From Penrose to Complementary Assets: The Evolution of the Resource-Based Literature

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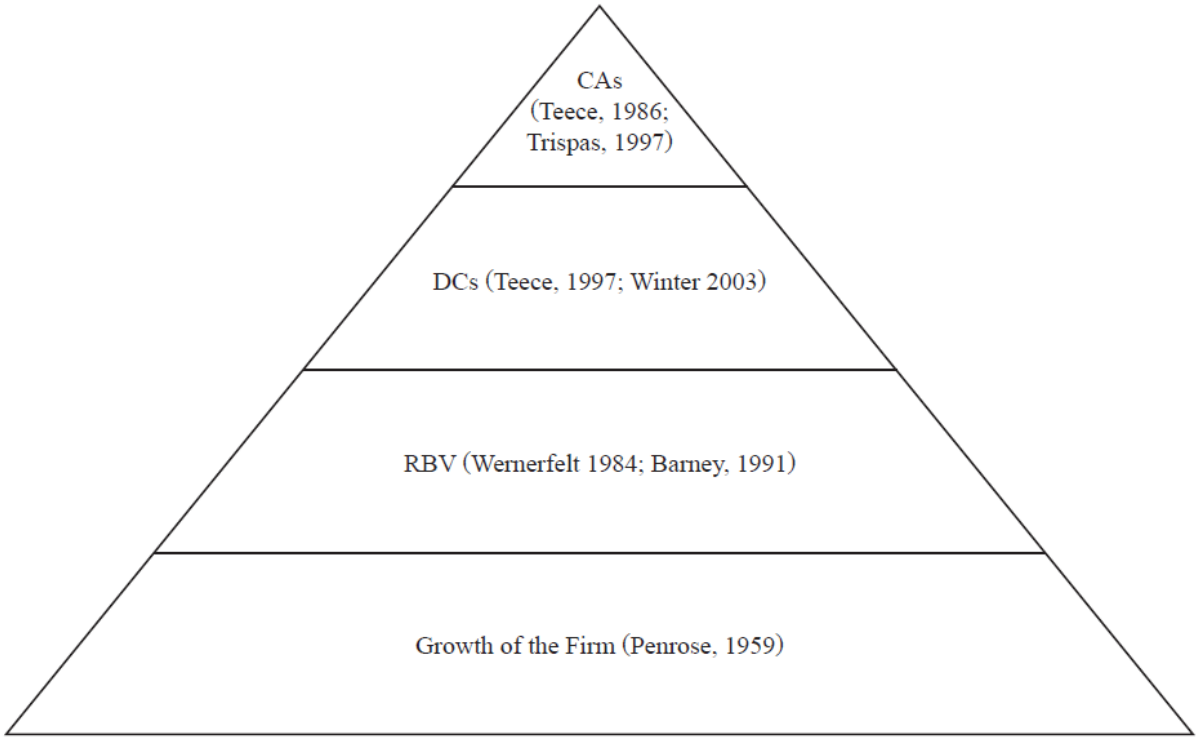
Although scholars recognize that the resource-based view (RBV) stems from Penrose's (1959) ideas (Barney, 1986; Wernerfelt, 1984), the evolution and continued evolution of the resource-based ideology has not been properly traced. The purpose of this paper is to trace this evolution, and connect several major areas of the literature: namely, Penrose, RBV, dynamic capabilities, and complementary assets (CAs). In tracing the resource-based evolution, the paper underscores the important and relevant aspects of resource-based ideology to modern management, untangles the incongruities in the literature, and identifies the weaknesses in the resource-based ideology.

INTRODUCTION

The RBV has gained significant scholarly attention in the last twenty years. It has become one of the most prominent strategic management theories, as thousands of articles draw on it. Out of the RBV, dynamic capabilities has developed. This theory looks at how firms reconfigure their resources to respond to rapidly changing environments (Teece et al., 1997). Because of the rapidly changing environments life science firms face, dynamic capabilities makes an excellent lens through which to examine life science firms. A firm displaying high-level capabilities is able to create complementary assets (CAs), which are the auxiliary assets needed in the commercialisation of an innovation (Teece, 2007). Figure 1 below traces the evolution of the resource-based literature. Starting with Penrose's (1959) Growth of the Firm, this review systematically works through this evolution.

FIGURE 1
RESOURCE-BASED PARADIGM EVOLUTION



Source: Author

PENROSE

Penrose's (1959) growth of the firm is one of the earliest theories to address why some firms grow at a faster pace than others. Not only is this an important piece because it is one of the first significant pieces to look at firm growth from a strategic management perspective, but it is also the basis for the RBV and several other modern strategic management theories.

According to Penrose (1959), a firm is an administrative structure with productive resources. These productive resources are both physical and human. The physical are the tangible assets, such as plants and materials. Human resources are the labour that the firm has available. The function of the firm is to engage these resources to create outputs. In order to maximise outputs, the firm must recognise productive opportunities, which are the opportunities of output that are available to the firm (Penrose, 1959).

Arguably, Penrose's largest contribution is her managerial view of the firm (Kor & Mahoney, 2004). Prior to her work in *The Growth of the Firm*, scholars mostly ignored the influence of management. She, on the other hand, saw management as one of the most important resources of the firm. Resources themselves are not enough to make a firm grow. Management is needed to convert resources to valuable outputs (Teece, 1986; Winter, 2003). These valuable outputs she calls 'productive services,' which she differentiates from resources that have no value until they are converted to something productive (Kor & Mahoney, 2004). A manager's firm-specific knowledge can adjust and expand, which allows a firm to grow over time; managers can be hired and trained in the long run. However, in the short run management expansion is limited because of the time it takes to hire them. This causes a bottleneck to growth, which is known as the 'Penrose Effect' (Uzawa, 1969). Penrose also makes significant contributions to the process of innovation within the firm. Specifically she attributes unused resources as

the source of firm innovation. This excess capacity is one of the key variables to firm growth (Penrose, 1959).

The variables described above are the building blocks of the RBV. One of the main architects of the RBV, Barney (1991, p.103), credits Penrose's contributions:

'Her work portrayed how resources may provide long-term rent streams'.

Many of the prominent theories in management trace back to Penrose's *The Theory of the Growth of a Firm*. Most notably are the RBV and dynamic capabilities models. Penrose's ideas on physical and human resources provided the foundation for the RBV (Rugman & Verbeke, 2005). *The Theory of the Growth of the Firm* also lays the groundwork for other growth theories, as it describes firm growth happening over a series of steps (Rugman & Verbeke, 2005).

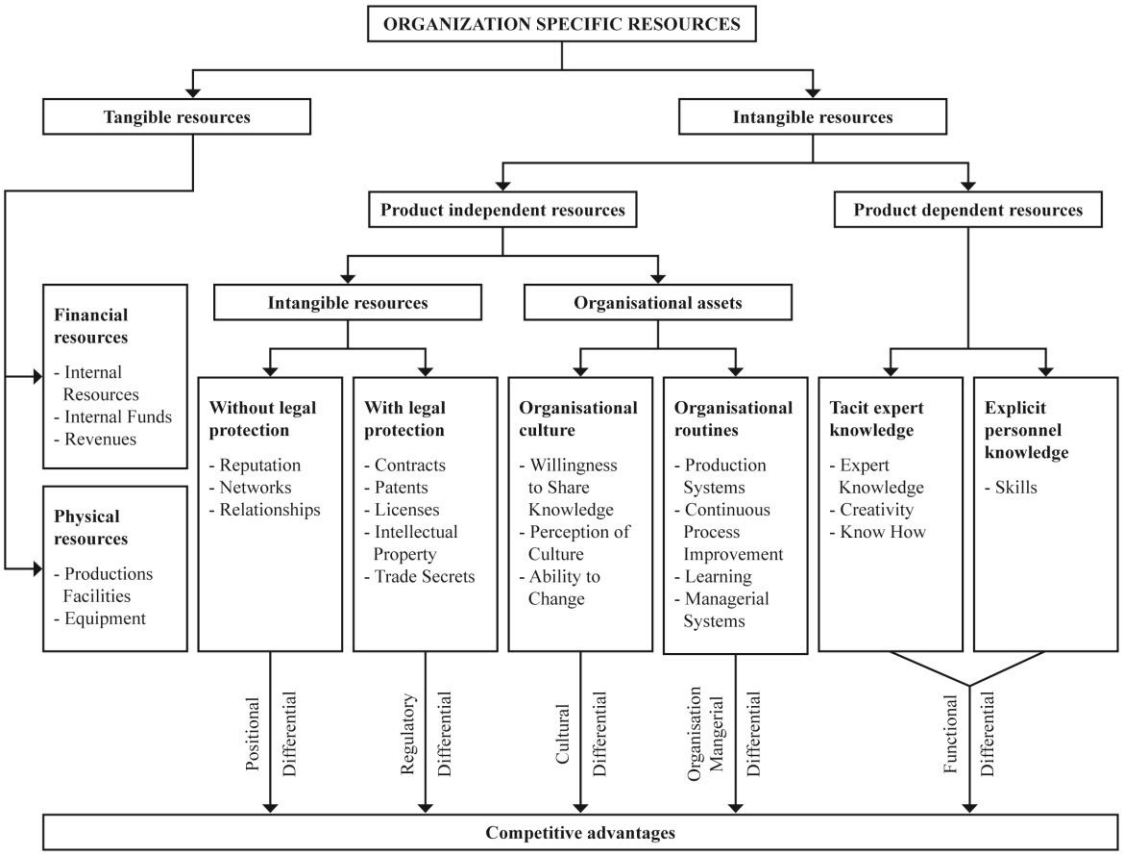
RBV

Penrose's main ideas are disseminated in her 1959 piece, but it was not until years later that her ideas were fully realized. Throughout the 1960's, 1970's and into the early 1980's, Industrial Organisational (IO) economics became popular in the strategic management literature (Conner, 1991). This literature is concerned with the influence of the outside forces on the market. By far the most influential work to come out of this school is Porter's Forces Model. According to the theory, the firm holds some degree of control in its strategic direction, but its ability to compete is limited within the confounds of its industrial environments (Miller & Dess, 1993). Whilst there is a sound basis for looking at environmental forces, critics contend that IO-related theories are overly concerned with outside forces and neglect firm resources and abilities. Although Hendry (1990) finds fault in assuming that markets work in equilibrium, many economic and political barriers show otherwise. Furthermore, studies have found that even firms that operate within sub-optimal environmental conditions are able to achieve above average economic rents (Schoemaker, 1990).

