Supply network emergence models and the development of nascent and emerging industries

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Abstract
This research aims to develop supply network emergence models through determining appropriate industrial system and supply network configurations, recognized as an essential component in the development of emerging industries. Methods evaluate changes to existing and emerging industrial structures, focusing on alternative product-process route combinations for the manufacture of terpene-based intermediates.

Keywords: supply network, emerging industries

Introduction
Emerging industries have been described as those “newly formed or re-formed industries that have been created by technological innovation, shifts in relative cost relationships, or emergence of new consumer needs” that “elevate a new product or service to the level of a potentially viable business opportunity” (Porter, 1980). The study of emerging industries is focused on identifying those characteristics that optimise opportunities for value capture through successful technology commercialisation. In the case of nascent industries, where supply networks often have yet to take shape, the challenge of network creation, including partner and geographic selection present additional uncertainties to the already demanding tasks of product and process technology development.

Current perspectives of early stage supply network development in these new industries are largely descriptive, and provide limited detail on configuration elements and options. The methodology presented builds on five proposed archetypal stages in the evolution of global value networks (Srai et al, 2014). The first stage involves the formation of ‘incipient’ or ‘nascent’ networks associated with a new technology. Here the technology, still unproven, is just coming into existence and the associated network may just consist of a laboratory in a university research centre with basic initial dialogue and contact between perspective supply chain partners and technology developers. It may evolve to a stage where the network starts to show signs of ‘order’, such as emerging commercial strategy and potential for partnering arrangements. The second stage is ‘emerging’, which encompasses a series of transitions from a viable pilot production of a new technology or delivery platform, to a partial or completed network with an end-user in the form of an ‘early adopter’. Here, multiple customers and competitive technologies begin to emerge, to the stage when the network starts to cohere into the form it will take for a mature, viable industrial system. The third stage is ‘mature’, where the network typically becomes significantly more complex,
possibly with multiple tiers and interconnections, and where specific roles are defined for a broader range of niche players that are often globally distributed. Five key network types or options have been identified at this mature stage of evolution and have been previously reported (Harrington and Srai, 2012).

**Literature Review**

One of the challenges facing nascent and emerging industries is that there is no defined strategy that a firm can follow. The lack of certainty in the environment and on the consumer needs forces firms to experiment with supply chain strategies through a process described as ‘effectuation’ (Sarasvathy, 2001). This process can be very time consuming and may increase time to market. Furthermore, this process makes it difficult to maintain a ‘first mover advantage’. In addition, focus on emerging industries with their inherent uncertainties is concurrent with changes in the industrial landscape for mature sectors, which have arisen from the twin impacts of globalisation and the dissolution of vertically integrated value chains. Both these cases have highlighted the importance of supply networks as an enabling element of industrial development.

It is also suggested that in order to successfully grow a firm from nascent to mature stages, various dimensions of the supply network, e.g. resources, partners, supplier, customers must be coordinated (Leibold *et al.*, 2002; Sarasvathy and Dew, 2005; Voelpel *et al.*, 2004). In particular, manufacturing value networks are central to building an effective business model (Jaworski *et al.*, 2000; Hills and Sarin, 2003; Simchi-Levi and Fine, 2010). Hence, adopting value network and supply network configuration mapping approaches may provide a set of techniques that can offer insight on the interaction between various stages of the manufacturing value chain and allow firms to develop appropriate supply chain strategies. Subsequent network configuration design and analysis, in the context of nascent and emerging networks, may provide insights on industry evolution (Srai and Gregory, 2008; Srai, 2010; Harrington and Srai, 2014).

**Research Methodology**

The research approach draws on the methodologies developed in recent industry landscape and supply network emergence studies (Srai, 2010; TSB, 2012;) which involve industrial system landscape mapping (Srai *et al.*, 2014) and supply network configuration analysis techniques (Srai and Gregory, 2008) applied and tested in emerging industry supply networks (IB, Photovoltaics, Plastic Electronics, Medical Diagnostics) where multiple co-existing technology platforms compete within existing and emerging industrial systems (Harrington and Srai, 2014).

The industrial systems mapping framework can inform the role of supply network in emerging industries through:

- Capture of industry structure at a broad industrial systems level
- Capture of alternative supply network configurations within the industrial system
- Identification of evolutionary phases of the network within the industry enabling the generation of a stages model of emergence from the perspective of the supply network.

For each of the industrial systems studied, the first level of analysis involved the generation of an industrial ecosystem map emphasizing the following elements, mapped across the
manufacturing value chain:

- Institutional players and secondary stakeholders
- Sector specialists and primary stakeholders
- Value chain actors and activities
- Supply network archetypes that form the supply chain

The industry mapping approach schematic - setting out the industry structure, its principal supply chain actors and processes - is illustrated in Figure 1.

