cramer V.=0.9164
Average Association:0.8989					

7. Association tables instant cameras

Instant 1975-1984	**Metering**	**Flash**	**Shutter speed**	**Focal Length**	**Lenses Speed**
Exposition	P. Chi(2)=1.9549 Pr=0.376 LR.Chi(2)=2.1990 Pr=0.333 Cramer V.=0.3126	P. Chi(1)=0.1170 Pr=0.732 LR Chi(1)=0.2165 Pr=0.642 Cramer V.=-.0765	P. Chi(6)=1.9549 Pr=0.924 LRChi(6)=2.1990 Pr=0.901 Cramer V.=0.312	P. Chi(8)=2.4561 Pr=0.964 LRChi(8)= 2.5339 Pr=0.960 Cramer V.=0.3504	P chi2(9) = 2.4561 Pr = 0.982 LRchi2(9) = 2.5339 Pr = 0.980 Cramér's V = 0.3504
Metering			P. Chi(12)=9.8469 Pr=0.629 LRChi(12)=11.2512 Pr=0.508 Cramer V.=0.4962	P. Chi(16)=30.9524 Pr=0.014 LR Chi(16)=21.4915 Pr=0.160 Cramer V.=0.8797	P. Chi(18)=31.7063 Pr=0.024 LRChi(18)=22.5380 Pr=0.209 Cramer V.=0.8903
Flash				P. Chi(8)=10.7407 Pr=0.217 LR Chi(8)=7.5966 Pr=0.474 Cramer V.=0.7328	P. Chi(9)=10.7407 Pr=0.294 LR Chi(9)=7.5966 Pr=0.575 Cramer V.=0.732
Shutter speed				P. Chi(48)=93.2143 Pr=0.000 LRChi(48)=56.0376 Pr=0.199 Cramer V.=0.8814	P. Chi(54)=93.2143 Pr=0.001 LRChi(54)=56.0376 Pr=0.398 Cramer V.=0.08814
Focal Length					P. Chi(72)=146.667 Pr=0.000 LR Chi(72)=75.1010 Pr=0378 Cramer V.=0.9574
Average Association: 0.8980					

8. Association tables disc cameras

Disc 1975-1984	**Metering**	**Flash**	**Shutter speed**	**Focal Length**	**Lenses Speed**
Exposition	P. Chi(2)=39.000 Pr=0.000 LRChi(2)=9.301 Pr=0.010 Cramer V.=1.000	P. Chi(1)=0.0270 Pr=0.869 LRChi(1)=0.0526 Pr=0.819 Cramer V=0.0263	P. Chi(2)=39.000 Pr=0.000 LRChi(2)=9.3013 Pr=0.010 Cramer V.=1.000	P. Chi(9)=39.000 Pr=0.000 LRChi(9)=9.3013 Pr=0.410 Cramer V.=1.000	P. Chi(12)=0.9750 Pr=1.000 LR Chi(12)=1.3607 Pr=1.000 Cramer V.=0.1581
Metering		P. Chi(2)=0.4561 Pr=0.796 LRChi(1)=0.7471 Pr=0.688 Cramer V.=0.1081	P. Chi(4)=40.3619 Pr=0.000 LRChi(4)=11.4548 Pr=0.022 Cramer V.=0.7193	P. Chi(18)=50.0733 Pr=0.000 LRChi(18)=23.3998 Pr=0.176 Cramer V.=0.8012	P. Chi(24)=9.1131 Pr=0.997 LRChi(24)=10.957 Pr=0.989 Cramer V.=0.3418
Flash			P. Chi(2)=0.1173 Pr=0.943 LRChi(2)=0.2194	P. Chi(9)=4.6917 Pr=0.860 LRChi(9)=3.5596	P. Chi(12)=39.000 Pr=0.000 LRChi(12)=9.301

			Pr=0.896 Cramer V.=-0.0548	Pr=0.938 Cramer V.=0.3468	3 Pr=0.677 Cramer V.=1.000
Shutter speed				P. Chi(18)=57.6588 Pr=0.000 LRChi(18)=19.9128 Pr=0.338 Cramer V.=0.8598	Pchi2(24) = 14.7086 Pr = 0.929 LRchi2(24) = 9.5643 Pr = 0.996 Cramér's V = 0.4342
Focal Length					PChi(108)=1433.157 Pr=0.013 LRChi(108)=81.5397 Pr=0.973 Cramer V.=0.6386
Average Association: 0.8783					

9. Association tables digital SRL

DSLR 1994-2004	Exposition	Metering	Flash	Shutter speed	Lenses Speed
Metering	P chi2(40) =62.6103 Pr = 0.013 LRchi2(40)=41.0360 Pr = 0.425 Cramér's V = 0.5055				
Flash	Pchi2(40)=67.2784 Pr=0.004 LRchi2(40)=54.9405 Pr=0.058 Cramér's V=0.5240	Pchi2(25)=20.561 Pr = 0.717 LRchi2(25)=24.170 Pr=0.510 Cramér's =0.2897			
Shutter speed	Pchi2(96)=134.4432 Pr = 0.006 LRchi2(96)=78.8838 Pr = 0.898 Cramér's V =0.5856	Pchi2(60)=89.9244 Pr = 0.007 LRchi2(60)=56.633 Pr = 0.600 Cramér's V=0.6058	Pchi2(60)=62.974 Pr = 0.372 LRchi2(60)=57.99 Pr=0.550 Cramér's V=0.5070		
Lenses Speed	P chi2(72)=82.0873 Pr = 0.19 LRchi2(72)=49.5383 Pr = 0.980 Cramér's V =0.4672	Pchi2(45)=50.6931 Pr = 0.259 LRchi2(45)=29.135 Pr = 0.968 Cramér's V=0.4645	Pchi2(45)=46.482 Pr = 0.445 LRchi2(45)=40.72 Pr = 0.654 Cramér's V=0.4447	P chi2(99)=124.0624 Pr = 0.045 LR chi2(99)= 66.0361 Pr = 0.996 Cramér's V =0.5416	
Pixels	Pchi2(96)=122.6933 Pr = 0.034 LRchi2(96)=73.6274 Pr = 0.956 Cramér's V =0.5595	Pchi2(60)=78.9871 Pr = 0.051 LRchi2(60)=54.462 Pr = 0.677 Cramér V=0.5678	Pchi2(60)=57.924 Pr = 0.552 LRchi2(60)=61.36 Pr = 0.427 Cramér' V=0.4862	Pchi2(144)=177.550 Pr = 0.030 LRchi2(144)=98.85 Pr = 0.998 Cramér's V =0.5495	P chi2(108) = 111.0747 Pr = 0.400 LRchi2(108) = 79.2218 Pr = 0.983 Cramér's V = 0.5124
Movie Pixels	Pchi2(24) =12.0156 Pr = 0.980 LRchi2(24)=11.0383 Pr = 0.989 Cramér's V =0.2859	Pchi2(15)=26.2117 Pr = 0.036 LRchi2(15)=15.707 Pr = 0.402 Cramér's V=0.4223	Pchi2(15)=16.3300 Pr = 0.360 LRchi2(15)=16.71 Pr=0.336 Cramér's V=0.3333	Pchi2(36) = 35.4240 Pr = 0.496 LR chi2(36) =23.2262 Pr = 0.951 Cramér's V =0.4909	P chi2(27) = 87.6499 Pr = 0.000 LR chi2(27) =35.1545 Pr=0.135 Cramér's V =0.7884
Focal Length	Pchi2(152)=240.841 Pr = 0.000 LRchi2(152)=99.972 Pr = 1.000 Cramér's V =0.8003	Pchi2(95)=123.614 Pr = 0.026 LRchi2(95)=67.709 Pr = 0.985 Cramér's V=0.7253	Pchi2(95)=100.0708 Pr = 0.341 LRchi2(95)=86.26 Pr = 0.728 Cramér's V=0.6526	Pchi2(209)=263.348 Pr = 0.006 LRchi2(209)=129.5631 Pr=1.000 Cramér's V =0.7137	Pchi2(171) = 260.0441 Pr = 0.000 LRchi2(171)= 138.4306 Pr = 0.968 Cramér's V =0.7841
Average Association: 0.6489					