These shortcomings brought scholars back to Penrose's growth ideas. Wernerfelt (1984) and Barney (1986) extended her ideas into the RBV of the firm. These pieces, concerned with integral resources, examined firm competitiveness from the resource side, instead of the product or industrial standpoint. Accordingly, the basis of competitive advantage in lies in a firm's bundle of resources (Wernerfelt, 1984); thus firms with superior bundles of resources enjoy superior performance. Conceptually, this is an easy theory to grasp, but in practice it is difficult to understand clearly. For starters, what constitutes a resource? Penrose defines a resource in terms of either physical or human capital. Physical capital consists of the tangible property of the firm (e.g. land, equipment, etc.), and human capital is the knowledge and abilities of a firm are contained within it workers. Werenerfelt (1984, p.171) offers a similar definition: '*Those attributes of a firm's physical, human, and organisational capital that do enable a firm to conceive of and implement strategies that improve its effectiveness'.*

Figure 2 presents Maier's (2004) comprehensive categorisation of resources. He divides resources into tangible and intangible assets. He then further breaks each of these categories down. Tangible assets are divided into two groups: financial and physical. Intangible assets are divided into person independent and person dependent resources. This is a comprehensive categorisation that is similar to several others offered in the literature (Black & Boal, 1994; R. Hall, 1992; Ray, Barney, & Muhanna, 2004).

FIGURE 2
ORGANIZATIONAL RESOURES



Source: Maier (2004, p. 221)

In theory, the categories and definitions of resources are straightforward. In practice though, they are not as clear cut. For example, when is access to a network considered a resource? If a life science firm can simply join a large network, such as the US Bio Organisation, is this still a resource? This grey area is a large source of criticism for the RBV (Priem and Butler, 2001). Measuring resources has proven even more problematic, especially for intangible ones. For example, how can the reputation of a firm be convincingly measured? To overcome these shortcomings, a number of RBV scholars have created ways to measure intangibles. Bontis, et al. (1999) suggest that there a host of correlations that can be looked at between intangible assets and objective measures, such as return on investment (ROI); these suggestions are further supported by several other studies (Barth & Clinch, 1998; Bowman & Ambrosini, 2003; Rodov & Leliaert, 2002). However, even these studies acknowledge that there is no perfect way to measure resources. It is especially difficult to measure all of a firm's resources. In an in-depth analysis of studies using the RBV, Newbert (2007, p. 141) found that 76% of RBV studies only examine one resource. Furthermore, he finds that less than 5% of studies looked at more than two resources, perhaps because it is so difficult to isolate resources; most modern firms are a web of interconnected resources, and often resources share functions (R. Hall, 1993). This is the central argument of Priem and Butler (2001) who contend that how resources create value cannot possibly be discerned. For example, how does a life science firm discern between the value of the scientific staff and their equipment? Life science firms usually have advanced scientific equipment, but it is rendered useless without the skilled scientists who use it; so in this instance which is more valuable, the equipment or the scientists? As this example illustrates, it is extremely difficult to gauge the value of a resource.

Barney (1991) and others contend that the valuable, rare, imperfectly in-imitable and non-substitutable (VRIN) framework discerns how a resource creates value. Accordingly, a resource must meet the VRIN criteria for it to help the competitive position of a firm; i.e. the resource is valuable, rare, imperfectly imitable and non-substitutable. A number of scholars feel that it is too difficult to discern whether or not a resource meets these criteria, and for this reason have rejected, at least parts, of the theory (Priem & Butler, 2001). However, many management scholars, at least to an extent, have accepted the VRIN framework, which explains why it is such a prevalent theory in management. However, not all resources are a source of permanent competitive advantage, as changing environmental factors influence the relative value of a resource (Eisenhardt & Martin, 2000; Fiol, 2001); i.e. changing environments and organisational factors degrade the value of certain resources whilst increasing the value of other resources. However, some scholars contend that firms consistently find and better allocate resources; therefore, some types of resources are a source of sustained competitive advantage (Barner, 2001; Mikado, 200).

Although the VRIN framework provides a basis for how a resource gives rise to competitive advantages, it does not explicitly state how resources are obtained or developed (Hoopes, Madsen, & Walker, 2003). Some contend that firms develop resources from superior resource picking abilities (Barney, 2001; Lounsbury & Glynn, 2001); whilst others contend that firms develop resources from other resources (Makadok, 2001; Teece et al., 1997; Winter, 2003). The lack of clarity in how resources are developed and used has even led to the contention that the RBV has no management implications (Priem & Butler, 2001). Accordingly, the RBV tells managers to obtain VRIN resources, but it offers no prescriptions or insights on how to obtain these resources. Furthermore, it gives little input on how to use the resources once they are obtained (Miller, 2003). Barney (2005) suggests that these are not problematic because the theory was never intended to be prescriptive. However, Starkey and Madan (2001) clearly show that there is a major disconnect between scholars and practitioners, and that if management research does not provide relevance to practitioners, then it will become irrelevant. Furthermore, Vila and Canales (2008) suggest that managers must have a clear picture of the issues they wish to address in the planning process. In its current state, the RBV makes it difficult for practitioners to define resource based issues, and for this reason the RBV needs to make strides to make a clearer connection to the practice of management.

DYNAMIC CAPABILITIES

The previous discussion indicates that the RBV has become one of the most widely used theories in management. It also suggests that it is a useful theory, but there are several flaws that limit its application. The most common criticism of it is its static nature (Priem & Butler, 2001). This makes applying a RBV lens to a fluid industry, such as the life sciences, difficult. Life science resource demands rapidly change, which changes the values of a firm's resources (Carayannopoulos & Auster, 2010). To get beyond the criticisms, researchers started applying a dynamic view of how resources are integrated, built, and reconfigured to respond to changing environments to create sources of sustained competitive advantage (Teece & Pisano, 1994). This view evolved into what is now called dynamic capabilities, which is one of the only frameworks to offer plausible insights on the growth of technology based firms.

Dynamic capabilities stems from the RBV (Helfat & Peteraf, 2003; Mikado, 2001; Teece et al., 1997). However, several other fields have also influenced its evolution; including organisational learning (Argyris & Schon, 1978; March, 1991), evolutionary economics (Schumpeter & Opie, 1934), transactions cost analysis (Coase 1937; Monteverde and Teece 1982) and competencies (Patel & Pavitt, 1997; Prahalad & Hamel, 1994). Dynamic capabilities draws heavily on how the firm absorbs and applies knowledge. In doing so it makes extensive use of Nelson and Winter's (1982) emphasis of routines, and the importance of the individual on organisational routines (Cyert & March, 1992). Whilst dynamic capabilities evolved from the RBV, it is important to note that the idea of resources does not simply go away because of the introduction of dynamic capabilities. Resources are central to how dynamic

Capabilities are formed and what they reconfigure. Several scholars (Bowman & Ambrosini, 2003; Eisenhardt & Martin, 2000; Helfat & Peteraf, 2003; Makadok, 2001) suggest that the traditional resource picking view is still important as well as complementary to dynamic capabilities; i.e. firms can have a competitive advantage in picking resources, but they can also use these resources more effectively by reconfiguring them in the most optimal manner.

Collis (1994) is one of the first to explicitly identify dynamic capabilities in his categorisation of *static*, *dynamic* and *creative*. A static capability is the ability of a firm to perform basic functions, including marketing and simple manufacturing; functions that almost any firm could easily become proficient at. He refers to dynamic capabilities as those that help the firm learn or grow. These are capabilities such as improving operational efficiency through trial and error. Creative capabilities he describes as 'metaphysical' (p.146), and are used for higher-level innovation. Whilst the ideas introduced by Collis are not markedly different than those in the modern-day theory of dynamic capabilities, he is rarely mentioned as a pioneer on the topic. Most notably, he is not cited in the most influential papers on dynamic capabilities, Teece, Pisano and Sheen (1997). This piece also emphasises the ability of a firm to reconfigure its resources, but it focuses on paths, positions and processes. Paths refer to the firm's history and future opportunities available to the firm. Past paths represent how it evolved, what it has learned and the major events that have influenced its decision-making. Future paths represent the strategic alternatives available to the firm. Positions refer to the resource stocks of the firm. These resource stocks have a large bearing on dynamic capabilities because resources are what dynamic capabilities reconfigure. Processes refer to the internal routines of the firm, especially those that have a significant impact on changing the firm. Another distinction of Teece et al.'s (1997) ideas on dynamic capabilities is the emphasis of rapidly changing environments, especially technical environments. The next section further compares notable dynamic capabilities' definitions offered in the literature.

Definitions and Frameworks of Dynamic Capabilities

Most research follows Teece et al.'s (1997, p. 516) definition: *'the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments'*. In a different vein, Eisenhardt et al. (2000, p. 1106) emphasise the importance of resources in their definition of dynamic capabilities: *'strategic and organizational processes like product development , alliancing, and strategic decision making that create value for firms within dynamic markets by manipulating resources into new value creating strategies'*. Solo and Winter (2002, p. 340) offer another definition emphasising the importance of the customer and the competition: *'A dynamic capability is a learned and stable pattern of collective activity through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness'*. The problem with these, along with the other definitions scattered throughout the literature, is that they are vague. Conceptually, most of the definitions make sense, but operationally it is almost impossible to pin down what a dynamic capability is from these definitions. Zahra et al. (2006) suggest that three common elements are confounded in the literature: 1) substantive capability, 2) environmental characteristics and 3) higher order capabilities. This problem is largely because of the lack of clear and specific definitions (Salvato, 2003). There has been a movement to clarify the definition, but this has gone in many uncoordinated directions, highlighted in Table 2-1. From this table, it is evident there are several inconsistencies. A central problem is that these definitions assume that a capability is only dynamic if it provides a competitive advantage. Tautologically this assumption is flawed. For example, the definition offered by Rind ova and Taylor (2002, p. 16): *'A newer source of competitive advantage in conceptualising how firms are able to cope with environmental changes'*. This definition does not delineate where competitive advantages stem from. It also fails to consider that a dynamic capability is often only a building block or one part of a competitive advantage.

In short, the definitions presented in the literature give a good sense of what dynamic capabilities are, but they are still not specific enough. A better direction for defining dynamic capabilities is to trace it back to its ontological roots and hierarchically break it down. Put differently, the concept is too

complicated to define in one sentence, and it would be better for the literature to break the definition into interrelated pieces.

