A Framework for Understanding Emerging Industries

Abstract

The emergence of new industries is a complex process, but it is important due to the potential for the growth of new firms and jobs and economic development. However, to date this process has been examined largely from specific disciplinary perspectives. This paper defines emerging industries, presents an inter-disciplinary framework, and shows the interaction, co-evolution, and synchronization of important elements that underlie emerging industries. These elements are technology, markets, firms, investment, government, production, and supply networks, and understanding the systemic nature of their interaction reveals the necessity of the alignment of these elements for industries to emerge. The paper presents emerging industry definitions and a review of literature on the elements that make up the paper's framework and combines disciplinary work to show the interaction of important elements. The paper also presents the emerging electric vehicle, solar photovoltaic, and biofuels industries as examples showing the co-evolution of elements and how synchronization has enabled these industries to emerge and grow. The paper offers inventors, firms, investors, and policy-makers an integrated perspective on the phenomena underpinning the industry emergence process. It highlights the obstacles and uncertainty of industry emergence in general and in particular for three exemplar emerging industries. The paper draws attention to the need to consider and attempt to influence the synchronization of a range of elements in order to commercialize a technological innovation. By identifying the misalignment of elements it is possible to target actions most needed to move a particular industry forward.

Key Words: Emerging Industries; Technology; Innovation; Systems

1.0 Introduction

Technology commercialization and the subsequent emergence of new industries have captured the attention of investors, firms, and nations because of the prospects they offer for commercial leadership, jobs, and wealth (e.g. Forbes and Kirsch, 2010; Hung and Chu, 2006; Van de Ven, 1993). However, emerging industries are not readily understood, influenced, or realized due to their dynamic, evolving nature, and the systemic influence of multiple and concurrent actors and phenomena (Musiolik and Markard, 2011; Forbes and Kirsch, 2010). The process of emergence has been studied from a wide range of perspectives, (e.g. Navis and Glynn, 2010; Patrucco, 2005; Adner and Levinthal, 2002; Aldrich and Fiol, 2007), but insights have frequently been disaggregated by disciplinary and industry focus (Forbes and Kirsch, 2010; Tushman, 2004; Bond and Houston, 2003). The need to integrate several perspectives has been recognised (e.g. Chocteau et al, 2011; Dass and Fox, 2011; Forbes and Kirsch, 2010; Malerba, 2006; Nelson and Winter, 1982), though this frequently remains within disciplinary boundaries. It is our contention that this integration should be expanded to incorporate a wider range of significant elements and that a focus on the interactions between those elements can usefully inform the analysis of and engagement with emerging industries.

This paper offers a framework for understanding emerging industries. This framework incorporates critical elements that represent parts of a wider system, each of which is interdependent and co-evolving. The approach we use in this paper is as follows: first we define emerging industries, second we draw on a broad, multi-disciplinary literature to present our framework of elements for explaining how industries emerge, third we present several of the important interactions between our chosen elements, and we use currently emerging industries, i.e. electric vehicles, solar photovoltaics, and biofuels to illustrate the interaction and interdependence of the elements, fourth we present how the synchronization of the elements may be necessary for an industry to emerge, and we close with conclusions and implications for inventors, firms, investors, and policy-makers. The next section defines emerging industries to set the context for the framework and outlines existing models of industry growth that can inform our exploration of emerging industries.

2.0 Emerging Industries

According to Aldrich and Fiol, "New industries emerge when entrepreneurs succeed in mobilizing resources in response to perceived opportunities." (1994, p. 647). More specifically, for technology-based industries, of the type to be considered here, the emergence of an industry can be seen as a process that is "based on a technological innovation meeting a new or existing customer need" (Calori, 1990). Emerging industries are said to be characterized by 'novel and coherent structures, patterns and properties driving the process of self-organization in complex systems' (Goldstein, 1999), and are described as 'newly formed or re-formed industries that have been created by technological innovations, shifts in relative cost relationships, emergence of new customer needs, or other economic and sociological changes that elevate a new product or service to the level of a potentially viable business opportunity' (Porter, 1980). In addition, influential actors initiate underlying processes that create markets, and these markets form industries when firms and other actors interact (Moran and Ghoshal, 1999). We combine these concepts and define industry emergence as the evolution of a system of elements shaping, and shaped by, technological innovation, the strategic behaviour of firms, the structure of markets and industries, the influence of institutions, and their interactions. We use this definition to guide our development of a framework and our understanding of the elements that drive the growth of new industries. In the next section we review models of industry growth and present a framework drawing together critical elements, interactions, and alignment between which we will go on to explore with the help of examples of emerging industries.