Lenses Speed	Shutter speed	Flash	Metering	Exposition	DSLR 2004-2011	Pixel	Pixel
				Pchi2(66)=73.860 Pr = 0.237 LRchi2(66)=59.900 Pr = 0.688 Cramér'sV=0.2809	**Metering**		
			Pchi2(48)= 87.908 Pr = 0.000 LRchi2(48)=63.6152 Pr=0.065 Cramér's V=0.3074	Pchi2(99)=148.3557 Pr = 0.001 LRchi2(99)=104.1261 Pr=0.343 Cramér's V=0.3251	**Flash**		
		Pchi2(72) = 100.2529 Pr = 0.016 LRchi2(72)=75.3110 Pr = 0.372 Cramér's V=0.2843	P chi2(54)=167.3282 Pr = 0.000 LR chi2(54)=86.6854 Pr=0.003 Cramér'sV =0.422	P chi2(154)=212.4613 Pr = 0.001 L Rchi2(154)=127.8754 Pr = 0.939 Cramér's V=0.3701	**Shutter speed**		
	Pchi2(126)=376.4757 Pr = 0.000 LRchi2(126)=121.6214 Pr = 0.594 Cramér'sV=0.5447	Pchi2(112)=91.574 Pr =0.921 LRchi2(112)=79.8292 Pr=0.991 Cramér'sV=0.2859	Pchi2(84)=104.0926 Pr 0.068 LRhi2(84)=44.2307 Pr = 1.000 Cramér'sV=0.3508	Pchi2(154)=212.4613 Pr = 0.001 L Rchi2(154) = 127.8754 Pr = 0.939 Cramér's V = 0.3701	**Lenses Speed**		
Pchi2(280)=430.3626 Pr =0.000 LRchi2(280)=141.750 Pr = 1.000 Cramér's V=0.4669	Pchi2(189)=230.0130 Pr=0.022 LRchi2(189)=139.9604 Pr=0.997 Cramér's V = 0.4048	Pchi2(168)=348.9418 Pr =0.000 LRchi2(168)=173.7482 Pr=0.365 Cramér's V =0.5305	Pchi2(126)=112.7868 Pr = 0.794 LRchi2(126)=84.576 Pr =0.998 Cramér's V=0.3471	Pchi2(231)=312.9149 Pr = 0.000 LRchi2(231)=175.7600 Pr = 0.997 Cramér's V= 0.4270	**Pixels**		
Pchi2(84)=179.4085 Pr =0.000 LRchi2(84)=108.4484 Pr =0.038 Cramér'sV=0.4605	Pchi2(54)=9.0882 Pr = 0.000 LRchi2(54)=68.3058 Pr = 0.091 Cramér's V=0.3254	Pchi2(48)=43.4065 Pr = 0.661 LRchi2(48=43.0285 Pr = 0.676 Cramér's V=0.2160	Pchi2(36)=25.3863 Pr = 0.907 LRchi2(36)=30.5365 Pr = 0.726 Cramér's V=0.1647	Pchi2(66)=124.9127 Pr = 0.000 LRchi2(66)=102.3797 Pr = 0.003 Cramér's V=0.3653	**Movie Pixels**		P chi2(36) = 57.9136 Pr = 0.012 LRchi2(36) = 32.9752 Pr = 0.665 Cramér's V =0.6277
Pchi2(574)=1.2e+03 Pr = 0.000 LRchi2(574)=282.885 Pr = 1.000 Cramér's V=0.7649	Pchi2(378)=635.9860 Pr = 0.000 LRchi2(378)=259.5930 Pr =1.000 Cramér'sV=0.7054	Pchi2(336)=437.6698 Pr = 0.000 LRchi2(336)=223.2068 Pr = 1.000 Cramér'sV=0.6229	Pchi2(252)=331.903 Pr = 0.001 LRchi2(252)=164.47 Pr = 1.000 Cramér'sV=0.6241	Pchi2(462)=637.8338 Pr =0.000 LRchi2(462)=276.3221 Pr = 1.000 Cramér's V= 0.6390	**Focal Length**	P chi2(57) = 115.4915 Pr = 0.000 LRchi2(57) = 49.1098 Pr = 0.762 Cramér's V = 0.9050	P chi2(228) = 312.8329 Pr = 0.000 LRchi2(228)=147.1312 Pr = 1.000 Cramér's V =0.7448

Average Association: 0.4878

Movie Pixel	Pixel
	Pchi2(126)=299.654 Pr =0.000 LRchi2(126)=187.91 Pr = 0.000 Cramér's V=0.5658
Pchi2(252)=439.8619 Pr = 0.000 LRchi2(252)=207.7365 Pr = 0.981 Cramér's V=0.7185	Pchi2(840)=802.677Pr= 0.818 LRchi2(840)=324.11 Pr=1.000 Cramér's V=0.5316

10. ASSOCIATION TABLES DIGITAL COMPACT CAMERAS

DCSLR 1995-2004	Exposition	Metering	Flash	Shutter speed
Metering	P.Chi(28)=269.0923 Pr=0.000 L.R.Chi(28)=261.254 Pr=0.000 Cramer V.=0.3463			
Flash	P. Chi(49)=112.0409 Pr=0.000 L.R. Chi(49)=91.9734 Pr=0.000 Cramer V.=0.1689	P. Chi(28)=69.0162 Pr=0.000 L.R. Chi(28)=68.2852 Pr=0.000 Cramer V.=0.1754		
Shutter speed	P.Chi(112)=271.5333 Pr=0.000 LR.Chi(112)=251.910 Pr=0.000 Cramer V.=0.2630	P. Chi(64)=194.0181 Pr=0.000 L.R. Chi(64)=209.6810 Pr=0.000 Cramer V.=0.2940	P. Chi(112)=293.4211 Pr=0.000 L.R. Chi(112)=176.0238 Pr=0.000 Cramer V.=0.2731	
Lenses Speed	P.Chi(196)=264.0816 Pr=0.001 LRChi(196)=224.327 Pr=0.081 Cramer V.=0.2596	P.chi2(112) = 137.0580 Pr = 0.054 LRchi2(112)= 151.3744 Pr = 0.008 Cramér's V = 0.2474	P. Chi(196)=284.7356 Pr=0.000 L.R. Chi(196)=193.7614 Pr=0.000 Cramer V.=0.2693	P. Chi(448)=648.7425 Pr=0.000 L.R. Chi(448)=413.1841 Pr=0.879 Cramer V.=0.2688
Pixels	PChi(119)=418.2073 Pr=0.000 LRChi(119)=229.800 Pr=0.000 Cramer V.=0.3263	P. Chi(68)=182.2086 Pr=0.000 L.R. Chi(68)=190.4060 Pr=0.000 Cramer V.=0.2850	P. Chi(119)=396.6161 Pr=0.000 L.R. Chi(119)=164.9818 Pr=0.003 Cramer V.=0.3175	P.chi2(272) =1.1e+03 Pr = 0.000 L.Rchi2(272)=468.3287 Pr = 0.000 Cramér's V =0.3423
Movie Pixels	P. Chi(63)=157.8607 Pr=0.000 LR Chi(63)=148.6247 Pr=0.000 Cramer V.=0.2005	P. Chi(36)=81.4789 Pr=0.000 L.R. Chi(36)=85.9005 Pr=0.000 Cramer V.=0.1905	P. Chi(63)=93.3156 Pr=0.004 L.R. Chi(63)=89.6465 Pr=0.000 Cramer V.=0.1565	P. chi2(144) = 308.121 Pr = 0.000 LR chi2(144)=258.1974 P=0.000 Cramér's V =0.2468
Focal Length	Pchi2(581) = 1.1e+03 Pr = 0.000 LRchi2(581) = 647.1794 Pr = 0.029 Cramér's V = 0.5202	Pchi2(332) = 557.2034 Pr = 0.000 LRhi2(332) = 445.9200 Pr = 0.000 Cramér's V = 0.4983	Pchi2(581) = 969.6174 Pr = 0.000 LRchi2(581) = 503.4950 Pr = 0.991 Cramér's V = 0.4965	Pchi2(1328) = 2.0e+03 Pr = 0.000 LRchi2(1328) = 978.1047 Pr = 1.000 Cramér's V = 0.4772

Average Association: 0.3164

DCSLR 2004-2011	Shutter speed	Flash	Metering	Exposition	Movie Pixels	Pixel	Lenses Speed
Metering				Pchi2(50)=368.0171 Pr = 0.000 LRchi2(50)=259.059 Pr = 0.000 Cramér'sV= 0.2734			
Flash			P.chi2(40)=185.3264 Pr=0.000 L.R. chi2(40)=93.1295 Pr=0.000 Cramér's V=0.1940	P. chi2(80) = 209.3867 Pr = 0.000 L.R chi2(80) =132.9671 Pr=0.000 Cramér's V =0.1630			
Shutter speed		Pchi2(96)=188.7951 Pr = 0.000 L.R. chi2(96) =154.2950 Pr=0.000 Cramér's V =0.1548	P.chi2(60) = 172.2865 Pr = 0.000 L.R.chi2(60) = 191.8577 Pr = 0.000 Cramér's V = 0.1870	P.chi2(120) = 399.3389 Pr = 0.000 LR.chi2(120)=363.8386 Pr = 0.000 Cramér's V = 0.2014			
Lenses Speed	P.chi2(336) = 731.3319 Pr = 0.000 L.Rchi2(336)=505.0546 Pr = 0.000 Cramér's V = 0.2495	P. chi2(224) = 347.9898 Pr = 0.000 L.Rchi2(224= 208.7114 Pr = 0.760 Cramér's V = 0.2108	Pchi2(140) = 198.1372 Pr = 0.001 LRchi2(140=151.8571 Pr = 0.233 Cramér's V = 0.2012	P.chi2(280) = 678.2933 Pr = 0.000 LR.chi2(280)=288.5212 Pr=0.350 Cramér's V =0.2632			
Pixels	P. chi2(252) =384.5421 Pr = 0.000 L.R.chi2(252)=314.6346 Pr = 0.004 Cramér's V = 0.1804	P.chi2(168) = 602.8562 Pr = 0.000 chi2(168) = 185.3237 Pr = 0.171 Cramér's V =0.2766	P. chi2(105) = 266.8953 Pr = 0.000 LRchi2(105)=126.5103 Pr = 0.075 Cramér's V = 0.2328	P. chi2(210) = 245.1254 Pr = 0.049 LR.chi2(210)=184.9273 Pr=0.893 Cramér's V = 0.1578			P. chi2(476)=561.6797 Pr = 0.004 LRchi2(476) =356.0133 Pr=1.000 Cramér's V =0.2427
Movie Pxels	P.chi2(156)=531.7265 Pr = 0.000 L.R.chi2(156)=369.1283 Pr=0.000 Cramér's V =0.2121	P. chi2(104) = 265.1986 Pr = 0.000 LR chi2(104)=136.1944 Pr = 0.019 Cramér's V = 0.1835	P.(65) = 124.0151 Pr = 0.000 L,Rchi2(65) = 127.3068 Pr = 0.000 Cramér's V = 0.1587	P.chi2(130) = 232.0147 Pr = 0.000 LR.chi2(130)=182.6542 Pr = 0.002 Cramér's V =0.1535		P. chi2(153) = 528.9791 Pr = 0.000 LR chi2(153)=413.6966 Pr = 0.000 Cramér's V =0.3234	P. chi2(252) = 240.7493 Pr = 0.684 LRchi2(252) =181.3779 Pr = 1.000 Cramér's V = 0.2184
Focal Length	Pchi2(1500) = 2.3e+03 Pr = 0.000 LRchi2(1500) = 1.3e+03 Pr = 0.999 Cramér's V = 0.4462	Pchi2(1000) = 1.5e+03 Pr = 0.000 LRchi2(1000) = 668.3064 Pr = 1.000 Cramér's V = 0.4322	Pchi2(625) = 888.1100 Pr = 0.000 LRchi2(625) = 518.3158 Pr = 0.999 Cramér's V = 0.4257	Pchi2(1250) = 2.5e+03 Pr = 0.000 LRchi2(1250) = 963.4124 Pr = 1.000 Cramér's V = 0.5054	Pchi2(1079) = 2.0e+03 Pr = 0.000 LRchi2(1079) = 489.7321 Pr = 1.000 Cramér's V = 0.5193		Pchi2(2296) = 3.2e+03 Pr = 0.000 LRchi2(2296) = 1.1e+03 Pr = 1.000 Cramér's V = 0.4493

