



Paper to be presented at the DRUID 2012

on

June 19 to June 21

at

CBS, Copenhagen, Denmark,

Focal actors and eco-innovation in production and distribution systems

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Abstract

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1. Introduction

The challenges of sustainable development have led governments and firms to establish ambitious goals: the UK government, for example, has set a national target for 80% reduction in greenhouse gas emissions from 1990 levels by 2050. Achieving these objectives will require accelerated and multi-targeted innovation in systems of production and distribution. Accelerated innovation is particularly important in the short to medium term – before energy systems are decarbonised – both to reduce absolute levels of resource use and to improve the efficiency of resource use. Multi-targeted innovation is required because in any production and distribution system

(PDS) – whether defined as a value chain, product life cycle or system of provision – there is likely to be a number of environmental ‘hotspots’.

Production-distribution systems are defined by material and product flows. Any production-distribution system can be considered to be embedded in other, less materially-based, systems. The analysis of production-distribution systems has been approached from several vantage points in the innovation studies literature: most commonly, from an economic or sociological perspective of science and technology in the ‘sectoral systems’ (Malerba, 2002) and ‘technological systems’ (Carlsson and Stankiewicz, 1991) or the ‘socio-technical systems’ approach (Geel, 2004). Whilst there are differences in the way the approaches treat the changing boundary of the system and the role of scientific advances (e.g. generation of new knowledge, networks of knowledge diffusion), economic factors (e.g. investments in human capital, research and development), institutional conditions (e.g. ‘rules of the game’ set by government policies, regulation, standards), infrastructures (e.g. energy, transport) and societal factors (e.g. practices, life styles and behaviours), all acknowledge (to a greater or lesser extent) the inter-dependence and co-evolution of these aspects to both create new paths for innovation and constrain it to existing ones, shaping both the direction *and* pace of change in the system. And as Coenen and Lopez (2010) note, the three approaches have explored sustainability: the sectoral systems literature through its concern with industrial competitiveness (which now encompasses environmental and social performance), the technology systems literature through its look at clean technologies, and the socio-technical systems literature through its analysis of energy and mobility transitions.

Acknowledging the co-evolution and co-dependency between agents, factors and innovation at a bounded systems level, in this paper we focus on the capacity of 'focal actors' (Huber, 2008) to shape the direction and pace of change toward a more sustainable PDS. Huber (*ibid.*) describes 'focal actors' as those in a "unique position [in the PDS] in that they combine a high degree of supply power with an equally high degree of demand power". In other words, 'focal actors' are likely to be responsible for innovating themselves, but it is their ability to stimulate accelerated, multi-targeted eco-innovation upstream that gives them their 'focal' status. In his empirical analysis of (technological) eco-innovations, Huber shows that most eco-innovations are adopted at the production (or pre-production) stage. He ascribes the 'focal power' to stimulate eco-innovation upstream to various organisations in different industries (e.g. energy providers, manufacturers, large industrial users) but does not detail the mechanisms used by the 'focal actors', short of their ability to "effectively implement supply chain management".

When analysing governance patterns in global supply chains ("global value chains"), Gereffi et al (2005) describe the retailer-led integration of the fresh vegetable supply chain serving UK supermarkets. Subsequent case studies covering other value chains (e.g. Wilkinson, 2006; Lowe & Gereffi 2009; Foster et al, forthcoming) reinforce the sense that in current food systems retailers, because of their purchasing power, wield considerable influence over the full supply chain. This buying power is augmented by the supermarkets' detailed knowledge of the purchasing patterns of final consumers, obtained from analysis of their own 'loyalty cards'. The notion that

major purchasers can use their influence to improve the environmental performance of supply-chains through their purchasing and supply-chain management practices is itself well-established (Green, Morton and New, 1998). Reflecting the hopes with which green procurement has been endowed, environmental policy-makers and other stakeholders in the food industry have engaged with retailers (supermarkets in particular) in the expectation that these organisations can use their influence to bring innovation to bear on remote environmental hotspots. The environmental impacts associated with the production and distribution of food products are not principally associated with retailing itself or with inbound transport of products to retailers. In many cases the greatest impacts are associated with primary production and/or the processing stage, or beyond the PDS at the consumption stage (see Foster *et al*, 2006 for many examples).