3.0 A Framework for Understanding Emerging Industries

3.1 Models of Industry Emergence

Explanations based on a single or a few factors and discipline-specific explanations offer useful, though partial, insight into the emergence and growth of industries. Klepper and Graddy (1990) acknowledge that their models are partial representations of the systems in which they are interested, assigning unexplained variations between cases as being due to "...exogenous factors that differ across industries that affect the pace and severity of the evolutionary process." (p.37). Malerba (2006) notes the difficulty of modelling demand

dynamics, firm dynamics, and technology dynamics simultaneously, and argues that the system cannot be understood from a single perspective.

Some models attempt to address these challenges by incorporating a wider range of additional agents and factors. The 'innovation systems' concept described by Jacobson and Bergek (2004), and others (Bergek et al, 2008; Salmenkaita and Salo, 2002); frames the multi-industry economy in the context of institutions and their interactions. This approach offers useful insight about systems, but its focus is on the economy rather than the industry and its emergence and evolution and also tends to be somewhat static. Other approaches adopt a more dynamic perspective. Spencer et al. (2005) see industry evolution as a process that involves the co-development of technology and institutions via repeated interactions among a range of industry participants. They offer a framework that shows how government and culture can help, hinder, or avoid doing harm to firms engaged in new industry creation. However, their approach is narrow, focusing primarily on government and culture.

The life-cycle literature also contributes to our understanding of the patterns of industry emergence. This literature presents how new industrial systems evolve from basic research to a technical solution in a progression often referred to as an industry, or product life-cycle (Grant, 2010; Jacobsson and Bergek, 2004; Klepper, 1997). A number of generic patterns of evolution have been proposed. Abernathy and Utterback (1978) define three phases of industry evolution: the "fluid", "transitional" and "specific" phases. Klepper and Graddy (1990) adopt a similar model with their stages 1, 2 and 3. Grant (2010) offers an industry development model using introduction and growth as equivalents to Utterback's (1994) fluid and transitional phases. Klepper (1997) provides a summary of these and other versions proposed by Williamson (1975) and Drew (1987):

> "Three stages of evolution are distinguished. In the initial, exploratory or embryonic stage, market volume is low, uncertainty is high, the product design is primitive, and unspecialized machinery is used to manufacture the product. Many firms enter and competition based on product innovation is intense. In the second, intermediate or growth stage, output growth is high, the design of the product begins to stabilize, product innovation declines, and the production process becomes more refined as specialized machinery is substituted for labour. Entry slows and a shakeout of producers occurs. Stage three, the mature stage, corresponds to a mature market. Output growth slows, entry declines further, market shares stabilize, innovations are less significant, and management, marketing, and manufacturing techniques become more refined" (p.148)

Moore (1996) proposes similar stages in the development of a "business ecosystem": "pioneering", "expansion", and "authority". Moore adds a fourth stage of "renewal" or "death", as do others (e.g. Grant, 2010), but this is not part of the emergence phase. Nairn (2002) proposes a model focused more directly on the commercialisation of technology. He identifies five stages: feasibility, prototype, viability, deployment and profitability. Both Moore (1996) and Klepper (1997) also point out that, in reality, the stages blur, and the managerial challenges of one stage often recur in another. Furthermore, innovation occurs at different rates and with different trajectories between industries, indeed, it has been

argued that the life cycle model does not apply to some industries (e.g. Klepper, 1997; Nelson 1994).

In summary, the contributions of others reveal either macro-level economy views or parts of larger systems that frame the emergence and growth of industries. We contend that none of these is fully inclusive and what is needed is a more systemic view that combines these largely disciplinary perspectives to inform our understanding of the underlying elements of industry emergence. We describe our approach as the synchronization of elements within an industrial system. In addition to the development of technology, successful emergence relies upon such elements as market acceptance, industry hegemony, government policy, and the availability of investment capital, appropriate production capabilities, and a functioning supply network. The evolution of each element is likely to be interrelated and relies on a process of co-evolution, whereby each influences, and is influenced by, developments elsewhere. Column 1 of Figure 1 shows our framework built around seven critical underlying elements affecting the emergence of an industry. The literature review below summarizes the contributions that inform our understanding of the individual elements of our framework.

3.2 Elements of a System of Industry Emergence

The elements we represent as 'process bands' in Figure 1 show the changes that generally occur as an industry emerges. These factors are based on the contributions of many authors. In the following section, we summarize an array of literature in order to assemble our interdisciplinary framework (Figure 1), and in Column 1 of Figure 1 we show example sources for each element.