Average Association: 0.2585

Lenses Speed					P.Chi2(560) = 747.0469 Pr = 0.000 LR Chi2(560)=456.7267 Pr = 0.999 Cramér's V = 0.1953	P .Chi2(364) = 479.0400 Pr = 0.000 LR Chi2(364)=377.5707 Pr = 0.301 Cramér's V =0.1940	Pchi2(3500) = 5.5e+03 Pr = 0.000 LRchi2(3500) = 2.0e+03 Pr = 1.000 Cramér's V = 0.4494	
Pixel						P. Chi2(273) =1.2e+03 Pr = 0.000 L.RChi2(273)=932.7801 Pr = 0.000 Cramér's V = 0.3114		
Movie Pixels							Pchi2(4375) = 4.7e+03 Pr = 0.001 LR chi2(4375) = 1.4e+03 Pr = 1.000 Cramér's V = 0.3686	

APPENDIX E- CORRELATION TABLES ALL CAMERAS

1. CORRELATION TABLES ROLL FILM CAMERAS

Roll film 1955-1964	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.195 (.004)	1.000				
Shutter speed	.117 (.056)	-.114 (.060)	1.000			
Flash	.188 (.005)	.068 (.178)	.352 (.000)	1.000		
Lenses Speed	-.091 (.108)	-.055 (.228)	-.315 (.000)	-.262 (.000)	1.000	
Focal Length	.062 (.200)	.077 (.148)	.474 (.000)	.269 (.000)	-.181 (.007)	1.000
K.M.O Measure of Sampling Adequacy					.677	
Bartt's Test of Sphericity – Approx Chi-square					113.748	
- Df					15	
- Sig.					.000	

Roll film 1965-1974	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	-.020 (.449)	1.000				
Shutter speed	.042 (.396)	-.113 (.236)	1.000			
Flash	.015 (.461)	-.226 (.072)	.105 (.252)	1.000		
Lenses	-.031	-.217	.060	.041	1.000	

Speed	(.423)	(.081)	(.352)	(.397)		
Focal Length	.468 (.001)	.114 (.234)	.150 (.168)	.034 (.415)	.038 (.403)	1.000
K.M.O Measure of Sampling Adequacy					.474	
Bartt's Test of Sphericity – Approx Chi-square					16.844	
- Df					15	
- Sig.					.328	

2. Correlation tables Non-Reflex cameras

NSRL 1955-1964	**Metering**	**Exposition**	**Shutter speed**	**Flash**	**Lenses Speed**	**Focal Length**
Metering	1.000					
Exposition	.186 (.002)	1.000				
Shutter speed	.126 (.024)	-.162 (.005)	1.000			
Flash	.060 (.173)	-.130 (.021)	.139 (.015)	1.000		
Lenses Speed	-.054 (.198)	.130 (.021)	-.052 (.207)	-.008 (.451)	1.000	
Focal Length	.068 (.143)	.003 (.483)	.064 (.160)	.014 (.411)	-.206 (.001)	1.000
K.M.O Measure of Sampling Adequacy						.483
Bartt's Test of Sphericity – Approx Chi-square						245.154
- Df						15
- Sig.						.000

NSLR 1965-1974	**Metering**	**Exposition**	**Shutter speed**	**Flash**	**Lenses Speed**	**Focal Length**
Metering	1.000					
Exposition	.305 (.000)	1.000				
Shutter speed	.016 (.418)	.011 (.444)	1.000			
Flash	.007 (.461)	.025 (.372)	.132 (.039)	1.000		
Lenses Speed	-.160 (.016)	-.182 (.007)	.136 (.034)	-.139 (.032)	1.000	
Focal Length	-.046 (.269)	.089 (.119)	.015 (.421)	.215 (.002)	-.119 (.056)	1.000
K.M.O Measure of Sampling Adequacy						.546
Bartt's Test of Sphericity – Approx Chi-square						47.055
- Df						15
- Sig.						.000

3. Correlation tables SRL cameras

SRL 1955-1964	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.291 (.000)	1.000				
Shutter speed	.041 (.317)	-.301 (.000)	1.000			
Flash	-.139 (.051)	-.174 (.020)	.172 (.021)	1.000		
Lenses Speed	.018 (.417)	.166 (.025)	-.391 (.000)	-.161 (.028)	1.000	

Focal Length	-.104 (.110)	-.085 (.159)	.389 (.000)	.236 (.002)	-.164 (.027)	1.000
K.M.O Measure of Sampling Adequacy Bartt's Test of Sphericity – Approx Chi-square - Df - Sig.					.568 90.213 15 .000	

SRL 1965-1974	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.080 (.168)	1.000				
Shutter speed	-.072 (.192)	.057 (.244)	1.000			
Flash	-.147 (.037)	.034 (.399)	.103 (.107)	1.000		
Lenses Speed	-.10 (.450)	-.290 (.000)	-.136 (.049)	-.054 (.257)	1.000	
Focal Length	-.089 (.141)	.010 (.452)	.056 (.248)	.180 (.014)	.003 (.487)	1.000
K.M.O Measure of Sampling Adequacy Bartt's Test of Sphericity – Approx Chi-square - Df - Sig.						.544 27.656 15 .024

SRL 1975-1984	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.151 (.013)	1.000				
Shutter speed	.264 (.000)	.272 (.000)	1.000			
Flash	.151 (.013)	.097 (.078)	.028 (.339)	1.000		
Lenses Speed	-.107 (.057)	-.092 (.090)	-.044 (.258)	-.093 (.086)	1.000	
Focal Length	.052 (.223)	-.003 (.481)	.077 (.129)	.101 (.069)	-.166 (.007)	1.000
K.M.O Measure of Sampling Adequacy Bartt's Test of Sphericity – Approx Chi-square - Df - Sig.						.578 53.690 15 .000

SLR 1985-1994	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.483 (.000)	1.000				
Shutter speed	.288 (.000)	.533 (.000)	1.000			
Flash	.095 (.121)	.154 (.028)	.094 (.124)	1.000		
Lenses Speed	-.030 (.355)	-.080 (.163)	-.057 (.243)	.159 (.025)	1.000	
Focal	-.023	.033	.103	.304	.373	1.000

Length	(.387)	(.341)	(.103)	(.000)	(.000)	
K.M.O Measure of Sampling Adequacy						.601
Bartt's Test of Sphericity – Approx Chi-square						135.307
- Df						15
- Sig.						.000

SRL 1995-2004	Metering	Exposition	Shutter speed	Flash	Focal length	Lenses speed
Metering	1.000					
Exposition	.360 (.000)	1.000				
Shutter speed	.458 (.000)	.536 (.000)	1.000			
Flash	.068 (.002)	-.303 (.262)	.258 (.007)	1.000		
Focal length	.094 (.326)	.048 (.190)	.180 (.045)	-.052 (.314)	1.000	
Lenses speed	.100 (.432)	.018 (.174)	.134 (.105)	-.002 (.494)	-.019 (.431)	1.000
K.M.O Measure of Sampling Adequacy						.658
Bartt's Test of Sphericity – Approx Chi-square						68.146
- Df						15
- Sig.						.000

4. CORRELATION TABLES 110 CAMERAS

110 1965-1974	**Metering**	**Exposition**	**Shutter speed**	**Flash**	**Lenses Speed**	**Focal Length**
Metering	1.000					
Exposition	.245 (.105)	1.000				
Shutter speed	-.211 (.140)	-.107 (.293)	1.000			
Flash	.245 (.105)	-.077 (.349)	.107 (.293)	1.000		
Lenses Speed	-.046 (.014)	-.046 (.409)	.015 (.469)	-.233 (.116)	1.000	
Focal Length	.119 (.002)	.119 (.273)	-.237 (.113)	.448 (.008)	-.104 (.299)	1.000
K.M.O Measure of Sampling Adequacy						.530
Bartt's Test of Sphericity – Approx Chi-square						24.721
- **Df**						15
- **Sig.**						.054

110 1975-1984	**Metering**	**Exposition**	**Shutter speed**	**Flash**	**Lenses Speed**	**Focal Length**
Metering	1.000					
Exposition	.351 (.000)	1.000				
Shutter speed	.392 (.000)	.386 (.000)	1.000			
Flash	.106 (.057)	-.028 (.339)	.175 (.004)	1.000		

Lenses Speed	-.321 (.000)	-.308 (.000)	-.239 (.000)	-.076 (.129)	1.000	
Focal Length	-.021 (.374)	-.028 (.339)	-.093 (.083)	-.347 (.000)	-.027 (.345)	1.000
K.M.O Measure of Sampling Adequacy						.667
Bartt's Test of Sphericity – Approx Chi-square						162.606
- **Df**						15
- **Sig.**						.000

5. Correlation tables 126 cameras

126 1965-1974	**Metering**	**Exposition**	**Shutter speed**	**Flash**	**Lenses Speed**	**Focal Length**
Metering	1.000					
Exposition	-.052 (.314)	1.000				
Shutter speed	-.023 (.414)	.058 (.291)	1.000			
Flash	.111 (.147)	.028 (.395)	-.050 (.319)	1.000		
Lenses Speed	-.122 (.125)	-.184 (.040)	-.167 (.057)	-.145 (.085)	1.000	
Focal Length	.247 (.009)	.284 (.003)	.048 (.326)	.309 (.001)	.116 (.137)	1.000
K.M.O Measure of Sampling Adequacy						.349
Bartt's Test of Sphericity – Approx Chi-square						61.135
- **Df**						21
- **Sig.**						.000