TABLE 1
DEFINITIONS OF DYNAMIC CAPABILITIES

Author	*Definition*
Helfat (Kaplan, Murray, & Henderson, p. 342)	The subset of the competences/capabilities that allow the firm to create new products and processes and respond to changing market circumstances.
Teece et al. (1997, p. 516)	The firm's ability to integrate, build and reconfigure internal and external competences to address rapidly changing environments.
Eisenhardt and Martin (2000, p. 1107)	The firm's processes that use resources – specifically the processes to integrate, reconfigure, gain and release resources – to match or even create market change. Dynamic capabilities thus are the organizational and strategic routines by which firms achieve new resources configurations as market emerge, collide, split, evolve and die.
Griffith and Harvey (2001, p. 598)	A global dynamic capability is the creation of difficult-to-imitate combinations of resources, including effective coordination of inter-organizational relationships, on a global basis that can provide a firm a competitive advantage.
Lee et al. (2002, p. 729)	A newer source of competitive advantage in conceptualizing how firms are able to cope with environmental changes.
Rind ova and Taylor (2002, p. 16)	Dynamic capabilities evolve at two levels: a micro-evolution through 'upgrading the management capabilities of the firm' and a macro-evolution associated with 'reconfiguring market competencies'.
Zahra and George (2002, p. 186)	Dynamic capabilities are essentially change-oriented and help firms redeploy and reconfigure their resource base to meet evolving customer demands and competitor strategies.
Solo and Winter (2002, p. 340)	A dynamic capability is a learned and stable pattern of collective activity through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness.
Winter (2003, p. 991)	Those that operate to extend, modify or create ordinary (substantive) capabilities.
Zahra et al. (2006, p. 920)	The abilities to reconfigure a firm's resources and routines in the manner envisioned and deemed appropriate by the firm's principal decision-maker(s).
Helfat (2007, p.1) Helfat and Peteraf (2009, p. 91)	The capacity of an organization to purposefully create, extend, and modify its resource base.

Source: Author based on Zahra et al. 2006.

Dynamic Capabilities Frameworks

The unbounded definitions of dynamic capabilities are complemented by the lack of a coherent framework. Many different authors (most notably, Eisenhardt & Martin, 2000; Makadok, 2001; Zahra et al., 2006) have proposed theoretical frameworks. However, as of yet not one of these has become widely accepted. These models share several commonalities. Almost all of the models view dynamic capabilities as a standalone theory that stems from the RBV. One notable exception to this is Mikado (2001), whose model does not substitute dynamic capabilities for resources. Instead his model views them as complementary; i.e. managers help firms grow by both strategically picking resources and using dynamic capabilities to optimise their resources.

Winter (2000) developed a hierarchical conceptualisation of dynamic capabilities based on Collis' categorisation. Winter's conceptualisation includes an ordered level categorisation of zero-level, first-order and second-order dynamic capability. A zero-level capability is the most basic and is the operational capabilities needed to run a firm in the short term. A first-order capability is dynamic, the ability of a firm to reconfigure resources and respond to market conditions. An example is the ability of a pharmaceutical firm to recognise an opportunity for a new drug development opportunity. A second-order is the capability of learning. This capability facilitates identifying, creating and modifying dynamic capabilities that are most useful in the firm's operations. According to this hierarchical model, all three are

linked together and build off of one another to create the total capabilities of a firm. Another premise of the model is that higher-level capabilities are not always beneficial to a firm, and in some cases, the cost of developing them is a poor use of resources. Whilst this is an interesting model, there are still many holes in it. Most notably, this model does not clearly define each level. Furthermore, it could also be argued that learning is a key element to the broader concept of dynamic capabilities. For these reasons few studies have used this model. Nevertheless, this hierarchical conceptualisation of capabilities has the potential to unearth insights on the values of their different types of dynamics. It would be beneficial for future research to synthesise and further the ideas presented by Collis (1994) and Winter (2003) into a more specific model(s).

The dynamic capabilities literature tends to emphasise three elements: (1) learning, (2) routines and (3) the environment. Each of these is detailed below.

Learning

The importance of learning is scattered throughout the dynamic capabilities literature. In their conceptualisation of dynamic capabilities, Eisenhardt et al. (2000) suggests that learning mechanisms underlie the development of dynamic capabilities. They suggest that firms with more experience in responding to change are more apt to develop dynamic capabilities. However, anecdotal and empirical evidence (Boccardelli & Magnusson, 2006; Macpherson, Jones, Zhang, & Street, 2004; Newbert, 2005) suggests the opposite. Take for example the rise of Google, Microsoft and Dell. These firms were all inexperienced and were in competition with well-established firms, yet all of them significantly outgrew their competitors because they learned quicker and responded better to changing business environments, even though they had little previous learning experience. Furthermore, Autio et al. (2000) found that new ventures have an advantage in the internationalisation process because of their learning advantage of newness; i.e. new firms do not have the bad habits of established firms and respond to market conditions more swiftly. Solo and Winter (2002, p. 348) propose a better view on the development of dynamic capabilities through three learning-related mechanisms: 1) past experience, 2) knowledge articulation and 3) knowledge codification processes; accordingly, these three mechanisms underpin learning capabilities.

Winter (2000) goes against the grain of these studies to explore when learning adversely effects a firm's dynamic capabilities. In this paper she suggests that firms can focus too much on learning and not make the most effective use of their resources. This piece is unique because it challenges the rhetoric so often seen in the literatures of dynamic capabilities, absorptive capacity and organizational learning that say learning always has a positive effect. Though learning is one of the most popular themes in dynamic capabilities, relatively little empirical support backs it up. Most of the learning studies cited in dynamic capabilities are studies from other fields that are synthesised into the analysis of dynamic capabilities. One notable empirical study is the Engelhard et al. (2002) analysis of the dynamic learning of a major pharmaceutical company. Their analysis indicates that it is critical for biopharmaceutical firms early on to enable learning capabilities and to create actionable knowledge based on what they have learned. Engelhard et al. (2002) also support the idea that knowledge is only important if it is actionable. In a similar study Swift and Hwang (2008) suggest that organisational learning requires organisation-wide commitment, including top managers, mid-level managers and line workers in order to articulate, codify, and disseminate knowledge derived. This piece is also significant in that it takes a holistic look at the learning approach, instead of just looking at the importance of top management in the learning process. In a similar vein Davies and Brady (2000) found in their study of telecommunication manufacturing firms that it is vital to develop organisational-wide learning capabilities from previous experiences.

Routines

The second reoccurring theme in the dynamic capabilities literature is routines. Teece et al. (1997) referred to these as processes in their conceptualisation of dynamic capabilities and defined this as

the way things are done within the firm. This emphasis on routines is a central source of criticism. The critics note that this is tautological, vague and immeasurable (Blomqvist, Kyläheiko, & Virolainen, 2002; Priem & Butler, 2001). Eisenhardt and Martin (2000) argue that these are criticisms of the RBV and that dynamic capabilities is differentiated because such routines are identifiable and empirically measurable. They point to product development and strategic decision making as examples of identifiable and measurable routines. However, strategic decision making is an abstract topic to measure, and there is little empirical support of how routines influence dynamic capabilities; so Eisenhardt and Martin's (2000) arguments do not completely dispel the critic's points of contention.

Zahra et al. (2006a) propose that organisational routines are an antecedent to organisational learning and change. This notion is supported by Inanity and Clark's (1994) study on the integration of dynamic capabilities in automobile and computer industries. Although an interesting and insightful study, its findings are far from conclusive because of the weak measures they drew from secondary data. Another study by Abuja and Lambert (2001) concludes that the routine of continual experimentation is critical to reconfiguring capabilities to respond to environmental conditions in the global chemical industry. According to this study, experimental routines are the basis of how new knowledge on which these firms compete is created. Whilst the aforementioned studies offer insights on the importance of routines, they do not empirically support the emphasis placed on routines as suggested in marquee works on dynamic capabilities (Eisenhardt & Martin, 2000; Teece et al., 1997; Winter, 2003; Zollo & Winter, 2002). This is not to suggest that routines are not important; rather more empirical work needs to isolate the importance of routines in dynamic capabilities.

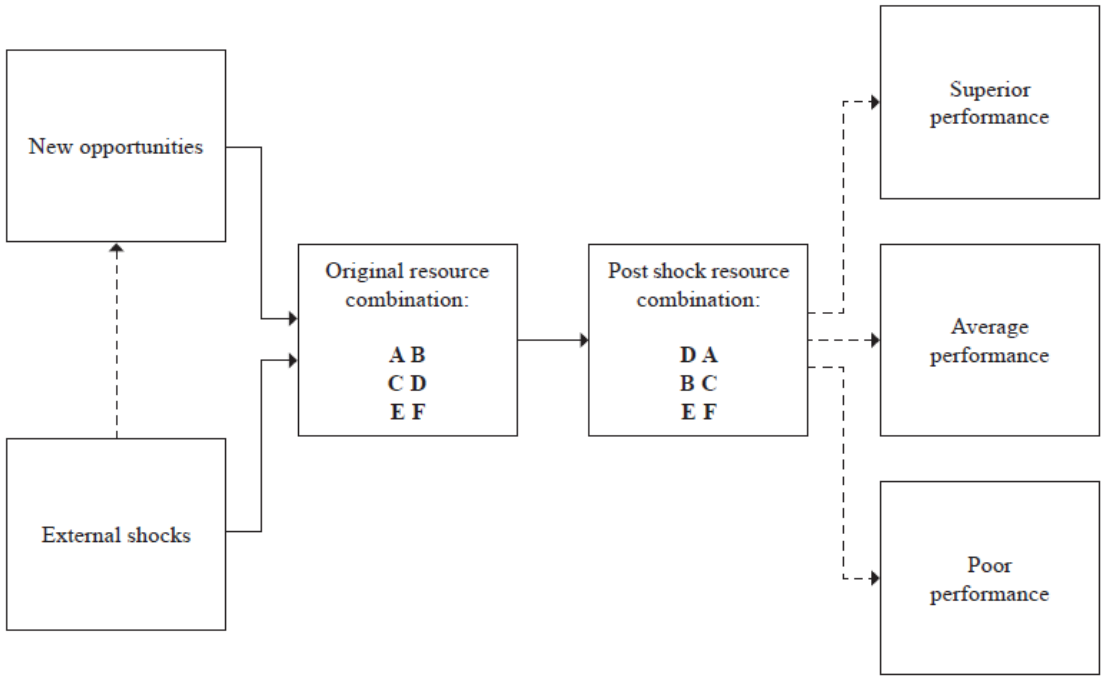
Environment

A third emphasis of dynamic capabilities models is the importance of the environment. Dynamic capabilities is an especially useful lens to examine firms in rapidly changing business environments (Blyler & Coff, 2003; Davies & Brady, 2000; Eisenhardt & Martin, 2000; D. Teece & Pisano, 1994; Teece et al., 1997). The importance of responding to a rapidly changing environment is a plausible explanation as to how young resource constrained firms can enter markets and outperform large and rich competitors (March, 1991). A prime example of this is the rise of Microsoft: A young firm started by two college dropouts who out-performed multibillion dollar firms, Microsoft credits much of their success, especially their early success, to their ability to out manoeuvre and respond to the tremendous technical changes taking place in the software industry (Stross, 1997). Researchers emphasise the importance of dynamic capabilities in technology-based industries such as software, biotechnology and semiconductors because the changing technology in these industries requires firms to quickly change their operations and product offerings in order to stay competitive. Conventional wisdom and anecdotal evidence support the effect rapidly changing environments have on firms; however; there is little empirical work to fully substantiate it. Most of the studies on the influence of environments cited in dynamic capabilities are from studies not specific to dynamic capabilities.