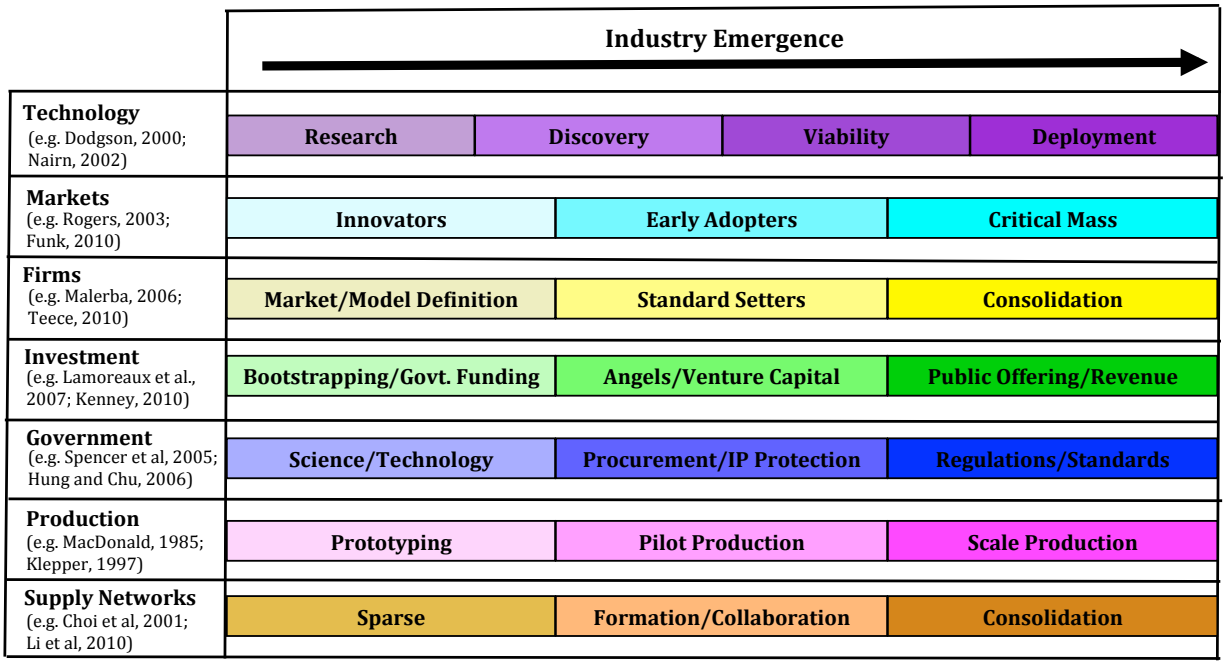

Figure 1 - Framework for Understanding Emerging Industries

We begin with technology and are guided by Dodgson (2000) who makes a distinction between technology and industry evolution, arguing that the former differs from technology commercialization in that its evolution does not necessarily require the development of a market. Instead, technology evolution is the advancement of the science and/or engineering. This evolution begins with research/innovation, evolves to discovery, which is proven as viable and is deployed as a technical solution (see Figure 1). The gaps in the process slow or prevent the emergence of a technology and an industry (Dodgson, 2000).

Like technology, the evolution of new markets for technology-based products has been found to follow a regular pattern. Rogers' (2003) description of diffusion and adoption is based on work that began in the first half of the last century. The rate of adoption of a new innovation is said to depend upon features of both the innovation itself, and potential consumers. Among the characteristics of innovation, five factors account for the majority of all variations: relative advantage; compatibility; complexity; trialability and observability. The chief characteristic by which potential consumers are categorised is level of adoption of innovations. Markets begin with "innovators", who are people who see the possibility of a product or service, and then people who are keen to adopt innovations as soon as possible, i.e. early adopters. Funk (2010) adds to this discussion by emphasizing "critical mass" as necessary for the emergence of an industry because often a technology or service needs to reach a level of adoption in order for users to appreciate its value, e.g. a critical mass of telephone users is necessary in order for there to be other people to phone.

Technologies and markets affect the structure and competitiveness of industries as they emerge (Schumpeter, 1934 and Malerba, 2006). First-mover firms envision opportunities and exhibit patience while an industry evolves, followed by standard setters who compete for market share as an industry is in its embryonic phase. As industry emergence continues, new industry entrants, or followers, seek to benefit as the focus shifts from product to process innovation.