6. Correlation tables compact cameras

Compact 1965-1974	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	-.104 (.276)	1.000				
Shutter speed	.219 (.170)	.166 (.103)	1.000			
Flash	-.028 (.172)	-.165 (.436)	-.012 (.473)	1.000		
Lenses Speed	-.304 (.312)	.086 (.038)	-.075 (.334)	-.110 (.264)	1.000	
Focal Length	.192 (.450)	.022 (.134)	.179 (.151)	.142 (.208)	.354 (.019)	1.000
K.M.O Measure of Sampling Adequacy						0.371
Bartt's Test of Sphericity – Approx Chi-square						18.147
- Df						15
- Sig.						.255

Compact 1965-1974	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	-.104 (.276)	1.000				

Shutter speed	.219 (.170)	.166 (.103)	1.000			
Flash	-.028 (.172)	-.165 (.436)	-.012 (.473)	1.000		
Lenses Speed	-.304 (.312)	.086 (.038)	-.075 (.334)	-.110 (.264)	1.000	
Focal Length	.192 (.450)	.022 (.134)	.179 (.151)	.142 (.208)	.354 (.019)	1.000
K.M.O Measure of Sampling Adequacy						0.371
Bartt's Test of Sphericity – Approx Chi-square						18.147
- Df						15
- Sig.						.255

Compact 1975-1984	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.683 (.007)	1.000				
Shutter speed	-.112 (.364)	-.278 (.191)	1.000			
Flash	-.098 (.381)	.111 (.366)	.093 (.387)	1.000		
Lenses Speed	-.461 (.066)	-.481 (.057)	-.254 (.213)	-.556 (.030)	1.000	
Focal Length	-.171 (.297)	.127 (.347)	-.479 (.057)	-.280 (.189)	.103 (.375)	1.000
K.M.O Measure of Sampling Adequacy						.219
Bartt's Test of Sphericity – Approx Chi-square						23.128
- Df						15
- Sig.						.081

Compact 1985-1994	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.291 (.001)	1.000				
Shutter speed	.355 (.000)	.239 (.004)	1.000			
Flash	.180 (.024)	-.088 (.167)	.342 (.000)	1.000		
Lenses Speed	.058 (.262)	.074 (.211)	.193 (.017)	.373 (.000)	1.000	
Focal Length	-.042 (.323)	-.250 (.003)	-.157 (.043)	-.017 (.426)	.037 (.343)	1.000
K.M.O Measure of Sampling Adequacy						.543
Bartt's Test of Sphericity – Approx Chi-square						134.959
- Df						21
- Sig.						.000

Compact 1995-	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length

2004						
Metering	1.000					
Exposition	.868 (.000)	1.000				
Shutter speed	.332 (.071)	.542 (.006)	1.000			
Flash	-.412 (.032)	-.312 (.085)	-.308 (.000)	1.000		
Lenses Speed	-.030 (.449)	-.104 (.327)	-.418 (.000)	.025 (.457)	1.000	
Focal Length	-.063 (.393)	-.183 (.214)	-.167 (.001)	.235 (.152)	.568 (.004)	1.000
K.M.O Measure of Sampling Adequacy						.355
Bartt's Test of Sphericity – Approx Chi-square						53.372
- Df						15
- Sig.						.000

7. Correlation tables disc cameras

Disc 1975-1984	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.517 (.000)	1.000				
Shutter speed	.535 (.000)	.989 (.000)	1.000			
Flash	-.103 (.266)	-.026 (.437)	-.019 (.455)	1.000		
Lenses Speed	-.188 (.126)	.002 (.496)	.011 (.474)	.052 (.376)	1.000	
Focal Length	-.266 (.094)	-.039 (.000)	-.031 (.427)	-.090 (.292)	.495 (.001)	1.000
K.M.O Measure of Sampling Adequacy						.645
Bartt's Test of Sphericity – Approx Chi-square						183.330
- Df						21
- Sig.						.000

8. Correlation tables instant cameras

Instant Cameras 1975-1984	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length
Metering	1.000					
Exposition	.266 (.110)	1.000				
Shutter speed	.018 (.467)	-.154 (.242)	1.000			
Flash	.657 (.000)	-.112 (.305)	.019 (.466)	1.000		
Lenses Speed	.081 (.357)	-.309 (.076)	.117 (.298)	.154 (.241)	1.000	
Focal Length	-.015 (.474)	-.351 (.050)	.318 (.070)	.010 (.481)	.848 (.000)	1.000
K.M.O Measure of Sampling Adequacy						.443
Bartt's Test of Sphericity – Approx Chi-square						48.595
- Df						15
- Sig.						.000

9. CORRELATION TABLES DIGITAL SRL

DSLR 1995-2004	**Metering**	**Exposition**	**Shutter speed**	**Flash**	**Lenses Speed**	**Focal Length**	**Pixel Picture**	**Pixel Movie**
Metering	1.000							
Exposition	.425 (.001)	1.000						
Shutter speed	.407 (.002)	.296 (.019)	1.000					
Flash	-.160 (.136)	-.253 (.040)	-.052 (.362)	1.000				
Lenses Speed	-.056 (.292)	-.078 (.313)	.009 (.476)	-.013 (.466)	1.000			
Focal Length	.080 (.352)	-.071 (.296)	.043 (.386)	-.062 (.337)	.937 (.000)	1.000		
Pixel Picture	.175 (.115)	.169 (.122)	-.007 (.481)	.121 (.204)	-.073 (.308)	-.130 (.187)	1.000	
Pixel Movie	-.033 (.412)	.071 (.315)	-.060 (.340)	.083 (.285)	-.090 (.270)	.072 (.311)	.063 (.334)	1.000
K.M.O Measure of Sampling Adequacy								.446
Bartt's Test of Sphericity – Approx Chi-square								134.689
- Df								28
- Sig.								.000

DSLR 2004-2011	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length	Pixel Picture	Pixel Movie
Metering	1.000							
Exposition	.100 (.121)	1.000						
Shutter speed	.255 (.001)	.359 (.000)	1.000					
Flash	-.003 (.486)	.295 (.000)	.227 (.004)	1.000				
Lenses Speed	.174 (.020)	.225 (.004)	.249 (.001)	.186 (.014)	1.000			
Focal Length	-.095 (.133)	-.038 (.327)	-.240 (.002)	-.010 (.455)	-.320 (.000)	1.000		
Pixel Picture	-.023 (.394)	.083 (.164)	.086 (.157)	.004 (.479)	.080 (.174)	-.088 (.151)	1.000	
Pixel Movie	-.132 (.060)	.272 (.000)	.033 (.349)	.325 (.000)	-.049 (.283)	.233 (.003)	.115 (.087)	1.000
K.M.O Measure of Sampling Adequacy							.633	
Bartt's Test of Sphericity – Approx Chi-square							118.678	
- Df							28	
- Sig.							.000	

10. CORRELATION TABLES DIGITAL COMPACT CAMERAS

DCSLR 1995-2004	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length	Pixel Picture	Pixel Movie
Metering	1.000							

Exposition	.570 (.000)	1.000						
Shutter speed	.437 (.000)	.438 (.000)	1.000					
Flash	.108 (.005)	.193 (.000)	.119 (.002)	1.000				
Lenses Speed	-.013 (.382)	-.027 (.263)	.238 (.000)	.003 (.059)	1.000			
Focal Length	.228 (.000)	.410 (.000)	.025 (.279)	.066 (.475)	-.032 (.228)	1.000		
Pixel Picture	.186 (.000)	.239 (.000)	.247 (.000)	.139 (.000)	-.024 (.287)	.117 (.003)	1.000	
Pixel Movie	.187 (.000)	.242 (.000)	.235 (.000)	.167 (.000)	.072 (.044)	.146 (.000)	.213 (.000)	1.000
K.M.O Measure of Sampling Adequacy Bartt's Test of Sphericity – Approx Chi-square - Df - Sig.								.748 630.165 28 .000

DCompact 2004-2011	Metering	Exposition	Shutter speed	Flash	Lenses Speed	Focal Length	Pixel Picture	Pixel Movie
Metering	1.000							
Exposition	.405 (.000)	1.000						
Shutter speed	.436 (.000)	.333 (.000)	1.000					
Flash	.166 (.001)	.140 (.000)	.131 (.000)	1.000				
Lenses Speed	-.056 (.039)	-.104 (.001)	-.106 (.000)	-.030 (.175)	1.000			
Focal Length	.124 (.000)	.296 (.000)	.136 (.000)	.026 (.207)	.000 (.500)	1.000		
Pixel Picture	.132 (.000)	.058 (.036)	.149 (.000)	-.036 (.133)	.193 (.000)	.118 (.000)	1.000	
Pixel Movie	.186 (.000)	.133 (.000)	.215 (.000)	-.051 (.055)	.138 (.000)	.229 (.000)	.591 (.000)	1.000
K.M.O Measure of Sampling Adequacy Bartt's Test of Sphericity – Approx Chi-square - Df - Sig.								.617 1017.511 28 .000

APPENDIX F-CPA AND DESCRIPTIVE STATISTICS

1. CPA AND DESCRIPTIVE STATISTICS ROLL FILM CAMERAS

Roll film 1955-1964	Obs.	Min.	Max.	Rollfilm 1965-1974	Obs.	Min.	Max.
Metering	80	0	1	Metering	14	0	1
Exposition	80	1	2	Exposition	14	1	1
Flash	80	1	3	Flash	14	1	1
Focal length	80	7.5	150	Focal length	14	43	105
F-stops	80	0	10	F-stops	14	1	10
				Lenses speed	14	2	11