Figure 3 conceptualises the effect that the environment has on the firm. The figure starts with an original resource combination that is then shocked by an outside event. Outside events are either new market opportunities or external shocks. Examples of external shocks are changing economic conditions, technological shifts or political events. The dashed line from external shocks to new opportunities in the figure represent the new paths that arise as the result of external shocks (Deeds et al., 2000; Zahra & George, 2002); thus external shocks either directly or indirectly impact the firm. A shock or combination of shocks causes a firm to respond and reconfigure its assets and capabilities. This is represented by the original resource recombination being reconfigured to the post-shock resource combination. Figure 3-3 below offers a simple example, but in actuality there can be hundreds, if not more, reconfigurations that a firm can go through. In this example only two of the three sets of resources are reconfigured post shock: AB and CD reconfigured to DA and BC, whilst EF stayed the same. This illustration shows that in many cases firms will reconfigure many operations, but some units or divisions will stay the same even after a

shock. The reconfigured resources then either lead to superior performance, average returns or poor performance. This is an important part of the conceptualisation because it illustrates Winter's (2000) notion that reconfiguration does not always lead to superior performance; if resources are not optimally reconfigured to respond to the external events, it can also lead to average or poor performance.

Figure 3
CONCEPTUALIZATION OF DYNAMIC CAPABILITIES



Source: Author

Empirical Studies on Dynamic Capabilities

Although the quantity and depth of empirical work is lacking, there are several notable empirical studies that help to substantiate the theory. Appendix 1 highlights these studies and shows that a broad consensus is emerging. One industry that has recently gained popularity for use in the empirical testing of dynamic capabilities is the life science industry (Anand, Oriani, & Vassolo, 2010; Ingelgard et al., 2002; Rothaermel & Hess, 2007). A recent study by Rothaermel and Hess (2007) looked into the antecedents of dynamic capabilities. Unlike previous studies on the topic, their research factored in the interaction of the three antecedents (individual, firm and network) of dynamic capabilities; instead of isolating them individually as previous studies have done (Christensen, 1997; Henderson & Cockburn, 1994; Zucker & Darby, 1997). Rothaermel and Hess (2007) suggest that there is important interaction between the individual, firm and networks levels in creating dynamic capabilities. In some cases they work as complements, but in others they can work as substitutes. Their study indicates that firms can substitute superior human capital for firm-level factors such as R&D capacity. Thus this study established that managers must weigh individual, firm and network resources when developing an overall firm strategy constitutes the most important contribution of this study. Although a noteworthy study, it is based on weak secondary data and ill-defined constructs and measurements. Therefore it needs further refinement and testing.

Another dynamic capabilities study that uses life science firms as the sample is Zucker and Darby's (1997) study on the influence of star scientists on the transformation of an organisation. Their findings suggest that star scientists greatly influence the growth and direction of a firm through their

innovative abilities. The scientists' innovations set the direction of the organisation and force it to reorganise to commercialise the star scientists' discoveries. Zucker and Darby (1998) followed this study up with an investigation clearly showing that knowledge spills over from universities to biotech firms located near universities. This tacit knowledge is a large source of dynamic capabilities for the recipient firms of the knowledge. Deeds et al. (2000) is another empirical study on dynamic capabilities that uses life science firms as the sample; it also highlights the importance of human capital and supports the notion that knowledge spilled over from universities provides important antecedents to dynamic capabilities. Another important finding from this paper is that it is better to keep top scientists in R&D than to have them as top executives. The management duties take away from their tacit scientific knowledge, which serves as a driving force to creating innovations that change a firm. This study suggests that it is important to have a top management team with business experience and scientific knowledge.

In a different vein, Madhok and Osegowitsch (2000) use dynamic capabilities at the macro-level to look at the diffusion of biotechnology around the world. They studied alliance and innovation flows of the US and Europe; their findings show that initially the technology flows were one way from the US to Europe, but over time the innovative capabilities built up in Europe and the flow of innovation became two way. Although an interesting study that gives a good overview of the evolution of the cross continental flow of biotech knowledge, it would have been even more interesting had they included some firm-level examples.

These studies clearly demonstrate that dynamic capabilities is starting to gain the empirical support that it needs to become a strong theory. However, empirical work as a whole on dynamic capabilities needs further development. Table 2 presents the key empirical studies done on dynamic capabilities from 1992-2010. From this table it is evident that Arend and Bromiley (2009) were justified in their assertion that dynamic capabilities does not have enough empirical support. Specifically there is little longitudinal work, and many of the studies examine dynamic capabilities post hoc. There are also few studies that have used mass surveys, and scant work on small firms exists.

The table above shows that some studies are starting to surface that use hypothesis testing, and certain areas are justified to do so. In certain areas the theory has grown to a point where it can be tested. However, there are many areas related to dynamic capabilities, such as the development of capabilities in small firms that cannot be properly tested because of the lack of defined measures and constructs. The largest problem restraining empirical testing in dynamic capabilities is the lack of a consistent framework. Teece et al.'s (1997) paths, positions and processes framework offers a way to address this. Essentially, this framework contends that competitive advantage lies in a firm's processes, which are determined from a firm's paths and positions. Previous paths are the past decisions and future opportunities that shape where a firm can go. Past decisions commit resources and often create rigidities because the firm is deeply tied to its earlier commitments. For example, Deeds and DeCarolis' (2000) study on new life science firms shows that a firm's future development opportunities is limited by investments made in earlier research. They suggest that often firms invest so heavily in a technology that they drain resources that could be used for future projects. Future paths represent opportunities available to the firm and how the firm strategizes and organises its resources to pursue these opportunities. Positions are the resources the firm uses to leverage in their pursuit of future paths. For example, life science firms often leverage their patents in the pursuit of developing a technology (Deeds et al., 2000; Madhok & Osegowitsch, 2000; Ziedonis, 2004).

Although Teece et al.'s (1997) paper lays out a viable framework for examining dynamic capabilities; i.e., probe the paths, positions and processes that lead to competitive advantage – little work examines all of these in a single study. As discussed above in the section on key empirical studies relating to dynamic capabilities, studies have examined competitive advantage and firm growth using parts of the framework, but surprisingly little work holistically examines the paths, positions and processes in a single study. Furthermore, it is hard to take a study that examines the paths leading to competitive advantage and then

compare it to a study that examines the positions that lead to competitive advantage. Dynamic capabilities is fundamentally process-based, and processes are hard to dissect and compare in multiple studies (Pettigrew, 1992). Therefore, a sharp need for research to examine the paths, positions and processes leading to growth in a single study exists. In-depth qualitative work is especially needed to unearth insights on:

- What past decisions create path rigidities?
- What future opportunities motivate reconfiguring resources and capabilities?
- What positions do firms leverage to create key resources and capabilities?
- What are the processes the firms use to create key resources and capabilities?

Dynamic Capabilities' Shortcomings and Conclusions

Intermixed in the discussion above are several shortcomings of dynamic capabilities: lack of a coherent definition, weak empirical support and difficult to measure constructs. Arend and Bromiley (2009) note these shortcomings along with several others; they even go as far as to use these shortcomings as a basis to abandon dynamic capabilities. One of their main assertions is that the theory does nothing more than restate previous work of absorptive capacity, strategic fit, first-mover advantage, organisational learning and change management. Accordingly, dynamic capabilities must add value beyond these theories and have a basis for prediction to be considered a credible theory. Their second criticism of dynamic capabilities is the inconsistent definitions in the literature. This is a view that is shared by many scholars, including those who publish on dynamic capabilities (Collis, 1994; Williamson, 1999; Winter, 2003). Arend and Bromiley's (2009) third grievance is that dynamic capabilities lacks rigorous empirical support. They clearly show that the little empirical support for dynamic capabilities mainly comes from weak quantitative studies that do not include a longitudinal component. They also illuminate the fact that most of the empirical support comes from post hoc studies; i.e. research that finds successful firms that have dynamic capabilities. A fourth grievance of Arend and Bromiley is the lack of coherent and logical proxies for measuring dynamic capabilities; there are too many measures of dynamic capabilities, which indicate that there are incoherent constructs. The fifth grievance of Arend and Bromiley (2009) is the lack of practical implications for dynamic capabilities.

Whilst Arend and Bromiley's (2009) criticisms have some merit, they do not take into account the entire body of work on dynamic capabilities and fail to consider that the theory is a young theory. Helfat and Peteraf (2009) offer a well thought out rebuttal to Arend and Bromiley (2009) that clearly acknowledges and addresses their concerns. They show that dynamic capabilities is a young theory that is just emerging from its conceptual stage; therefore, it will have some foundational issues to iron out. Helfat and Peteraf (2009) also refute the suggestion that there is weak empirical support. They point to several strong empirical studies (Helfat, 1997; Ingelgard et al., 2002; Zahara, Ireland, & Hitt, 2000), and also reiterate that because of its youth, dynamic capabilities should not be expected to have an established body of empirical work.