With the evolution of technology and markets, firms develop corresponding business models. Teece (2010) emphasises the fact that a business model is always provisional, in the sense that it will be replaced in time by one that takes advantage of technological or business innovations. In emerging industries, the most appropriate business model is unlikely to be apparent, so firms will adopt a wide range of forms. Successful firms will be those whose managers are able to learn and adjust to changing conditions (Teece, 2010; Zahra and Nielsen, 2002; Low and Abrahamson, 1997; Macdonald, 1985). As the industry emerges, what begins as a search becomes more certain as managers and entrepreneurs learn from experience, and from each other (see Figure 1). For example, firms consider licensing models where their revenue comes from the sale of their product or process designs, they further develop their technology into components for an end-market product, or they develop the end-market product themselves (Fosfuri, 2006). These conditions are more likely to exist beyond the earliest stages of industry emergence. As an industry continues to emerge, more firms may license their technology, vertically integrate, outsource commodity aspects of their value chains or choose niches in the industry value chain, as all of this manoeuvring leads to industry consolidation.

In addition to the dynamics of technology, markets, and firms, investments represent the life-blood of research, innovation, development of value chains, and commercialization (Lamoreaux and Sokoloff, 2007; Kenney, 2010). There exists a symbiotic relationship between investments and industry emergence, as investment is needed for the industry to evolve and with this evolution the nature and extent of investment opportunities change. As illustrated in Figure 1, the availability and sources of investment are likely to evolve over time with changes in the other components of the system.

Entrepreneurs and firms often provide early financial resources in a form known as 'bootstrapping'. However, in science and engineering, governmental entities often provide research and technology grants. Governments can play the role of the visionary projecting the benefits from investments today for technology, firms, jobs, tax revenues, and industries in the future (Lundvall et al., 2002; Connell, 2009). Because this is a highly speculative time frame of great uncertainty and risk, founders and governments are likely to be the primary sources of investment funds. As an industry (and technology) continues to emerge, risks often decrease or at least become better understood, so investors with profit motivation are more likely to be attracted. Investments from angels, venture capitalists, and public offerings often replace personal and government investment. During the later stages of industry emergence, more firms may reach the point where their financing is internally generated in the form of retained earnings, accounts receivable, and sale of assets, though even at this point, new entrants, and those introducing radical innovations are likely to continue to require government and other early-stage funding sources (Hung and Chu, 2006).

In addition, governments use a range of mechanisms to influence the direction and pace of industry growth, and, as shown in Figure 1, they tend to use them at different times for different effects (Hung and Chu, 2006). In the earlier stages of an industry's existence, government's role is most likely to involve support for basic research with limited emphasis on seeding particular new industries. General areas of research are supported with the focus on ways to address technical challenges or need to expand the application of existing technologies. Government support in the form of grants, subsidies, and procurement contracts, and intellectual property protection is also often important (Block and Keller, 2010). The government may continue these roles as an industry grows, but interventions may be more targeted, at both product and process improvements, and their roles in the establishment of regulations and the setting of standards are likely to become more prevalent as the risks and opportunities of industries are better understood and as competition increases (Aldrich and Fiol, 2007). It is also important to note that one of the constraints in emerging industries is the uncertainty throughout all the elements described here. Often times countries imitate a technology that has been largely proven elsewhere, but then address other institutional, financial and market factors through a centralized organizing mechanism (government) to enable synchronicity. This is done to capture the growth in an emerging industry, not to spark the initial emergence.

In addition to the technology, market, firm, investment, and government dynamics, production and supply networks also change as an industry emerges (see Figure 1). Firms often need to develop a broader range of production capabilities and inputs themselves in the early stages of an industry's emergence in order to piece together their products or

processes. As the industry emerges and matures, production becomes more specialized and the supply network transforms to support the industry, but the factors influencing that transformation are widespread, and difficult to manage in a conventional sense (Reed and Walsh, 2002; Choi et al., 2001; Li et al., 2010).

Our framework in Figure 1 is built around seven underlying elements affecting the emergence of an industry. Our review of the literature above supports our framework, but our larger contribution is the illumination of the interactions between the individual elements and their synchronization, which enables industries to emerge.

4.0 Interactions of the Elements Affecting Industry Emergence

This section explains the interaction of the elements described above and uses examples drawn from technology-based emerging industries and interaction diagrams to exhibit the synchronization and systemic concepts. The evolution of the various elements affecting an industrial system takes place in parallel and, as discussed earlier, at different rates, and with distinctive dynamics. However, it is clear that elements co-evolve throughout the process of emergence, essentially because they are elements of the wider industrial system that is emerging. In this section, the interaction between the elements of the system will be explored through a consideration of the phenomena underpinning the operation and development of new industrial systems. The focus will be on the ways in which the various elements influence and are influenced by each other. The discussion here concerns the elements of an industrial system; many individual agents, institutions and organisations are likely to be involved in any one of them. We draw illustrative examples from the, electric vehicles, solar photovoltaics, and biofuels industries. Table 1 shows the recent estimated revenue growth for these three industries highlighting how they have grown at different paces and to different levels. The sections below will help explain how different elements and their interactions have influenced the emergence of these industries.