Roll film	1955-1964		1964-1974	
	Components		Components	
	1	2	1	2
Metering	.353	.691	-.044	-.769
Exposition	.277	.708	.795	-.182
Shutter speed	.780	-.199	.366	.355
Flash	.668	-.028	.180	.566
Lenses Speed	-.570	.146	.091	.581
Focal length	.673	-.270	.839	-.202
EigenValues	2.034	1.114	1.514	1.394
% of Variance	33.895	18.574	25.231	23.234
Cumulative % variance	33.895	52.469	25.231	48.465
No. Of observation	80		14	

2. CPA AND DESCRIPTIVE STATISTICS NON-REFLEX CAMERAS

NSLR 1955-1964	Obs.	Min.	Max.	NSLR 1964-1975	Obs.	Min.	Max.
Metering	248	0	1	Metering	178	0	1
Exposition	248	1	2	Exposition	178	1	4
Flash	248	1	2	Flash	178	1	3
Focal length	248	26	105	Focal length	178	8	85
F-stops	248	0	10	F-stops	178	0	16
Lenses speed	248	.95	28	Lenses speed	178	.95	11

NSLR	1955-1964			1965-1974		
	Components			Components		
	1	2	3	1	2	3
Metering	.182	.726	.417	.657	-.296	.302
Exposition	-.516	.658	.126	.608	-.328	.417
Shutter speed	.606	-.012	.415	-.049	.524	.735
Flash	.460	-.173	.506	.372	.703	-.105
Lenses Speed	-.545	-.190	.543	-.620	.120	.417
Focal length	.448	.424	-.446	.452	.490	-.261
EigenValues	1.376	1.206	1.111	1.530	1.214	1.058
% of Variance	22.933	20.102	18.510	25.499	20.239	17.628
Cumulative % variance	22.933	43.035	61.545	25.499	45.739	63.367
N. of Observation	248			178		

3. CPA AND DESCRIPTIVE STATISTICS SRL CAMERAS

SLR 1955-1964	Obs.	Min.	Max.	Obs.	Min.	Max.	Obs.	Min.	Max.	Obs.	Min.	Max.	Obs.	Min.	Max.
Metering	140	0	1	148	0	3	209	0	3	154	1	7	90	1	8
Exposition	140	0	2	148	1	2	209	1	7	154	1	7	90	1	7
Flash	140	1	3	148	1	3	209	0	3	154	0	5	90	1	6
Focal length	140	25	90	148	35	80	209	125	116	154	35	180	90	28	800
F-stops	140	0	12	148	1	14	209	0	15	154	1	18	90	4	18
Lenses speed	140	1.2	11	148	1.2	11	209	1.2	18	154	1.2	16	90	1.3	45

SRL	1955-1964		1965-1974		1975-1984		1985-1994		1995-2004		
	Components		Components		Components		Components		Components		
	1	2	1	2	1	2	1	2	1	2	3
Metering	-.292	.612	.531	-.552	.639	.139	.697	-.190	.683	.251	.092
Exposition	.570	.460	-.244	-.572	.584	.369	.849	-.176	.786	-.192	-.099
Shutter speed	.745	.373	.517	.067	.643	.401	.752	-.106	.845	.092	-.003
Flash	.525	-.169	.518	.459	.406	-.346	.353	.550	.455	-.642	-.090
Lenses Speed	-.595	-.326	-.622	.469	-.406	.535	.003	.741	.177	.259	.881
Focal Length	.611	.191	.369	.467	-.406	.535	.211	.786	.210	.705	-.465
Eigen Value	1.967	1.181	1.400	1.285	1.594	1.135	1.942	1.548	2.081	1.084	1.018
% Variance	32.781	19.676	23.339	21.416	26.568	18.919	32.359	25.808	34.689	18.071	16.965
Cumulative % of Variance	32.781	52.458	23.339	44.755	26.568	45.488	32.359	58.167	34.689	52.760	69.725
N. Obs	140		149		91		154		91		

4. CPA AND DESCRIPTIVE STATISTICS 110 CAMERAS

110 1965-1974	Obs.	Min.	Max.	Obs.	Min.	Max.
Metering	28	0	2	254	0	3
Exposition	28	1	2	254	0	3
Flash	28	1	2	254	0	3
Focal length	28	25	53	254	20	116
F-stops	28	1	13	254	0	15
Lenses speed	28	1.7	11	254	1	14.6

110	1965-1974		1975-1984	
	Components		Components	
	1	2	1	2
Metering	.830	-.596	.734	.086
Exposition	.285	-.134	.694	.284
Shutter speed	-.311	.653	.736	-.068
Flash	.572	.616	.271	-.771
Lenses Speed	-.531	-.226	-.619	-.174
Focal length	.783	.016	-.137	.799
EigenValues	2.088	1.232	2.038	1.356
% of Variance	34.800	20.532	33.968	22.599
Cumulative % variance	34.800	55.332	33.968	56.567
N. Observations	28		254	

5. CPA AND DESCRIPTIVE STATISTICS 126 CAMERAS

126 1965-1974	Obs.	Min.	Max.
Metering	115	0	2
Exposition	115	1	3
Flash	115	0	2
Focal length	115	20	80
F-stops	115	0	13
Lenses speed	115	1.4	11

126	**1965-1974**		
	Components		
	1	**2**	**3**
Metering	.496	-.367	.612
Exposition	.481	.237	-.571
Shutter speed	.138	-.633	.011
Flash	.617	.211	-.219
Lenses Speed	-.315	.692	.448
Focal length	.760	.319	.323
EigenValues	1.553	1.218	1.054
% of Variance	25.887	20.301	17.568
Cumulative % variance	25.887	46.188	63.756
N. observation	115		

6. CPA AND DESCRIPTIVE STATISTICS COMPACT CAMERAS

CSLR 1965-1974	Obs.	Min.	Max.	Obs.	Min.	Max.	Obs.	Min.	Max.	Obs.	Min.	Max.
Metering	35	0	3	14	0	1	121	0	3	21	1	3
Exposition	35	1	3	14	1	2	121	1	5	21	1	7
Flash	35	1	3	14	1	2	121	1	5	21	1	5
Focal length	35	35	55	14	26	50	121	28	140	21	21	162.5
F-stops	35	2	11	14	3	13	121	0	17	21	6	17
Lenses speed	35	1.4	4	14	1.7	5.6	121	1.4	5	21	2	5.7

Compact Camera	**1965-1974**			**1975-1984**			**1985-1994**		**1995-2004**	
	Components			**Components**			**Components**		**Components**	
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**1**	**2**
Metering	.733	.369	-.041	.764	.318	-.489	.536	-.410	.748	.543
Exposition	-.293	.274	-.661	.783	.483	-.039	.291	-.695	.813	.434
Shutter speed	.340	.613	-.338	.524	-.459	.623	.622	.265	-.743	-.194
Flash	.216	.028	.691	.464	-.486	.681	.650	.263	.571	-.189
Lenses Speed	-.794	.379	.189	-.854	.219	-.238	.696	.426	-.534	.726
Focal length	-.127	.816	.383	-.230	.715	.422	-.167	.523	.618	.543
EigenValues	1.431	1.398	1.214	2.199	1.767	1.041	2.132	1.487	2.765	1.377
% of Variance	23.845	23.306	20.229	36.653	29.454	17.349	30.457	21.245	46.078	22.194
Cumulative % variance	23.845	47.151	67.280	36.653	66.107	83.456	30.457	51.702	46.078	69.032
N. Observation	35			14			121		21	

7. CPA AND DESCRIPTIVE STATISTICS DISC CAMERAS

Disc 1975-1984	Obs.	Min.	Max.
Metering	39	0	2
Exposition	39	1	2
Flash	39	1	2
Focal length	39	12.5	109
F-stops	39	0	12
Lenses speed	20	1.2	19

Disc	**1975-1984**		
	Components		
	1	**2**	**3**
Metering	.727	-.255	-.139
Exposition	.940	.106	.050
Shutter speed	.939	.110	.053
Flash	-.058	-.020	.983
Total volume	.809	.169	.060
Lenses Speed	-.062	.855	.114
Focal length	-.122	.844	.160
EigenValues	2.970	1.561	1.053
% of Variance	42.431	22.304	14.753
Cumulative % variance	42.441	64.735	79.488
N. Observation	39		

8. CPA AND DESCRIPTIVE STATISTICS INSTANT CAMERAS

Instant picture 1975-1984	Obs.	Min.	Max.
Metering	20	0	2
Exposition	20	1	2
Flash	20	1	2
Focal length	20	12.5	137
F-stops	20	0	12
Lenses speed	20	1.7	11

Instant picture	**1975-1984**	
	Components	
	1	**2**
Metering	.044	.931
Exposition	-.571	.262
Shutter speed	.415	-.050
Flash	.210	.858
Lenses Speed	.885	.050
Focal length	.921	-.103
EigenValues	2.177	1.686
% of Variance	36.285	28.093
Cumulative % variance	36.285	64.378
N. Observation	20	

9. CPA AND DESCRIPTIVE STATISTICS DIGITAL SRL CAMERAS

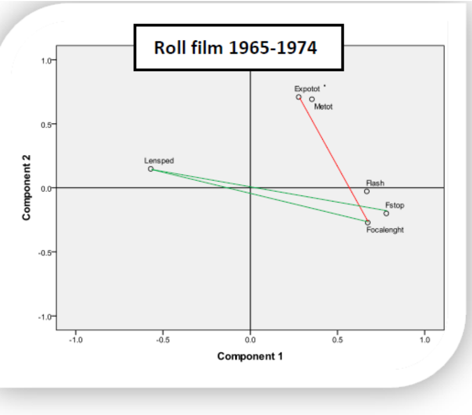
DSLR	1995-2004			2005-2011		
	Components			Components		
	1	2	3	1	2	3
Metering	.105	.799	.095	.347	-.400	.459
Exposition	-.094	.771	.057	.677	.307	.098
Shutter speed	.077	.656	-.063	.714	-.142	.126
Flash	-.102	-.375	.579	.548	.450	.131
Lenses Speed	.975	-.001	.080	.610	-.314	-.114
Focal length	.972	-.048	.159	-.386	.597	.314
Pixel Picture	-.215	.257	.653	.219	.068	-.821
Pixel Movie	-.055	-.034	.596	.244	.789	-.069
EigenValues	1.980	1.873	1.165	2.019	1.560	1.043
% of Variance	24.754	23.411	14.559	25.234	19.498	13.043
Cumulative % variance	24.754	48.165	62.724	25.234	44.732	57.775
N. Observation	156			49		