In short, dynamic capabilities has the underpinnings of a strong theory. First, it can show causality. For example, several of the studies discussed above show how dynamic capabilities can cause a firm to have more creative capacities (Eisenhardt & Tabrizi, 1995; Harreld et al., 2007; Majumdar, 2000). Second, it is measurable. For example, it can be measured through new product development (Drnevich & Kriauciunas, 2011), patents (Katila & Ahuja, 2002) and learning outcomes (Zollo & Winter, 2002). Third, dynamic capabilities has shown predictive powers. For example, studies have predicted that firms with learning capabilities can better contend with rapidly changing environments (Romme et al., 2010; Zollo & Winter, 2002). Furthermore, the importance of learning capabilities in certain settings has been disconfirmed (Kale & Singh, 2007), which shows that dynamic capabilities has the theoretical quality of being able to be falsified. Although dynamic capabilities has shown the underpinnings of a theory, it is

still far from robust. It is still in its nascent stage and lacks defined measures and constructs for small firms, especially for small life science ventures.

There is no perfect theory in management – whether the RBV, the five forces model, or transactions cost analysis. Dynamic capabilities is no exception. It has ill-defined constructs and measures and little empirical support to back it up. Although many of the criticisms are valid, there is potential for future research to address these. Moreover, it is one of the few theories that can properly account for rapidly changing environments. It also has a sound theoretical basis because it draws heavily on the RBV (Eisenhardt & Martin, 2000; Teece et al., 1997; Winter, 2003). Furthermore, Teece et. al. (1997) paths, positions and processes framework offers a way to tie the theory together. At the highest level firms are able to use their paths, positions and processes to create CAs (Teece, 1997; Trispas, 1997, Rothaermel, 2001). These are auxiliary assets needed in the commercialisation of a technology. CAs are often a large source of competitive advantage as they create unique competitive positions (Teece, 1986; Tripsas, 1997). The next section of this review delineates the literature on CAs.

COMPLEMENTARY ASSETS

This section is dedicated to further discussing one of the highest levels' outputs of dynamic capabilities – CAs. These are high level auxiliary assets and capabilities needed in the commercialisation of innovations (Teece, 2007). CAs are especially relevant to life science firms as these are needed to commercialise innovations in the field (Rothaermel, 2001a). This topic is also relevant to the present study because R&D has been viewed through a CAs lens (Gans et al., 2002; Teece, 1986). This section provides a description of CAs, overviews the empirical work on CAs and discusses the shortcoming of the CAs framework.

Description of CAs

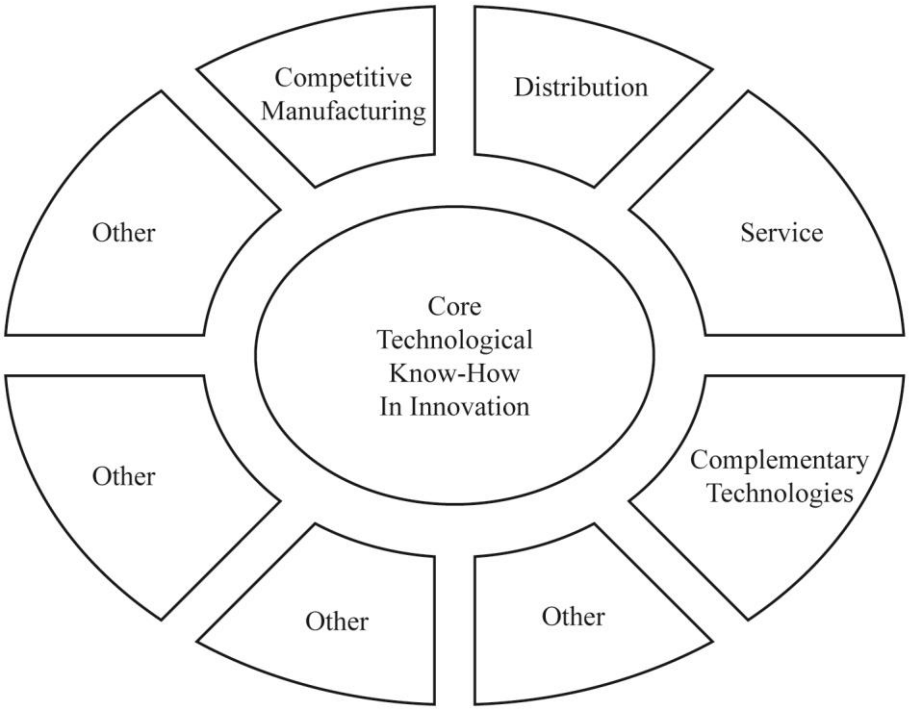
Teece (1986) formally introduced CAs as the auxiliary assets and capabilities needed to commercialise an innovation. Edvinsson and Sullivan (1996, p. 360) offer a slightly different definition specific to knowledge-based firms: '*the string of assets through which the technology must be processed in order to reach the customer'*. Teece (1986) further proposes three broad categories of CAs: 1) general CAs (GCAs) 2) specialised (SCAs) and 3) co-specialised complementary assets (CCAs). GCAs are generic assets needed in commercialisation that are easily purchased on the open market, for example, general shipping. If a firm can ship its goods through a company like UPS or Federal Express, then this is a GCA; the shipping is needed for commercialisation, but it is easily obtained on the free market. SCAs are similar to GCAs, but they cannot be obtained on the free market. They are assets with a unilateral dependence that are needed for commercialisation. An example of an SCA is service capabilities of a medical device firm. In many cases medical devices require specialised service capabilities to maintain the product, and if a firm is unable to service the device, then the device cannot be commercialised. In many cases medical device firms partner with specialised service firms to provide the specialised service for their medical device(s), which could be a unilateral dependence because the medical device has to have the specialised service capabilities to be commercially viable, but the service provider does not need the medical device firm to stay in business; they have other clients that could sustain their business. CCAs are assets that are mutually dependent on each other. An example of this is Microsoft and IBM in the early 1980's. In the beginning of Microsoft they needed IBM for the hardware platform to run their software, and IBM needed the Microsoft software platform for programs to make their hardware usable and desirable.

Figure 4 presents Teece's (1986) illustration of the CAs needed to commercialise an innovation. He identifies four areas that are usually involved with the commercialisation of an innovation: 1) competitive manufacturing, 2) distribution, 3) service and 4) complementary technologies. The illustration also includes 'other' boxes to represent CAs not encompassed in the four other areas, an example being

compliance capabilities for a pharmaceutical company. In many cases biopharmaceutical companies have to have specialised capabilities in meeting government regulation before their products can be sold (Hopkins & Nightingale, 2006). This illustration gives a good conceptualisation of the CAs needed in commercialisation.

The present research is specifically interested in R&D and financial resources, and as discussed earlier, R&D has been viewed through a CAs lens. It would be interesting for empirical work to explicitly see where R&D fits in within a CAs framework, as there is little research that has looked at this. Furthermore, finance has not been viewed through a CAs lens, but it would be interesting to see if it could be. Capital should not be viewed through such a lens, but the capabilities in raising capital could be. Conceptually they meet the definition of CA, auxiliary assets or capabilities needed in the commercialisation of an innovation (Teece, 1986); i.e. the capabilities to raise capital are auxiliary capabilities needed to fund the development of other assets.

FIGURE 4
CAs NEEDED IN COMMERCIALISATION



Source: Teece (1986, p. 289)

The ideas discussed above indicate that CAs is rooted in the RBV. Many researchers contend that capabilities are resources that can be used to build competitive advantages from (Barney & Hansen, 1994; Helfat & Peteraf, 2003; Mahoney & Pandian, 1992; Peteraf, 1993). It follows that SCAs/CCAs are resources that can be used to build competitive advantages; they meet the criteria of the RBV; valuable, rare, imperfectly imitable and non-substitutable (Barney, 1991). SCAs and CCAs are valuable because commercialisation cannot happen without them. By definition, they are rare because they are not easily purchased on the free market. They are inimitable because they are not easily reproduced. Lastly, they are non-substitutable, as little else can fill the void needed for the SCAs/CCAs. If a CA does not meet all of these requirements, then it is a GCA. Moreover, SCAs and CCAs are the product of the highest level of dynamic capabilities (Teece, 2007). Firms must be able to either create the CCAs and SCAs needed for the commercialisation of innovations or cooperate with other firms to obtain these assets (A. M. Arora & Ceccagnoli, 2006; Rothaermel, 2001a). This requires firms, both internally and externally, to constantly

manage their asset combinations and rearrange them to create the appropriate CCAs and SCAs needed to commercialise their innovations. Moreover, abnormally high profits are obtained when a firm creates a platform that other firms need as CCAs (Meyer, 1997; Yang & Jiang, 2006). For example, Microsoft created an operating system that other software firms needed to commercialise their software. This platform provided a source of competitive advantage that yielded massive profits for Microsoft.

The discussion above shows why CCAs and SCAs are at the pinnacle of the resource pyramid presented at the beginning of the chapter in Figure 1. They are the most refined resources needed in the commercialisation of innovations. Even though CCAs and SCAs offer possible insights into how firms obtain hyper-returns, there is little research that looks at the topic. The next subsection looks into the reasons for this.

Empirical Work on CAs

Although Teece's (1986) seminal work on CAs is well-noted, there is relatively little empirical work to support it. Numerous studies touch on CAs, but few directly examine it. This section highlights the noted empirical studies to date.

Moorman and Slotegraaf (1999) looked at the CAs needed for product commercialisation. Their study identifies and tests a model of complementary capabilities. The model emphasises the interaction between information and capabilities (namely marketing, technical, R&D and distribution) of the firm. It suggests that flexibility is imperative to responding to new information; i.e. firms' capabilities must be flexible and work in conjunction in developing the assets needed for product commercialisation. In a similar study, Mitchell (1992) looked at the role of CAs in the medical diagnostic imaging industry. His research indicates that the SCAs of sales and service buffer, to a point, incumbents from new, more innovative competitors. Similarly, Trispas (1997) analysed the typesetter industry between 1886 and 1990 and found that SCAs played a critical role in buffering incumbents from new competition. The new and often more innovative firms lacked specialised sales and service capabilities that kept them from overtaking the incumbents that possessed these SCAs. The buffering property of SCAs is also backed up by Rosenbloom and Christensen (1994), who suggest firms have a whole value network that has to change in order for a new firm with a new innovation to enter the market.