Table 1 – Revenue in $Billions/Year

	2000	2002	2004	2006	2008	2010
Hybrid-Electric Vehicles	1	3	6	21	45	60
Solar Photovoltaic Power	1.1	1.9	4.5	6.3	25	67
Biofuels	0.3	0.3	0.4	1.1	1.7	2

Sources: USDOE, 2011; EPIA, 2012; Thurmond, 2012

4.1 Technology, Markets and Investment

For the emergence of a new industry, a technology, or more likely a number of technologies and resources, sometimes referred to as complementary assets (Teece, 1986; Rothaermel and Hill, 2005), must be incorporated into products. These products are offered to the market, in the hope of sales, generating returns for the businesses and other investors. As suggested by Klepper and Graddy (1990), the response of the market depends on the attractiveness of the benefits offered by a product (for particular customers), given the price at which it is sold. The most significant factor is, then, product value, the balance

between cost and benefit (DeSarbo et al., 2001). Investment is required to enable the development of new technology, in order to allow its incorporation into products of an acceptable value. Initially, this value will be attractive to a relatively small number of potential customers (Rogers, 2003), for whom the benefits to be derived from the product outweigh the cost associated with it (cost in financial terms, and in terms of factors such as risk, or unreliability). Initial sales, however, can provide returns that become a source of investment to further develop the product. Furthermore, evidence of sales might encourage others to provide investment funds. The basic relationships are presented in Figure 2.

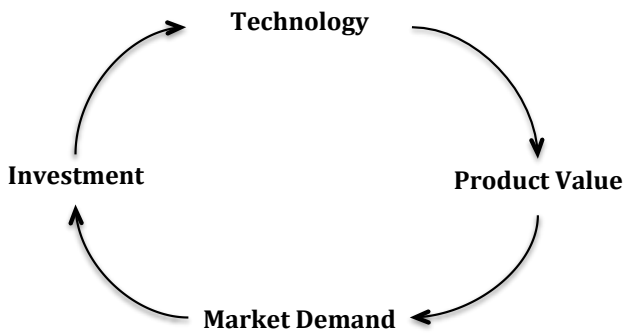

Figure 2 - Technology, Markets, and Investment

The emergence of a new industry relies on this positive feedback cycle enabling the development of the technology, product value, market demand and investment, each of which is interdependent. Increased market demand may lead to increased availability of funding which in turn enables the development of technology which can be integrated to increase the benefits, or reduce the cost, of the products offered to the market, which could lead to increased demand, and so on. This relationship, however, can also operate to constrain, or reverse the growth of a system. Falling demand, can result in reduced availability of investment funds, and hence constrain the development of technology that can lead to a lack of competitiveness in terms of product value, and further reduced sales.

These interactions usually start with the discovery of an idea or technology. Industry growth can be hindered by what is described as an interest gap (Dodgson, 2000). This interest gap can be formidable and some technologies never advance beyond the point of discovery because they are too expensive to develop, lack commercial application, or are superseded by a competing technology (Adner and Levinthal, 2002). This was the case with solar photovoltaic technology, which languished in laboratories until US government-driven need for remote power for the space program spurred further development of the technology. In this case, the incentive to invest in the development of the core technology arose from a clear market demand (the space program), and the availability of (government) investment funding that accompanied it. The resultant improved product value subsequently enabled increased market demand, at least partly by overcoming the resistance to adoption, generating increased investor demand, and the possibility of further development of the technology (leading to subsequent 2nd, 3rd and 4th generation photovoltaic technology).

The interactions of technology, markets, investment, and product value are also illustrated by the electric vehicle industry, which has been emerging with technological innovation, government and venture capital, market acceptance, and increasing product value. The core technology for an electric vehicle has been available and in use for over 100 years, though it was largely ignored, for widespread application at least, when the internal combustion engine became the industry standard in the early 1900s (Ofek and Ribatt, 2010). Limited market demand reduced the availability of investment and the commercial incentive to develop the technology further, in other words, the market, investment and technology elements were not adequately synchronised.