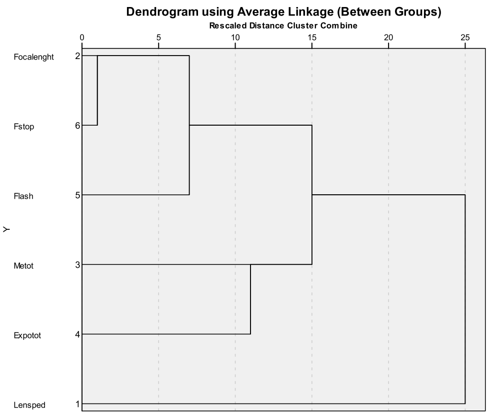
10. CPA AND DESCRIPTIVE STATISTICS DIGITAL COMPACT CAMERAS

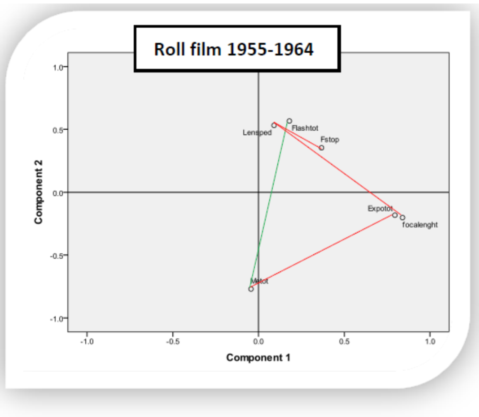
Dcompact	1995-2004		2004-2011	
	Components		Components	
	1	2	1	2
Metering	.732	-.225	.570	-.297
Exposition	.808	-.202	.628	-.490
Shutter speed	.696	-.070	.555	-.273
Flash	.319	.502	.151	-.391
Lenses Speed	-.007	.586	.043	.577
Focal length	.540	-.270	.503	-.084
Pixel Picture	.489	.275	.592	.600
Pixel Movie	.493	.480	.689	.504
EigenValues	2.520	1.076	2.119	1.509
% of Variance	31.469	13.444	26.482	18.862
Cumulative % variance	31.496	44.941	26.482	45.482
N. Observations	947		599	