**Figure 1. Industrial ecosystem mapping approach: Capturing the global value network and external stakeholders to aid the understanding of industrial ecosystems.**

An example of the industrial ecosystem mapping approach is illustrated in figure 2 e.g. case study involving the UK biotechnology sector (Srai, 2010; Srai et al., 2014). This shows the generic layers that collectively aid visualisation and analysis. Working from the bottom up, the key layers – and their relevance – are described as follows:

- **Core Firms** – this defines the complex network of principal firms directly involved in supplying products and services in a chosen industry sector, together with their interdependencies, value chain contribution and geographic location. This basic definition of the ‘global value network’ then allows capture of associated key data, such as flows of revenue, materials and information.

- **Core Products and Core Processes** – these linked layers are included to add vital information required to help characterise the global value network in terms of the product structure and how this relates to the transformation processes and technologies. These layers are particularly important when disruptive product or process changes might radically alter network structures and dynamics.

- **Institutional Players and Sector Specialists** – these two layers complete the ecosystem by identifying the external stakeholders who do not directly add value to products and services, but who may play key enabling roles and have an interest and influence in industry development. These players are particularly relevant when they are providing finance, infrastructure, equipment or fundamental research that can affect the outcome.
Terpene-based sustainable chemical feedstocks

Transition from fossil-based feedstocks to renewable alternatives is a key challenge for the 21st Century. Major efforts are underway to address this with work currently focused on carbohydrates, fats and oils, and lignins all of which give rise to fundamental technological barriers due to the incompatibility of complex and oxygen-rich materials with conversion technologies developed for simple hydrocarbon-based petrochemical feedstocks. This often requires biological feedstocks to undergo costly and inefficient transformations and separations prior to deployment in existing supply chains.

In contrast, terpenes are an abundant class of natural products based on the C-5 isoprene unit. As hydrocarbons they are easily separated from aqueous environments and can be readily upgraded using existing petrochemical technologies. While terpenes have been used in limited quantities since antiquity (notably as flavours and fragrances) they have yet to be exploited systematically for the production of platform chemicals even though they represent a potentially vast resource: global biogenic production of terpenes is $10^9$ t/yr. Significant volumes of useful terpenes are already available on global markets at low cost (production of turpentine oils and limonene are 330,000 and 30,000 t/yr, respectively, the former costing 0.09-0.19€/L). While this is sufficient in itself to justify a viable value-added chemical platform (metrics comparable to those for lignin: 1.1m t/yr at £250-2,000 per t) such figures will be dwarfed in the near future through the large-scale (multimillion t/yr) microbial production of terpenes such as farnesene for biofuels via the engineering of isoprene metabolic pathways. This industrial biotechnology (IB) approach promises large-scale and geographically flexible supplies of terpenes via fermentation of plant sugars and cellulosic
waste. Thus, the exploration of new generic technologies for the chemical exploitation of terpenes is timely, not only in terms of sustainable utilization of current global resources, but also to take advantage of major developments in IB. However, key challenges to be addressed in the context of terpene-based manufacturing include:

- Development and optimization of sustainable chemical transformations;
- Scale-up of intensive conversion processes;
- Development of new terpene sources; and
- Systems-level understanding of technical, environmental and economic factors associated with new terpene-based manufacturing technologies.

Target outputs from this research project look to provide a competitive advantage for one of the UK’s most successful industries. Chemistry-reliant industries contributed an equivalent of 21% GDP to the UK economy in 2007, they support 6m jobs and turnover is growing at 5% pa. The utilization of IB is vital to sustaining competitive advantage, with the value of the UK IB market in 2025 estimated at £4b to £12b. Specific to this project, the development of new integrated technologies for terpene-based manufacturing, ultimately via microbial fermentation of waste cellulose, will provide competitive advantage for UK industries through new sustainable manufacturing processes, reduced feedstock costs, security of supply and reduced environmental impact. The UK will benefit further from export of new technologies and services and from development of new skills vital to future low carbon manufacturing.

**Preliminary Mapping - Terpenes**

Preliminary industrial eco-system maps were developed (Padrón Castro, 2013) and classified in four sections: Institutional, value chain, industrial actors and technology and these are summarized as follows:

There are two main institutions that support the UK government in strategy definition in the context of bio-based industries: the Technology Board of Strategy (TSB) which is the UK’s innovation agency and the National Non-Food Crop Centre (NNFCC) which acts as an advisor for projects in order to support policies through the interpretation of scientific, technical and market information and enable development of effective policy and regulatory frameworks. Within the UK government, the departments of Energy & Climatic Change and Business, Innovation & Skills have developed a strategic plan in Bio-energy and Bio-Industrial technology in order to position the UK as a leader in green products based on a low-carbon economy. Regarding institutions where knowledge is developed and transferred, they were classified in three categories: Universities, centres of research and a series of partnerships between research institutions or between companies and research institutions.