The technological constraints, or bottlenecks, experienced as the electric vehicle has made its return during the past decade, illustrate that "technology" is a multifaceted element in industry emergence. Many of the critical challenges are associated with technologies complementary to the core electric motor such as those associated with batteries, power electronics, drive train components, and charging stations. For example, current technologies result in batteries that have proven to be expensive, generate too much heat, and offer too few hours of dependable charge. The result has been that market demand remains a problem; consumers have proven fickle about adopting electric vehicles as gasoline prices have fluctuated. It appears that price sensitivity is more powerful for this industry than concerns about climate change, local pollution, and dependence on foreign oil. There has been a group of early adopters, but by-and-large, it has taken consumer tax credits and price shocks to sway buyers.

4.2 Firms and Industry Dynamics

An important factor influencing the size and structure of the industry is its attractiveness to new entrants and incumbents. That attractiveness is dependent to a significant extent upon the demand that exists in the market. Figure 2 illustrated some of the factors influencing demand, but the size and structure of the industry will also influence the system depicted. Figure 3 illustrates the interaction of these elements, and synchronization of all of these elements is necessary for an industry to emerge and grow.

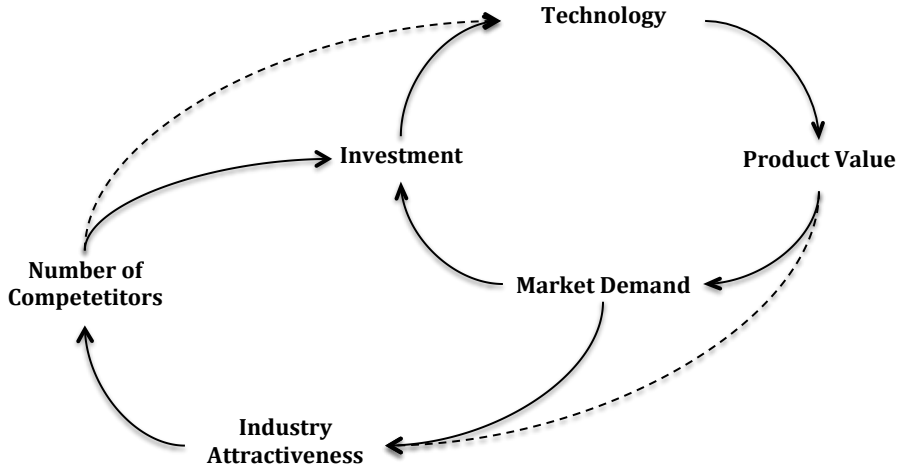

Figure 3 - Industry Dynamics, Technology, and Market Interaction

The size of the industry and the degree of competitiveness can influence the attractiveness of the system to investors, while competition can also influence technology development. In Figure 3, the broken lines represent effects that might be mediated through these factors. Hence, the perceived product value might make an industry more or less attractive to firms. The "dynamics" arise because as, for example, technology matures, and with it product value (perhaps in the form of the emergence of standards, or dominant designs), market demand is likely to increase (through the adoption cycle described earlier), making the industry attractive to different types of firms. First-mover firms during the beginning of an industry are usually few in number because of technology and market immaturity and often focus on establishing their position through gaining intellectual property protection for their innovations. There may be a lack of clarity for the direction of technology as well as markets, so the pre-revenue currency is knowledge and patentable findings.

While there are usually few competitors during the early stages, unless the leading patent holders license their technology widely, there are also likely to be a small number of firms competing for the lead standard as the industry moves forward. Standard setting is influenced by many determinants such as quality and value, but also political and even social influence. In other words, the best technology does not always end up being the standard bearer as government or customer decree, network effects, and even celebrity endorsement can influence technology and market leadership (Funk and Methe, 2001).

A surge of new entrants, or market followers, occurs as firms seek to distinguish themselves because they have expertise in process innovation, and competition often shifts to scaling production and lowering costs (Suarez, 2004). Innovation turns to scaling production processes in order to lower per-unit costs. In many industries there is a decline in the number of firms and an overall consolidation of the industry as it continues to emerge (Klepper and Graddy, 1990). Firm focus shifts to cost, pricing, and market share. Price competition and acquisitions are common signals for this industry phase, because firms are struggling to hold market share, cover capital costs, and stay profitable, and barriers to industry entry shift from technological to capital costs for scaling and innovating production processes.

Here too, the process underlying the observed behaviour can be seen in Figure 3. The emerging industry structure leads to a different competitive environment, as market demand moves from early adopters to early and late mainstream customers (Rogers, 2003) with requirements, for example, for greater reliability and simplicity of operation. This demands a different type of technology development, with the refinement of established concepts, and an emphasis, perhaps, on process rather than product feature improvement.