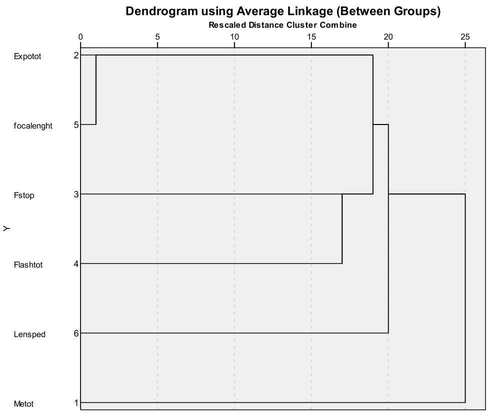
APPENDIX G- EPISTATIC RELATION AND HIERARCHICAL REPRESENTATIONS ALL CAMERAS

1. Roll Film Cameras

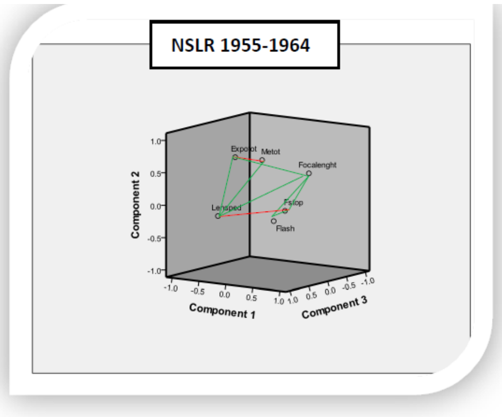


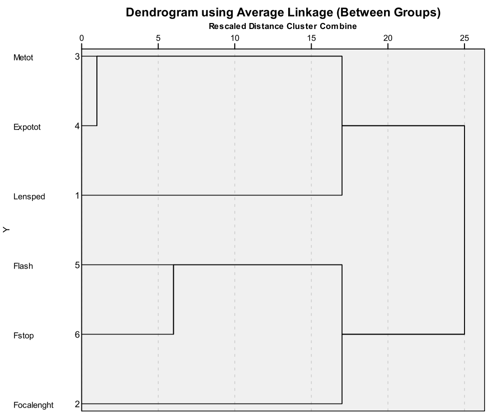


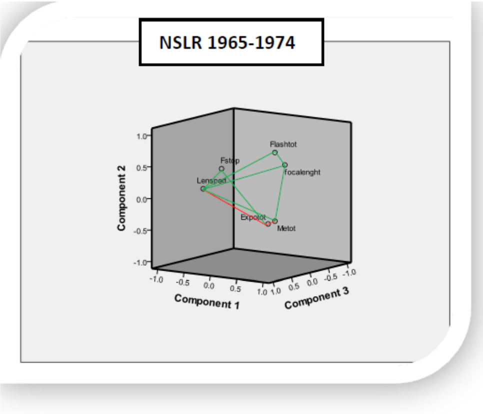


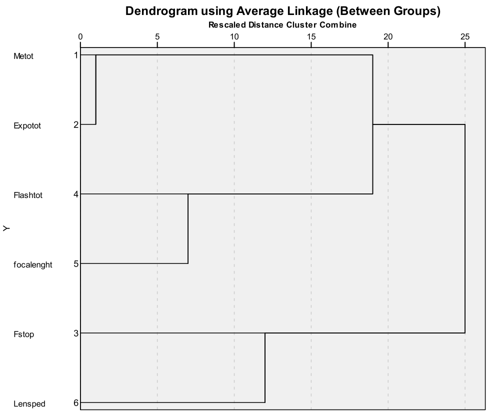


2. NSLR Cameras

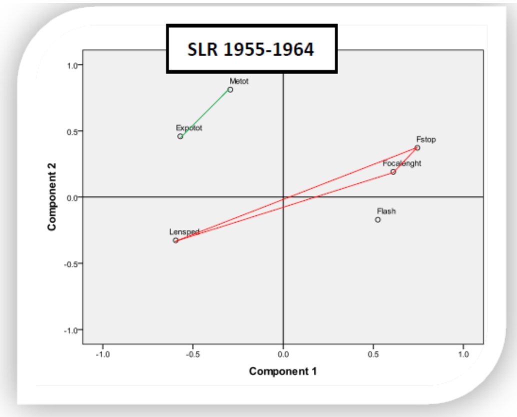


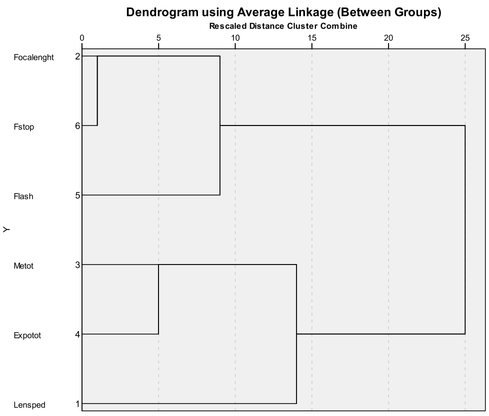


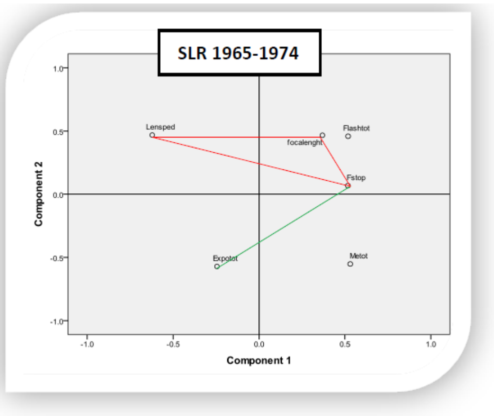


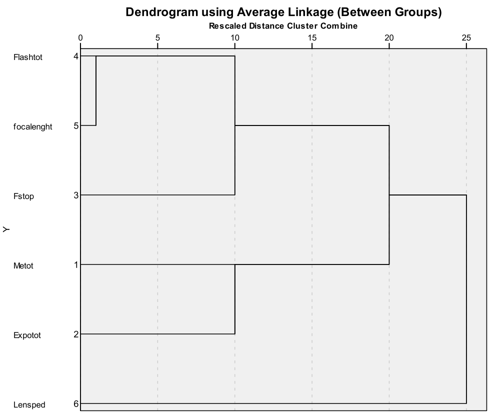


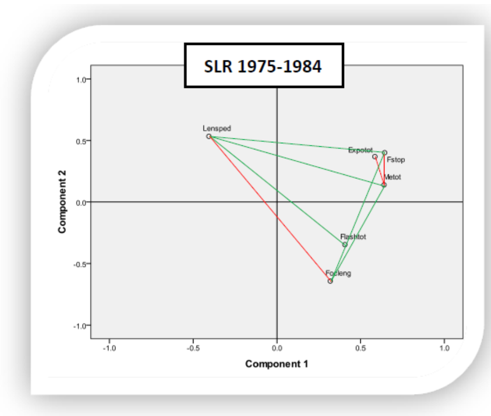
3. SRL Cameras

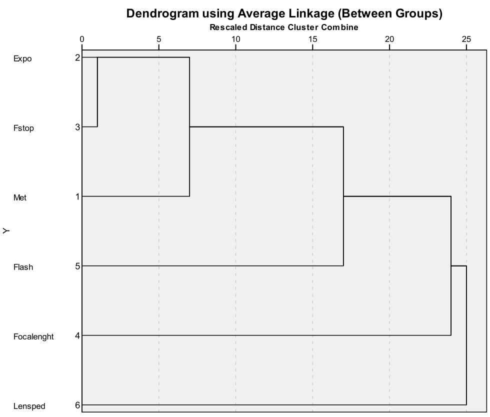


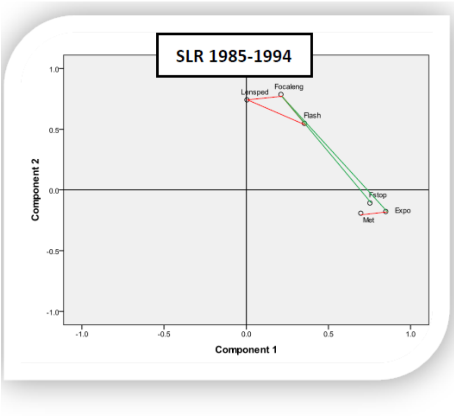


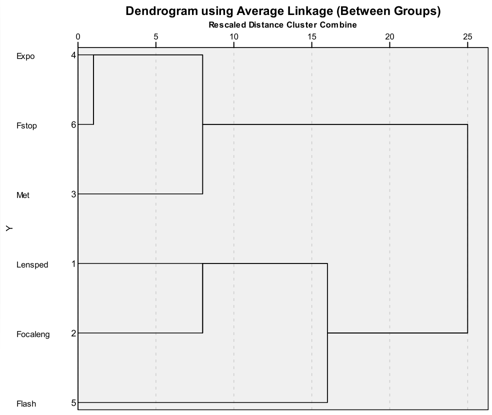


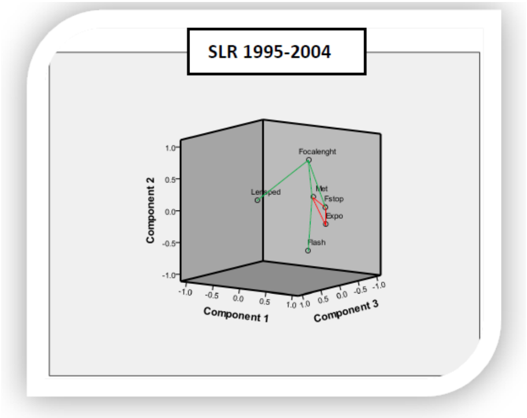


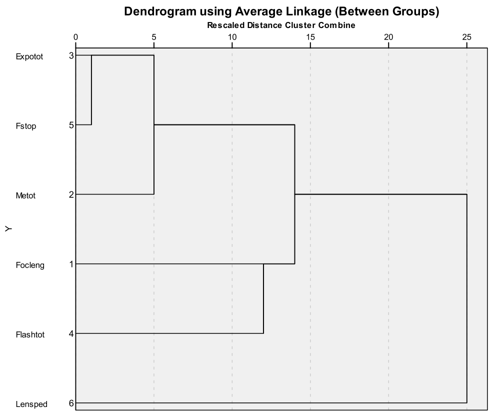




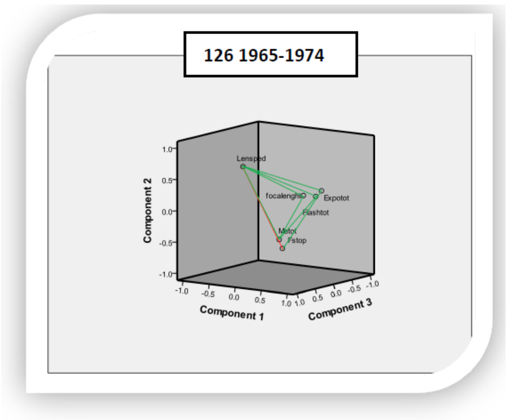


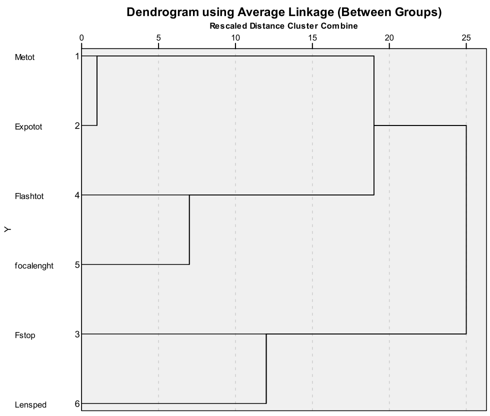




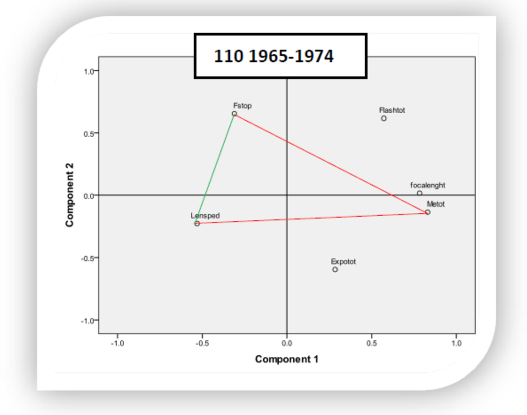


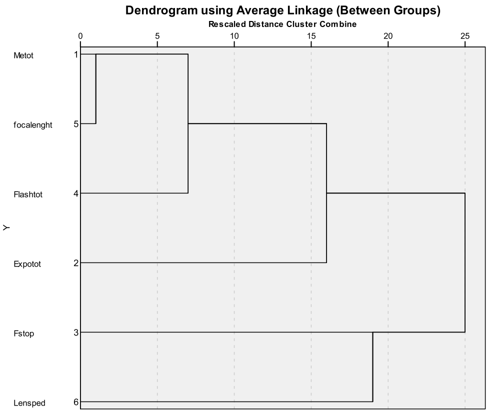
4. 126 Cameras

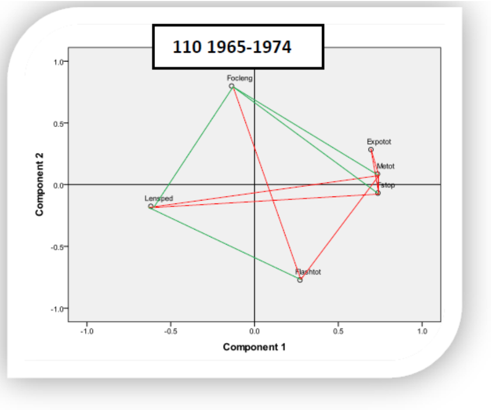


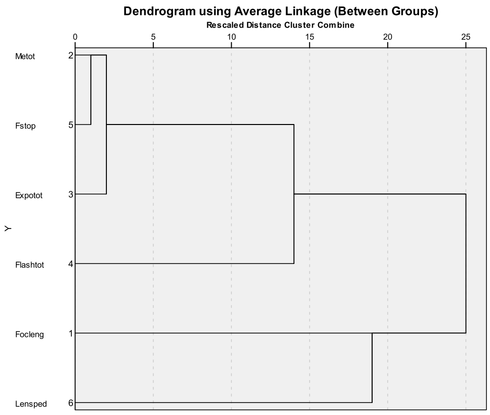


5. 110 Cameras

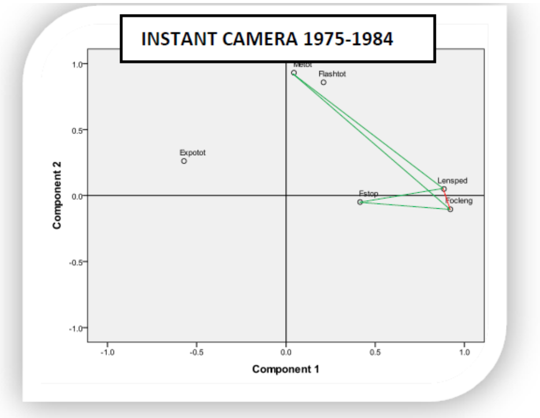