The value chain map (figure 3) summarizing the supply chain in three main stages: R&D and design, production and distribution & services e.g. R&D looks to capture the activities of technology development in transformation processes (including chemical and physical processes) and the associated equipment required to carry out the operations. The following step is the proof of concepts for a later application in current operations or in new facilities that requires the construction of facilities. Production: In this stage, the sources of raw materials, the type of auxiliary materials that are needed and the main transformation processes that have been studied are summarized. The Distribution & Services stage includes the main markets that terpene-products could target and is defined here according to the properties of the compounds and possible applications.
The supply network structure (figure 4) includes the key issues that the current bio-based industry is facing and consequently the possible impacts on potential customers. Here, the main issues within the supply network are related to the feasibility of the business model and to the operations, specifically in quality assurance and meeting demand.

Figure 4 summarises the main potential actors in a terpene-based supply chain, specifically current terpene suppliers, companies that have terpenes as waste, auxiliary suppliers, potential operators of bio-refineries and some possible tier 1 customers. A description of each category of the industrial actors is as follows:
• Terpene suppliers: Companies who currently import terpenes or manufacture from essential oils.
• Waste from other industries: Companies that have waste with a high concentration of terpenes (mainly companies from pulp paper and juice industries).
• Auxiliary Suppliers: Companies who produce catalyst, enzymes and microorganisms for industrial use. These three elements were considered because they are required in the current studied transformation processes of terpenes.
• Potential Bio-refinery Operators: Potential companies that may be involved in the transformation processes from basic terpenes to specific terpenes.
• Customers: Potential companies that may use a terpene as a raw material.

The Technology map, summarised in Figure 6, considers the most efficient processes for an industrial application. It does not consider the technologies required for the manufacturing of auxiliary raw materials.

Figure 5: Preliminary Industry actors – Terpenes (adapted from Padrón Castro, 2013)

Figure 6: Preliminary Technology Map – Terpenes (adapted from Padrón Castro, 2013)
Preliminary Findings – summary

The terpenes industry may be categorised as nascent as relationships and developments remain in an embryonic stage of maturity. Supply network structure includes one tier of suppliers and two tiers of customers. The suppliers are classified as raw materials suppliers (terpenes from plants, marine resources and wastes from other industries) and auxiliary suppliers (materials required in the transformation processes). On the other hand, the tier one customers are the industries that may use chemicals derived from terpenes for the manufacture of products with tier two customers being the end users. The value chain activities are mainly focused in the stages of R&D, Design and Production. In the R&D and design stages the added value activities relate to the development of technology, the proof of concepts and to the design of equipment and facilities. In the production stage, the added value activities are centered around the manufacturing of auxiliary materials and in the operations of extraction and transformation of the terpenes. Technologies for terpene transformation may be categorized as: catalytic, biochemical and biological. Up until now, the most efficient catalytic process has been heterogeneous catalysis. Biochemical processes are based on enzymatic reactions and biological processes focus on the use of microorganisms for the degradation and transformation of the compounds (e.g. fermentation).

Future work: Evolution paths for terpene-based manufacturing

This research looks to assess potential evolution paths for terpene-based manufacturing. The research aims to develop industrial and supply network emergence models through the determination of appropriate industrial system and supply network configurations, recognized as an essential component in the development of emerging industries. Methods seek to evaluate changes to existing and emerging industrial structures, including (a) primary feedstock sourcing, (b) implications of alternative product-process route combinations for the manufacture of terpene-based intermediates, and (c) end industrial and commercial use applications.

Future-state industry and product-process supply network configurations, which are the desired outcomes of the research, will be evaluated in terms of the emergence of new institutional, industrial and supply network actors that facilitate the transition to the manufacture of terpenoid feedstock and associated products. It is anticipated that several iterations of supply network configuration will be assessed to evaluate possible changes to the industrial landscape, including changes to feedstock supply, assessment of potential impacts to the existing asset base, and exploring value capture mechanisms for those involved in the new technology. Supply chain transition maps for selected configurations will involve (1) End user demand-side analysis to evaluate (a) existing petrochemical supply chains that might be replaced with renewable feedstocks, (b) renewable feedstocks based supply chains potentially replaced by terpene-based intermediates with new properties not currently available, (2) Production process route analyses that explore potential archetypal product-process combinations which emerge that might form the generic steps, or reaction sequences, in a renewable terpene-based process, and (3) Supply-side analyses that explore the different feedstock sourcing routes available, including naturally occurring sources than may be chemically exploited, by-product resources from current industries (e.g. paper industry waste streams that may support chemical transformations and process scale-up studies), and future IB-based supply sources that might help support large industrial scale operations.

The supply chain implications of these alternative industrial systems will be evaluated in terms of emerging supply chain actors, supply dynamics, scale, cost and end-use
applications. Scenario development tools will be selectively used to explore supply-demand sensitivities and set the agenda for the chemistry and chemical engineering challenges that need to be addressed. Supply chain configuration analysis will involve mapping from ‘substrate’ type and source through to ‘intermediate products’ and ‘best end point’ applications drawing on methodologies previously described. Research novelty is in the exploration of potential configuration options and evaluation of supply network dynamics from technology routes still under development to both assess and inform their attractiveness as alternative production processes. These alternative industrial and business models will be assessed in terms of value creation, capture modalities, and industrial resilience.

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