Firm strategy and industry dynamics can be illustrated from the emergence of the electric vehicle industry. Start-up firms making cars, batteries, and other components have been the early leaders to get products on to the market. For example, Tesla, a Silicon Valley start-up, which has received significant government and venture funding and launched a public offering, has made over 30,000 of its expensive luxury sedans. Tesla has proven itself as a niche car maker and is proving the feasibility and technological readiness of the industry. However, established automakers have introduced or are planning to introduce electric vehicles, and it would be naïve to overlook the long-term influence of car makers such as

Toyota, GM, and Ford in an industry controlled by several large companies. This illustrates how multiple factors, including industry size and structure, can affect an industry's emergence. In the electric vehicle industry there are at present both young firms funded by venture capital (Tesla), and major corporations (Toyota, GM, Ford, Nissan) able to rely upon their own internal resources, but compared to many industries, there are few competitors because high capital and learning costs have slowed technological innovation and product value and limited market demand.

In addition, it is not uncommon for firm strategy options to be unclear in the earliest days of industry emergence as firms seek to develop value in the form of intellectual property, processes or unique content. For example, while selling its own vehicles, Tesla has also licensed its technology to Toyota and BMW. Many firms active in the early stages of an emerging industry may lack saleable assets, so decisions about long-term strategy would be premature. The extent of market demand is uncertain, the product qualities most valued by customers have yet to be determined, and all but the more adventurous investors are likely to be reluctant to commit. This is evident in the electric vehicle industry as there continues to be experimentation with respect to business models, particularly with respect to the development of the charging infrastructure, and the supply of the vehicles themselves. For example, the Better Place offers its vehicles for free if a driver commits to buying enough miles of travel, similar to buying minutes in the cell phone industry.

4.3 Roles of Government

Government can influence supply through funding, infrastructure, and skills, and demand through procurement. Moreover, government sets rules as the key regulator. Figure 4 reflects these points and expands on them. Government is shown as operating through two primary routes: through direct investment in technology (labelled "government funding"), and through direct procurement, subsidies, or regulation (labelled "government intervention"). Government action is unique among the elements of the system in that the intention is usually to influence the system, perhaps as a whole. Other elements essentially involve agents with their own, relatively selfish, interests uppermost in their minds. However, government action is influenced by the observed behaviour of system elements, and it is important that a range of interacting elements is considered.

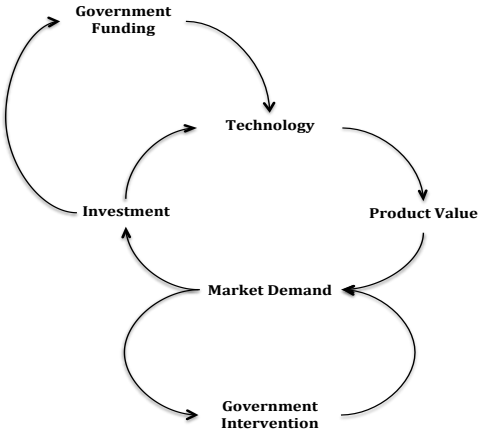

Figure 4 - Government

The emergence of the modern biofuels industry is the result of a combination of technological innovation and government intervention. Government mechanisms such as subsidies, procurement, investment incentives, public education programs, regulation/standards, and macroeconomic policies can encourage innovation and commercialization leading to industry growth and tax revenues and subsequent government support. While government entities can play a significant role in industrial systems and industrial emergence, they, and other entities can introduce uncertainty to the system as policies can change, just as competitors and suppliers can change, entering and exiting an industry. Whilst industrial organisations will often seek to influence government, the uncertainty of industrial systems requires actors, namely firms, to enhance their agility, i.e. their ability to recognize the variability in their system and their capability to adjust their strategy when system change dictates adjustment.

The role of government is also particularly important in the case of electric vehicles. Governments in the US, Israel, Denmark, Japan, China, Germany, and the UK have introduced incentives for electric vehicle purchases, and billions of dollars have been dedicated to promote electric vehicle manufacturing and the development of other technology, and the infrastructure for the electric vehicle industry. These subsidies have included help to locate electric vehicle manufacturing, loans for electric vehicle manufacturers, and grants for battery and component firms and battery recycling. Governments have also procured electric vehicles for test fleets, built charging systems, and upgraded power grids.

4.4 Production and Supply Networks

The role and nature of production and supply networks vary with the changing needs of firms in an emerging industry. Throughout emergence, production is the expression or actualization of an industry's innovations. Figure 5 illustrates how the evolution of technology influences the nature of production, which, in turn affects product value. For product value to increase, as it must to sustain the system depicted in Figure 2, production processes and facilities, and supply networks must evolve to be capable of delivering the scale and reliability demanded by the growing markets (Reed and Walsh, 2002). This in itself is, however, dependent to some extent on investment in technologies and processes, which is in turn influenced by the market growth that is only possible through the evolution of the production base and supply networks.