Much of the recent work on CAs focuses on alliances and networks (e.g, Eckhardt & Shane, 2010; Motohashi, 2008; Rothaermel, 2001a; Rothaermel, 2001b). Rothaermel (2001b) examines the role of inter-firm alliances and CAs in the biopharmaceutical industry, suggesting that incumbent firms enhance their industry position by using their established CAs to commercialise the innovations of new entrants. The study also indicates that often incumbents have well-established positions and SCAs, but often are not as innovative as the new entrants. In addition, the study finds new entrants lack the SCAs that established firms have, such as specialised manufacturing. Thus it is often better for the incumbent and the new entrant to form alliances to fully exploit innovations and SCAs. Rothaermel (2001a) came to similar conclusions from another 2001 study of CAs in the biotechnology industry. This study differed from his other 2001 study in that it focused on the alliances of large biotechnology companies, finding that firms focusing on exploiting CAs outperform firms focusing on creating new innovations. The study also indicates that the biotechnology industry focuses on establishing mutually beneficial CAs. Interestingly, he did not follow Teece (1986) in calling these CCAs because, in his view, it was too difficult to discern between SCAs and CCAs and that the difference was irrelevant for the study. Similarly, Rothaermel (2001b) felt the real importance is whether an asset was generic or specialised. In a similar vein, Rothaermel and Hill (2005) justifies using SCAs and CCAs interchangeably because it was not critical to the study. In this study they also conjecture that it is very difficult to a draw a distinction between CCAs and SCAs. Several other studies follow the same protocol in not distinguishing between SCAs and CCAs (Arora & Ceccagnoli, 2006; Christmann, 2000; Tripsas, 1997); instead calling any specialised assets, whether and SCA or CCA, an SCA. Although the distinction between CCAs and SCAs

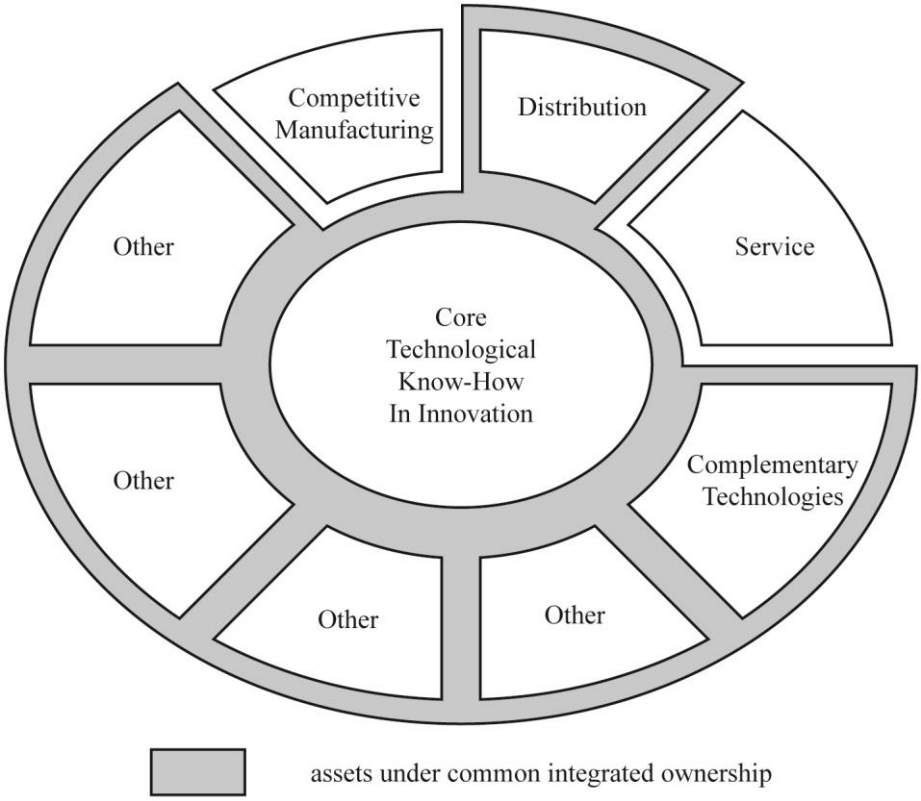
was not critical to these studies, distinguishing them would have improved the studies by magnifying the importance of bilateral alliances.

Many others have taken a similar approach as Rothaermel (2001, 2001a, 2005) and looked at the role of alliances in the creation of CAs. Harrison et al. (2001) notes the importance of resource complementarities in the formation of alliances. According to this study, synergies are created between two firms that mutually create assets that are needed for commercialisation. In a similar vein, Teece (2003) notes the importance of CAs that are created through alliances in the commercialisation of knowledge-based innovations. Several others look at the importance that alliances play in establishing CAs for start-up firms. Most notably, Baum et al. (2000) suggest that start-ups benefit themselves by early along in the venture aligning themselves with alliances, integrating themselves in efficient alliances and aligning themselves with rivals when the opportunity for learning outweighs the risks of working with a competitor. Hopkins and Nightingale (2006) put forward that alliances offer a CA in the form of risk reduction. Their study looks at the risk-spreading of biotechnology firms and concludes that firms can reduce risk by creating alliances with firms that have specialised risk management capabilities.

It is interesting that these studies note the importance of alliances to life science firms in creating CAs. However, studies on CAs and alliances do not examine how alliances interact to create the CA of R&D. The life science literature discussed in chapter two emphasised the importance of alliances to R&D, and the present chapter put forth R&D as a possible category of CA (Lowe & Taylor, 1998), yet studies have not thoroughly probed whether or not alliances lead to the CA of R&D. This thesis is specifically interested in R&D and probes whether partnerships lead to the development of CAs.

The discussion in the two paragraphs above indicates that cooperation is important. Even firms pursuing competitive strategies will most likely have to have some degree of cooperation with other firms; i.e. suppliers, competitors or customers. Teece (1986) highlighted this in his conceptualisation in figure 5 below. This illustration shows that many areas (shaded) are jointly controlled through alliances (cooperative strategies), whilst other areas are completely controlled by the innovating firm (competitive strategy). Although this figure gives a good conceptualisation of the fact that often cooperative and competitive strategies are pursued at the same time, it fails to consider that individual CAs can have elements of cooperation and competition. For example, R&D can mostly be undertaken by an individual firm, but the individual firm may have partners for select R&D functions.

FIGURE 5
CAs UNDER JOINT CONTROL



Teece (1986, p. 291)

The largest problem plaguing the empirical work on CAs is the lack of defined measures. The studies on CAs use many different measures. Whilst it is good to have different measures to look at the theory from different perspectives, consistent measures are needed for comparative purposes (Johnson & Onwuegbuzie, 2004). Furthermore, the lack of consistent measures also raises reliability and validity concerns for the framework. Gans and Hsu (2002) developed five-point Likert scales to measure the importance and degree of specialisation of CAs. Their scales are the most accurate measures offered to date and are adapted by several others (Parmigiani & Mitchell, 2009; Pries & Guild, 2007, 2010). Other than the measurements offered by Gans and Hsu (2002), there have been few other reliable and valid independent variable measures offered to date. The dependent measures are not as problematic in CAs because these measures are adapted from studies in related areas, such as firm growth, the RBV, and transactions costs.

CAs and Patents

Patents are an important resource that influences CAs. Arora and Ceccagnoli (2006) looked at the effect that patents have on CAs and found that firms with weaker patent protection rely more on stronger CAs to commercialise their products. They also find that firms with stronger patents rely more on licensing to commercialise their goods; because their value added activities are in the patent and not the SCAs/CCAs. This work has been supported by several others (Colombo, Grilli, & Piva, 2006; Deeds et al., 2000; J. S. Gans & S. Stern, 2003). Grauff et al. (2003) examines the effect of intellectual property in the mergers and acquisitions of agricultural biotechnology firms. The results from their study indicate that firms merge with each other to align their complementary intellectual property portfolios. In a similar vein, Edvinsson and Sullivan (1996) suggest that patents themselves do not fully protect technology. Instead they contend that SCAs/CCAs are needed to protect novel innovation. Though patents protect

innovations as a whole, some important processes or ideas cannot always be patented. Furthermore, processes and ideas can be exposed in the licensing process when information is shared; the exposed information could be used to create competing innovations (Lanjouw & Schankerman, 2001). Difficult to obtain, SCAs/CCAs offer protection that patents cannot because they protect knowledge and make it so other firms cannot commercialise a similar innovation. Edvinsson and Sullivan (1996) emphasise this in their model of innovation, which is based off of four major elements: human capital, structural capital, complementary assets and intellectual property.

Size is another mitigating factor in the development of CAs needed to commercialise patents. Arora and Fosfuri (2003) offer a model of rent vs. revenue for patents. This model looks at what factors drive a firm to either license their innovations or to commercialise their innovations themselves. One mitigating factor is the size of the firm. Small firms often do not have the resources and capabilities to commercialise an innovation; instead they often focus on one particular process such as R&D. Because of the lack of assets and capabilities to commercialise an innovation, small firms often license their ideas; even though the rents they earn are less than if they commercialised the products themselves (Pries and Guild, 2010). Conversely, large firms that develop innovations often control the upstream and downstream activities. Not only does this allow them to earn higher rents from their innovations, but it also shields them from competition. Furthermore, controlling the downstream activities also allows firms to reduce transactions costs (Heller & Eisenberg, 1998). Each company that is involved in commercialisation adds layers of transactions; especially in the case of patent licenses where contracts consume substantial time and resources in developing (Hennart, 1988; Oxley, 1997).

From the discussion above it seems natural that large firms should control the upstream and downstream activities in developing an innovation. However, an increasing percentage of downstream research comes from small firms (Jones, 1999; Nicholas, Ledwith, & Perks, 2011; Van Beuzekom & Arundel, 2009). For this reason large firms are working with small firms to create CCAs/SCAs to commercialise the innovations conceived by small firms. The competition for the most novel ideas is intense and has led to large firms investing in smaller R&D firms that have ideas with grand potential (Arora & Gambardella, 1990). This investment helps secure the innovation rights for the larger company.