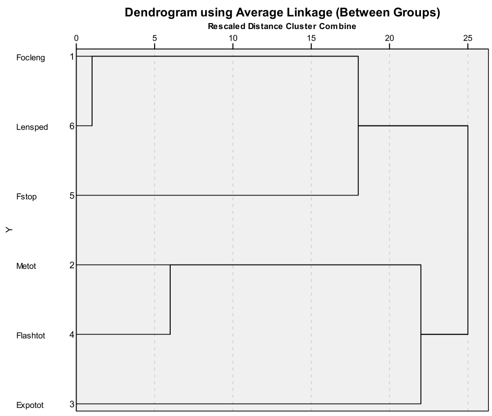




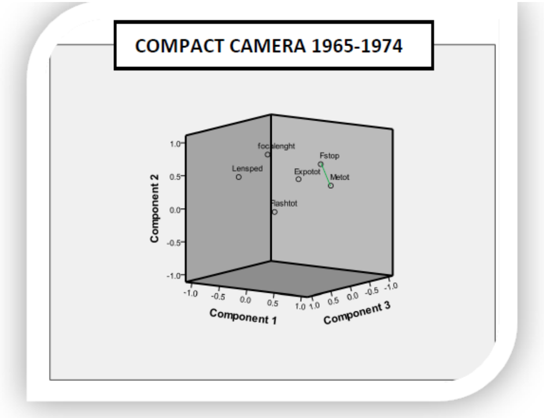


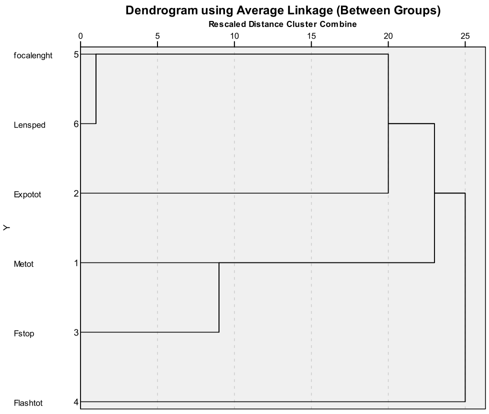
6. Instant cameras

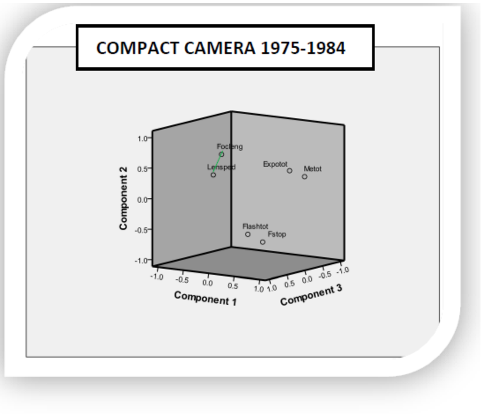


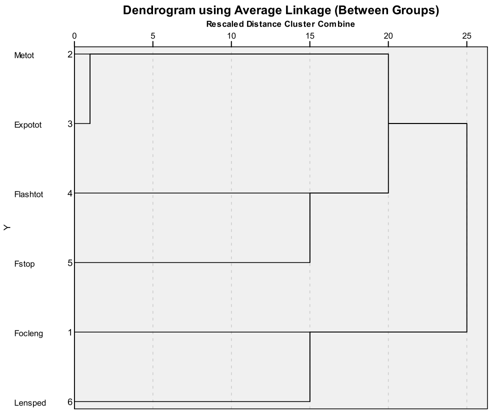


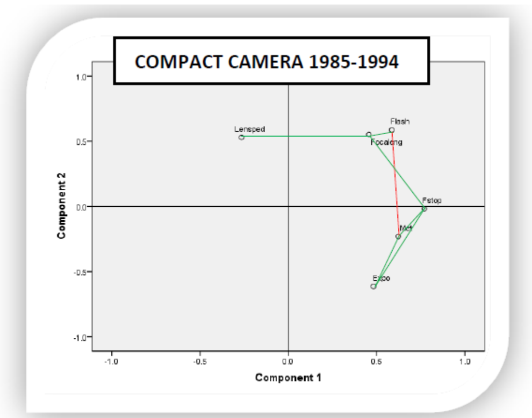
7. Compact Camera

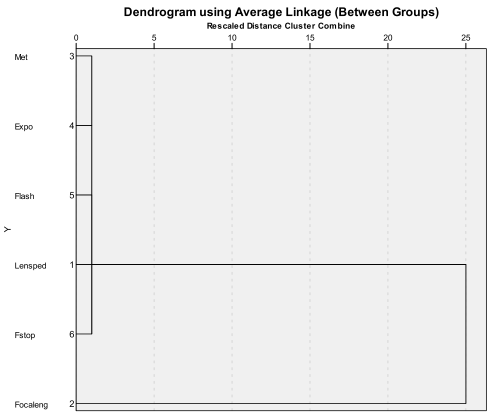


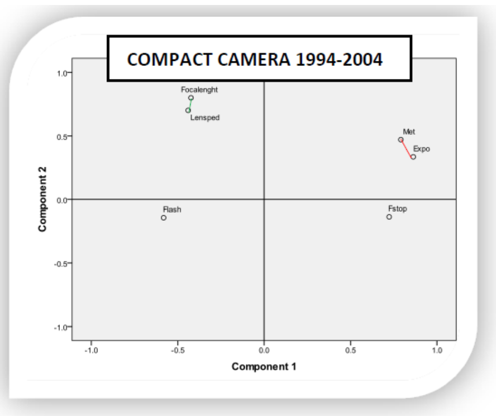


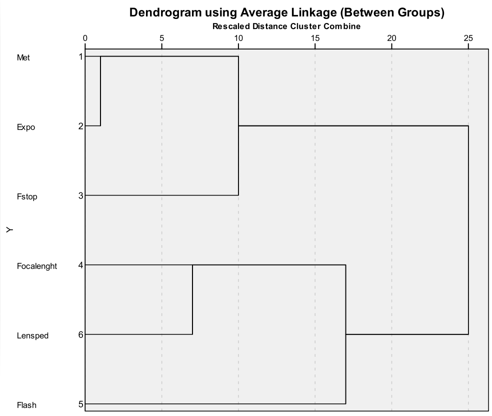




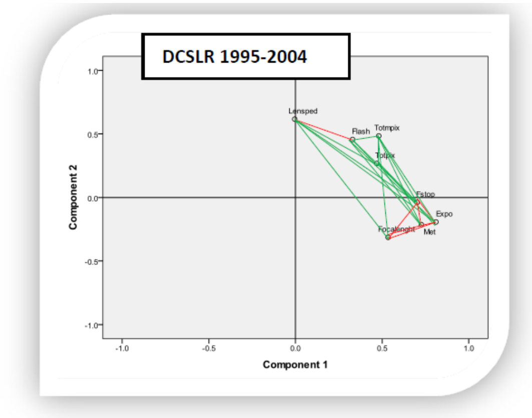


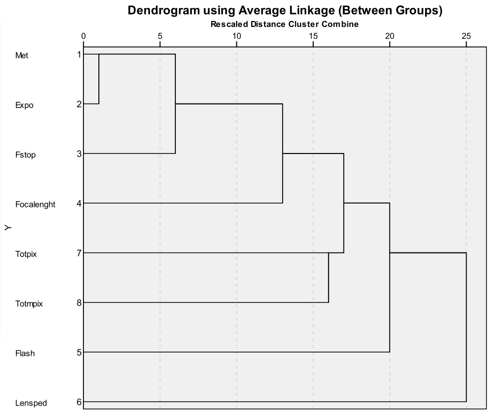


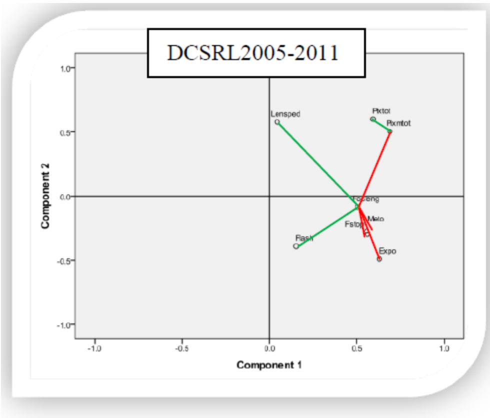


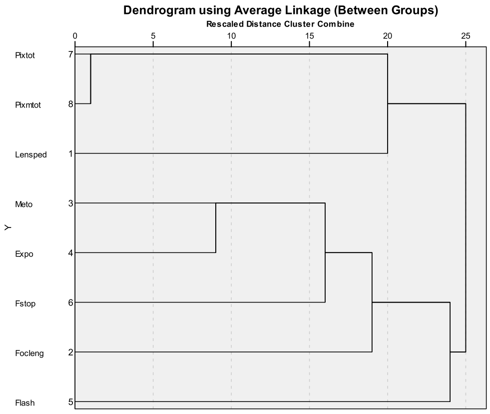


8. DCSLR Cameras

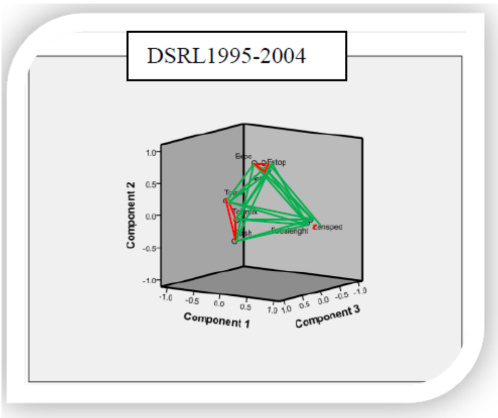


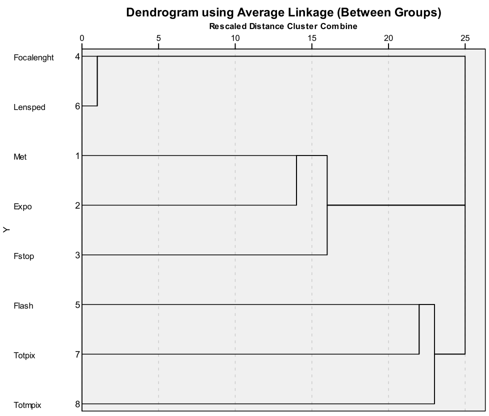


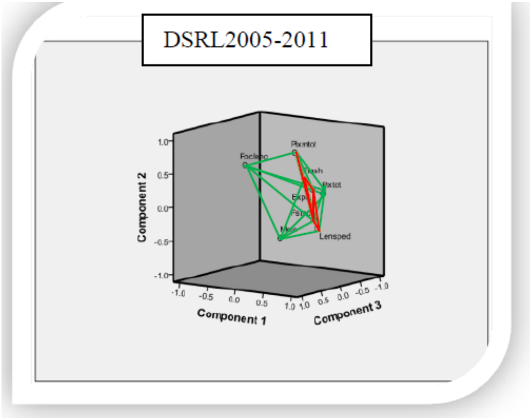


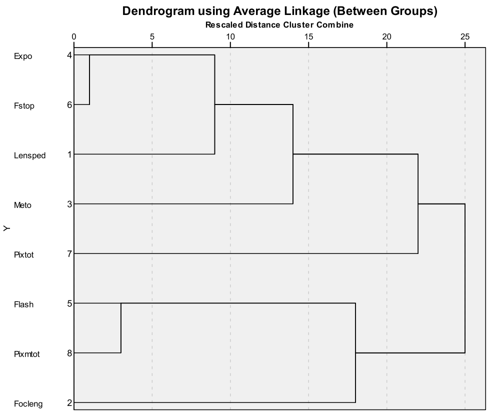


9. DSLR Cameras






DSRL2005-2011
Component 2
Component 1
Component 3
Focleng
Pixmtot
Flash
Pixtot
Expo
Fstop
Meto
Lensped


Dendrogram using Average Linkage (Between Groups)
Rescaled Distance Cluster Combine
0
5
10
15
20
25
Y
Expo 4
Fstop 6
Lensped 1
Meto 3
Pixtot 7
Flash 5
Pixmtot 8
Focleng 2

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