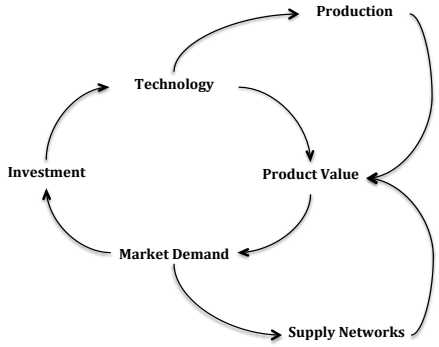

Figure 5 - Interaction with Production and Supply Networks

The interaction and dependence of elements of an emerging industry are illustrated by the biofuels industry. Supply networks are central to the production of biofuels as feedstock material must be located by quality and in consistent quantity. Equally critical is the development of off-take partners that wholesale and distribute the produced biofuel. Efficient, consistent quality production at a low enough cost to compete with petroleum products is central to the viability of biofuels. Producers of biofuels compete against each other for venture financing and production target amounts, but also against an oligopoly of large, global petroleum firms. Per gallon costs for biofuels must be price competitive with petroleum-based fuels. This loop leads back to technological innovation as investment funding and market demand enable production expansion and process innovation for better economies of scale and product innovation for better product value. All of these aspects drive the growth of the biofuels industry and emphasize the complex, dynamic, adaptive, self-organizing interactions of an emerging industry.

The connections are similarly evident in the solar photovoltaic industry. Over the first half of the last decade, there was a shortage of silicon for manufacturing solar cells. This has been in part an issue of overall supply (ramping a production facility is capital intensive and involves lead time) and also an issue of demand for silicon for other electronic applications. Both of these forces led to high silicon prices. In the last five years silicon prices have fallen significantly due to increases in capacity availability and a slow down in the electronics industry (Lorenz et al., 2008; EPIA, 2012). In addition, across the value chain, economies of scale have pushed prices down, especially for manufacturing solar cells and modules, but also for components and installation. These occurrences in the global solar photovoltaic industry resemble the interactions shown in Figure 5 with particular significance of production and supply networks for the emergence of the industry (also see Table 1).

5.0 Conclusions and Implications

The study of emerging industries is challenging but important because of the potential for firm and job growth, but to-date it has often been examined largely from specific and relatively narrow perspectives. Where multiple elements have been considered, their interactions have not generally been explored in a systemic way. This paper presents an interdisciplinary framework of elements that exhibits the interaction, co-evolution, and synchronization of these elements, which underlie industry emergence. The seven elements we focus on are unlikely to be the only ones that influence industry emergence, and others such as labour or spatiality may be critical for a particular industry, and the significance of some, government for example, will vary significantly from one case to another. More generally, the art of the analysis lies in understanding which elements are most relevant for a given industry at a particular point in time, and how these elements interact. The concepts introduced in this paper require further development, but they have implications for a wide range of industry actors and stakeholders.

For inventors and those managing firms, this paper draws attention to the need to consider and attempt to influence the synchronization of a range of system elements in their efforts to commercialize a core concept. Inventors and firms can fall prey to focusing on too few elements when projecting the evolution of their technology and business. They may

envision success because they have a leading technology, only to be frustrated by delays and failure. The discussion presented in this paper indicates the need for a broader and deeper understanding; one that includes the elements presented in our framework, but also one that seeks to anticipate the connections between the elements and takes a proactive approach to influence these aspects such as by educating investors and policy-makers, considering new business models, and building production capabilities and supply networks.

Investors are likely to gain similar insights from this paper, and they may choose new investment strategies based on a more complete emerging industry picture. Investors will need to weigh the risks of many aspects of an industrial system, which will offer them a more realistic picture of the situation they face.

Policy-makers can benefit by focusing their attention on numerous elements and their systemic interaction and co-evolution. Policy-makers can encourage the emergence of particular industries by coordinating the multiple parties representing the elements most relevant to their targeted industries and by encouraging appropriate interaction of key elements in order to help an industry emerge and continue its growth. By identifying misalignment of elements they may identify what action might most successfully be implemented.

Finally, this paper contributes to our understanding of emerging industries, but also indicates the need for more rigorous testing of the framework and the elements on different types of industries, industries in different contexts, and industries at different stages of emergence. We envision this paper helping multiple parties as they play their roles in the emergence of an industry, but we also seek to continue the conversation about how to better understand and encourage the emergence of new industries.

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