It is surprising that small firms are often the source of knowledge and innovation needed for the development of CCAs and SCAs, especially in capitally intensive industries such as the life science industry. This phenomenon is credited to two things: the spill-over effect from universities and the fact that small firms are more flexible and can more quickly respond to changing technological environments. There is a clear correlation between the spill-over of innovations from universities to industry, especially to small firms. Studies indicate that in areas with top-tier research universities, there are an inordinately high number of innovative start-ups (Anselin, Varga, & Acs, 1997; Jaffe, Trajtenberg, & Fogarty, 2000; Jaffe et al., 1993). The ideas for innovations are often birthed in universities and then either sold to firms located near the university or a spin off firm is created near the university. This is especially prevalent in life science innovations where scientists like to stay on the university's faculty whilst still pursuing the opportunity to commercialise innovations (Audretsch & Stephan, 1999; Zucker et al., 2002). The second reason attributed to the innovativeness of small firms is flexibility. Small firms have the advantage of newness and are not entrenched in bureaucratic routines the way large, established firms are (Autio et al., 2000). Acs and Audretsch (1987) suggest that small firms have an advantage in innovating in industries, such as life science, that are technologically intensive. Furthermore, the literature on absorptive capacity suggests that new firms often have an advantage in recognising opportunities (Cockburn & Henderson, 1998a; Stock, Greis, & Fischer, 2001). In short, small firms are often innovative because of their university ties and the fact that they are flexible and dynamic.

An Unexplored Framework

Perhaps the reason so many researchers avoid the explicit use of the term CAs is that it is so elusive to define and measure. Teece (1986) describes CAs as support assets or capabilities needed for the commercialisation of an innovation. Whilst in theory this seems clear, in practice it is much more difficult to pin down, especially for SCAs and CCAs. Take the example of manufacturing capabilities in the pharmaceutical industry: if a firm has truly unique manufacturing capabilities, then this would be considered an SCA or CCA. However, if a firm could contract the manufacturing of a drug out, would this be an SCA or CCA? If the contract manufacturer has truly unique capabilities and formed a partnership with a pharmaceutical firm, and both were reliant on each other, then this would be a CCA. But if the R&D firm in this example could set this alliance up with a few different manufacturing firms that had unique and specialised production capabilities, would this be an SCA or CCA? As this example shows, there is clearly a grey area in defining CAs, especially in discerning amongst GCAs, SCAs and CCAs. Moreover, measuring CAs has proven even more difficult. For example, Rothaermel (2001a) attempted to measure complementary alliances based on secondary data of biopharmaceutical alliances and new product development. The results indicate that incumbents prefer alliances to leverage CAs over those to create new innovations. However, the analysis fails to show how a coded variable based on secondary data can differentiate between an alliance for the purposes of obtaining a CA and an alliance for creating new innovations. This is not to criticise this research, as it was an excellent study that provided much needed insight on CAs; rather this illustrates how difficult it is to measure CAs. One way to overcome these difficulties is to capture the essence of CAs in survey and interview studies. Qualitative work is especially needed to unearth insights on the connections between CAs and firm growth. These insights are needed to create valid and reliable measures.

Appendix 2 below outlines the major empirical work done on CAs. This table is much leaner than the table presented earlier in the chapter on the empirical work on dynamic capabilities. CAs lacks the conceptual and empirical robustness of a major framework. However, there are several strong studies that have conceptually laid the ground work for the framework (e.g., Eckhardt & Shane, 2010; Edvinsson & Sullivan, 1996; Teece, 1986), and several other studies that provide an empirical base for it (e.g, Rothaermel & Hill, 2005; Tripsas, 1997). More studies in the fields of strategic management, internationalisation, entrepreneurship and marketing need to study the role of CAs in firm growth.

Year over year a higher percentage of firms in developed countries are technology-based firms (Conway, Janod, & Nicoletti, 2005). Technology firms require ancillary assets to commercialise their innovations (D. J. Teece, 1986), yet the management literature has failed to properly investigate the topic. Stieglitz and Heine (2007) make a strong argument on the merits of using CAs in the study of strategic management. Specifically they conjecture that CAs are an important part of the strategic direction of firms and need to be factored in. They also suggest that CAs should be centrally coordinated by management, and that controlling CAs on an ad hoc basis to the firm does not work because the whole firm must be integrated with the CAs, a key point that other studies on the topic have missed. Another area that is specifically lacking, especially with regard to new ventures, is how firms create CAs. Many of the studies discussed above note the importance of alliances in ascertaining key CAs, but not all CAs are accessed through partners. Little work investigates how firms internally develop CAs. Moreover, there are few studies that examine the interface between creating CAs and finance; i.e. how CAs are capitalised, which is especially relevant for new ventures that are resource constrained. Thus the question remains: how do young firms overcome financial restraints to create or acquire CAs?

CAs is an offshoot of dynamic capabilities, and as the name suggests, it has potential to complement research on dynamic capabilities. CAs offers unique insights into the auxiliary assets and capabilities needed in the commercialisation of innovations, especially in high tech innovations. It has sound theoretical backing, but unfortunately lost momentum shortly after it was introduced. However, as of late it has started to regain momentum and is being led by Frank Roethermel who has produced several influential pieces (2001a, 2001b, 2005) in the last ten years. Several others have also joined him (Arora & Ceccagnoli, 2006; Ceccagnoli, Graham, Higgins, & Lee, 2010; Colombo et al., 2006; Helfat & Peteraf, 2003; Hopkins & Nightingale, 2006; Stieglitz & Heine, 2007; Swink & Nair, 2007), and the topic should see great progress in the next ten years. CAs has great research potential in many different fields, especially those interested in high tech firms.

This section discussed several shortcomings of CAs with two notable ones being (1) it is difficult to empirically define and measure and (2) it lacks a clear framework. This makes it difficult to generate and test hypotheses and is why there is not a more robust body of empirical studies that have tested CAs. However, CAs is an off shoot of dynamic capabilities, which allows it to be examined from a dynamic capabilities framework; i.e. probe the paths, positions and processes that lead the development of CAs.

CONCLUSION

It is apparent from this review that Penrose's (1959) ideas on the importance of resources to firm growth are alive and well. Her ideas evolved into the RBV and are now transforming into the theory of dynamic capabilities. Findings from the review suggest that dynamic capabilities is a unique theory rooted in the RBV that has particular potential for use in the study of high technology firms. This review also suggests that CAs is a complementary framework rooted in dynamic capabilities. CAs offers unique insights on the auxiliary assets and capabilities that are needed to commercialise innovations. It is an especially useful framework on firm growth because it allows research to look at growth from several different angles.

This paper has highlighted the evolution of the resource-based literature: from Penrose to CAs. There is no paper of note that has traced this evolution. Furthermore, the last notable review on the resource based literature was Sapienza et al. (2006), thus, the present paper is an important update on the current state of the resource-based literature. The present paper is also important because it puts forth that CAs is latest evolutionary step of the resource-based view.

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APPENDIX 1
EMPIRICAL STUDIES ON DYNAMIC CAPABILITIES

Study	Measurement	Research focus	Findings
*1. Van de Ven and Polley (1992)	Single biomedical innovation over a five year period; in-depth case study with multiple sources and on-going observation	Examined the process of trial and error learning in technological innovations by a joint venture created to commercialize products.	– Observed greater escalation of commitment and other types of non-rational behaviour than implied in the learning literature – Suggested the following to increase adaptation ability: • separate planning from resource funding • limit 'impression management' opportunities • foster frank communication across departments and levels.
2. Eisenhardt and Tabrizi (1995)	36 Computer-related firms, (72 projects); case studies – multi-respondents per project	Examined effects of planning, CAD tools, teams, supplier involvement, reward, and time schedules on product development time.	– Found planning and CAD tools *increase* the time to develop new products – Cross-functional teams, frequent iterations, leader power, and trial-and-error learning decrease development time.
3. McGrath (McGrath, 1995)	23 Financial services firms; over 200 interviews	Exploratory research to see how firms process and learn from poor outcomes in internal corporate venturing.	– Noted three processes needed to learn from disappointments: • recognition of failure (*measurement*, *involvement*, *communication* of results) • interpretation of results into a business model that can be tested • action taken to change routines.
4. Helfat (1997)	The 26 largest energy firms over extended period of time; historical and secondary data	Examined if success of responses to changes in external conditions depends on existing stocks of complementary know-how and assets.	– Firms with larger stocks of complementary technological knowledge and physical assets experienced greater increase in capabilities. – Yet, such increased capabilities could not compensate for the large drop in real oil prices.
5. Brown and Eisenhardt (1997)	6 firms in computer industry (41 projects); case studies	Examined the ability of firms to change their competences continuously in response to high velocity environments.	– Reject notion of punctuated equilibrium and event-based approaches in favour of time-paced responses. Learning and dynamic capability creation based on: • well-defined managerial responsibilities and project priorities • extensive communication • frequent low-cost experiments and iterations.
6. Moorman and Miner (1998)	One electronics instruments firm; one food products firm (107 action events over nine months); survey data on selected events	Examined the effects environmental turbulence, improvisation, and organization memory on product and process efficiency/effectiveness.	– Turbulence has a weak positive effect on use of improvisation. – When turbulence is low, improvisation has negative effect on effectiveness; when turbulence is high, the effect is positive. – Organization memory has a negative effect on improvisation. – However, organization memory significantly improves positive effects of improvisation on all process and product outcomes.
7. Kazanjian and Rao (1999)	225 Computer-related companies; survey data in two waves Hypothesis tests on survey data	Examined factors influencing engineering capability institutionalization in firms highly dependent on this expertise.	– Found managerial advocacy key positive factor. – Found mixed results with regard to CEO background. – Found institutionalization more likely with smaller TMTs. – Found no effects of formalization or centralization..
8. Bosch et al. (1999)	Publishing firms; illustration of two cases	Focused on how organization form and combinative capabilities mediate effects of prior related knowledge on absorptive capacity.	– Definitive conclusions hard to draw, but arguments regarding organization forms are • Functional form is + for efficiency, - for flexibility, - for speed. • Divisional form is - for efficiency, + for flexibility, + for speed. • Matrix form is - for efficiency + for flexibility, + for speed
9. Majumdar (2000)	39 telecommunication firms over 16 yrs; secondary data	Examined effects of structural changes in the environment on resource accumulation, configuration, and utilization capabilities of firms.	-Concludes that contrary to popular beliefs, larger more stable firms can indeed transform their capabilities in the face of overwhelming structural changes to the industry.

10. Autio et al. (2000)	59 electronics firms; panel survey data over four-year period, some validation from repeat surveys and secondary sources Hypothesis testing based on survey responses	Examined the effects of early inter-nationalization on the prospects of smaller firms' growth. Argued that such firms may possess learning advantages over older firms.	– Found that internationalization at an early age was associated with greater growth both domestically and internationally. – Found product imitability to be positively rather than negatively associated with growth. – Found knowledge intensity positively related to growth.
*11. Madhok and Osegowitsch (2000)	Data on international alliances, joint ventures, licensing, acquisitions and new Greenfield subsidiaries of European and US biotechnology firms Hypothesis testing based on secondary data	Examined the cross national flow of biotechnology innovations between the US and Europe.	-Found that initially biotechnology innovation was a one way flow from the US to Europe. -Found that as Europe developed capabilities, innovation became a two-way flow
*12. Deeds et al. (2000)	94 publicly held biotechnology firms Hypothesis testing based on secondary data	Examined the effects of technological and management skills on new product development.	-Found that location near research based universities is key to developing scientific dynamic capabilities. -Found that top scientists are more effective in a research role than in a top management role.
13. Zahra et al. (2000)	321 high technolog y firms (from 12 different sectors); survey data with validation from second respondents and secondary data Hypothesis testing based on survey responses	Examined the effects of international diversity and mode of market entry on technological learning and performance of high technology firms.	– Found that international diversity had positive effects on the breadth, depth and speed of technological learning in new internationalizing high technology ventures. – Found that knowledge integration significantly enhanced the positive effects of diversity on the breadth, depth and speed of technological learning. - Found that modes of entry also significantly affected breadth, depth and speed of learning. – Found a positive relationship between international diversity and performance.
14. Abuja and Lambert (2001)	97 global chemical; secondary data, especially patent citations	Examined how large corporations create breakthrough inventions and how exploration of novel, emerging, and pioneering technology helps them overcome competency traps.	– Found inverted-U shaped relationship of exploration of novel and emerging technologies with creation of breakthrough invention. – Found positive relationship of exploration of pioneering technologies with creation of breakthrough invention. – Concluded that continual activity and experimentation are needed for firms to renew and reconfigure capabilities.
*15. Engelhard et al. (2002)	Action research: interviews with 26 different individuals involved with R&D at three different pharmacy firms.	Examined organizational learning techniques in the creation of actionable knowledge.	-Suggests that the learning capability of a firm has to be dynamic in order to create complex knowledge. -Suggests knowledge assessment is an important capability.
16. Katila and Abuja (2002)	124 Robotics firms; secondary data, especially patent citations Hypothesis testing based on secondary data	Examined the effects of search depth and search breadth on a firm's ability to create change in product introduction.	– Found a positive relationship between search breadth and depth on new product introduction; but beyond a certain level, additional depth begins to reduce new product introduction. – Concluded that exploitation is a broader concept and more beneficial than previously believed.
*17. Rothaermel Hess (2007)	A cross national sample of 35 pharmaceutical firms' alliances and innovation output; data collected from secondary sources of information covering 24 years Hypothesis testing based on secondary data	Examined the antecedents of dynamic capabilities looking at the interaction of individual, firm and network antecedents.	-Found that the 3 levels of antecedents are not always complementary. -Often human capital (individual level) can substitute for the other two levels (firm and network)

18. Harreld and O'Reilly (2007)	A case study on IBM. Data collected from secondary data.	Examined the success of IBM from a dynamic capabilities perspective.	-Found IBM has been able to thrive largely based on the ability to reorganize itself in the face of rapidly changing technology and competition environments .
19. Kale and Singh (2007)	175 computer, telecommunications, pharmaceutical, chemical and electronics firms that have been involved in alliances Hypothesis testing based on survey responses	Examined the process of learning in alliances.	-Found that learning that involves articulation, codification, sharing, and internalization of alliance management know-how leads to superior performance.
20. Macher and Mowery (2009)	93 manufacturing processes in 36 different manufacturing facilities from 32 different semiconductor firms from 1995 to 2001.The sample consisted of firms from the US, the EU, Japan, Korea and Taiwan Hypothesis testing based on secondary data	Examined the role of R&D and learning on capabilities .	-Found support for the arguments of Teece et al. (1997), Eisenhardt and Martin (2000), Solo and Winter (2002) and Winter (2003) that managing and reconfiguring capabilities is crucial in high-technology industries. -Found that deliberate learning is important to creating capabilities. -Found 'learning before doing' is the most effective approach.
*21. Chiaroni et al. (2009)	Two step (1) an interview panel of 20 industry experts (2) An analysis of the open innovation modes used by 20 large pharmaceutical companies	Examined the organizational modes of open innovation and how these effect drug development.	-Found that the characteristics of the biotech industry are mitigating variables in the implementation of open innovation.
22. Newey and Zahra (Newey & Zahra, 2009)	40 interviews with multi informants from two firm case analysis and comparison	Examined how dynamic capabilities react to changes within the individual firm.	-Found that firms build absorptive capacity in value networks whilst they are developing new products. -Found that learning captured at the product planning level is the most beneficial.
23. McKelvie and Davidsson (2009)	Sample of 108 Swedish new (<10years) SMEs from various industries Hypothesis testing based on survey responses	Examined the effect the founder human capital, access to employee human capital, access to technological expertise, access to other specific expertise and access to two types of tangible resources had on the development of dynamic capabilities.	-Found that resources and changes to resources are important to forming dynamic capabilities. -Found changes in resources have more influence on the development of dynamic capabilities then the stock of resources does. -Suggested that the firm is a dynamic stock of resources rather than a static stock.
*24. Narayanan et al. (2009)	Multiple interviews with several layers of management at one pharmaceutical firm	Examined the cognitive orientations of key personnel, managerial action within the firm and the firm's internal and external contexts and how these effected the development of capabilities.	-Suggests that key personnel have a significant impact on the development of capabilities; not because their actions were inimitable but because of their persistence in developing the capabilities led the dynamic capabilities. -Found that external contingencies have a major impact on the development of dynamic capabilities.
25. Romme, Zollo and Berends (2010)	Experiment simulation of how executives develop knowledge routines in the face of different environmental variables Hypothesis testing based on experiment results	Examined how firms respond to various factors to develop knowledge.	-Suggests that the impact of deliberate learning on dynamic capability is non-linear, complex, and in some instances counter-intuitive.

Source: Adaptation and Expansion of Zahra et al. (2006)

APPENDIX 2
KEY CAs STUDIES

Author	Area of CA Looked At	Type Of Study	Results
Teece (1986)	Introduction and conceptualization of complementary assets	Conceptual Paper	-Introduces GCAs, SCAs, and CCAs
Edvinsson and Sullivan (1996)	Conceptual model of intellectual capital	Conceptual Paper	-Introduces a model of intellectual capital based on human capital, structural capital, complementary business assets, and intellectual property
Tripsas (1997)	CAs as a buffer to competition	Hypothesis testing based on historical data of the typesetter industry	-Firms can buffer themselves from new more innovative firms if they have well established specialised CAs
Shane (2001)	Developed and tested a model of firm formation based on four variables: the age of the technical field, effectiveness of patents, the tendency of market segmentation, and the importance of CAs	Took 1,397 patents from MIT and looked at how many of these led to firm foundation.	-Found that firm foundation off of university patents is more likely when technical fields are young, markets are segmented, patents are more effective, and marketing CAs are less important
*Rothaermel (2001a)	Alliance formation for the purposes of developing CAs	Testing based on secondary data of Alliances of large international biopharmaceutical firms	-Incumbents that focus on developing networks to exploit CA outperform firms which focus on networks to develop innovation
*Rothaermel (2001b)	Alliances formation for the purposes of developing CAs	Testing of secondary data of alliances of large international biopharmaceutical firms. Focuses on incumbents alliances with new firms to access new technologies.	It is better for firms to focus on developing SCAs and CCAs than on further developing technology.
*Rothaermel (2002)	Alliance formation. How firms go about forming alliances	Testing secondary data of 325 new biotechnology firm alliances	New biotech attractiveness is related to its new product development.
Funk (2003)	Looked at how firms can exploit information advantages to gain preferential access to CAs	Examining five major Japanese cell phone producers. Collected data through 17 interviews.	Found that firms that had an information advantage over the competition were able to gain preferential treatment to valuable CAs.
*Graff et al. (2003)	Tests an overarching hypothesis that the biotech agriculture seed industry has changed because of advanced CAs	Taking two sets of mergers and alliance data on agriculture biotech firms: one set of 60 and one set of 46.	Found that the agriculture biotech industry has reorganized itself through mergers and acquisitions to exploit CAs.
West (2003)	Looks into the optimal combination of open and closed source code in software platforms	Uingd four major software companies as case studies: Apple, IBM, SUN, and Microsoft.	Suggested that hybrid strategies of open and closed source will provide the highest returns. This strategy will enable other firms to use the platforms as CCAs.

*Hopkins and Nightingale (2006)	Risk management as a complementary asset	Examining four biotechnology case studies.	Found that risk management is a useful SCA/CCA. Firms should align themselves with partners that have complementing risk management capabilities.
Swink and Nair (2007)	Tested the theory of complementarities on manufacturing design and advanced technologies	A survey of 224 technical manufacturing firms	Found that manufacturing design is important complementarily to advanced manufacturing.
Stieglitz and Heine (2007)	The role of CAs in strategy	Conceptual	Suggested that CAs are an important factor in strategy. Suggested that top managers must properly account for CAs and also create or secure CAs needed to be competitive. Suggested that CAs are important resources that fit into the RBV framework.
Motohashi (2008)	Strategic use of patents by Japanese firms	Secondary data testing of Japanese patents	Indicated that smaller firms with undeveloped CAs have a higher propensity to license than firms with developed CAs. Indicated that large firms tend to be the licensor to obtain innovations so that they can exploit their developed CAs.
Parmigiani and Mitchell (2009)	Source of complementary manufacturing assets	A survey of 193 US manufacturing firm.	Found that firms often concurrently source manufacturing assets from several sources. Noted that knowledge is a key factor on the source of manufacturing assets. Indicated that experience firms are more apt to concurrently source than inexperienced firms.
Eckhardt and Shane (2010)	Technological innovation and entrepreneurial activity	Secondary data on 201 industries over a 15 year period	Found that technical innovation is an important driver to entrepreneurship. Discovered that CAs are not a big restraint to the dissemination of innovation.
*Ceccagnoli et al. (2010)	The role of CAs in technology outsourcing	Secondary data from the pharmaceutical industry	Found that firms with more CCAs outsource less of their technology. Indicated that increased transactions costs can stimulate the demand for technology from external sources.

Source: Author