Most of the eco-innovations described in studies of product systems are incremental in nature and there remains doubt about the extent to which 'focal' actors can exert their influence to bring about more far-reaching change, transforming production and distribution systems that extend beyond their own first and second-tier suppliers. For example, can they significantly change practice in a wide and dispersed production base such as exists for milk in the UK to tackle emissions in the way that Lowe & Gereffi (2009) suggest powerful actors in US beef and dairy supply-chains might? If meeting environmental objectives involves re-configuring infrastructures can they go further and act (to build on Van der Vleuten's (2003) terminology) as 'system re-builders'?ⁱ Or are there path-dependencies and other systemic factors

that lock-in retailers to current arrangements and restrain their innovation-leading activity, inhibiting such changes?

Understanding the role of 'focal actors' can therefore be useful from both an environmental and an innovation perspective, and food systems offer fertile territory for the exploration of the questions raised above. In this paper we attempt to unpack some of the ways in which 'focal actors' have stimulated eco-innovation upstream and assess the potential for them to catalyse further-reaching eco-innovation in the future. In our case study of the milk production PDS, we find that retailers are engaged in two demand-led mechanisms to stimulate eco-innovation along established trajectories: 'triggering demand' (stimulating the development of eco-innovations within or beyond existing supply chains through procurement) and 'interactive supplier-buyer innovation' (collaborating with supplier organisations in the development and implementation of eco-innovations). We discuss how their role could be extended to "re-build" the milk PDS around more far reaching technologies and highlight the inherent difficulties this presents.

To that end, the paper is structured as follows. In section 2 we outline our research method. In section 3, we explain how the milk system has evolved to have the structural characteristics it currently exhibits, highlighting the co-evolution of the milk PDS with other systems in which it is embedded. Given what we know about the dynamic nature of innovation systems, one can expect the identity of the 'focal actor' to change over time as a result of disruptive events and in section 4 we discuss the emerging 'focal' role of the supermarkets in accelerating incremental eco-

innovation across a time period of increased environmental awareness and concern for the sustainability of the industry. In section 5 we consider an environmental technology – anaerobic digestion – whose deployment is sometimes portrayed as offering a step-change in the environmental performance of dairy farms but whose development is potentially compromised by the arrangement of current PDS and role of the ‘focal actor’. Section 6 reflects on how the concept of ‘focal actors’ helps us understand better eco-innovation in production and distribution systems.

2. Research method

This paper is based on a case study of the milk PDS. Qualitative research methods lend themselves to ‘exploratory’ and ‘explanatory’ case study research (Saunders et al., 2007) and we combined semi-structured interviews with a thorough review of secondary material to inform this work. Our approach was to understand how the milk PDS has evolved to have the structural characteristics it currently exhibits, identify where the environmental impacts exist along the system, explore – through interview and analysis – *which* actors have ‘focal’ power in the PDS system to stimulate eco-innovation and *how* they do this, and to consider the benefits/drawbacks of relying on current ‘focal’ actors for eco-innovation and long-term PDS sustainability.

The milk PDS in the UK is both an economic and environmentally significant sector. In 2009 (the latest available figures), the UK was the third largest milk producer in the European Union and the ninth largest in the worldⁱⁱ. Dairying accounts for over one fifth of total agricultural production by value in the UK and is the largest single

farming sector by valueⁱⁱⁱ. Drinking milk is a staple of the British diet: the average person in the UK consumes 116 litres of milk per year, equivalent to 3.8 pints per person per week^{iv}. It is also a staple of UK supermarket sales, with fresh milk representing the single largest food category by sales value for most major retailers. There are also significant environmental impacts associated with the milk PDS, not only greenhouse gas emissions concentrated at the milk-producing end of the system but also fertiliser production and application, concentrate feed production – both of which take place “upstream” of the farm – and the enteric methane emissions from cattle and from manure management that arise on the farm.

Characteristic of ‘systems’ approaches to the study of innovation, the first phase of our research was based mainly on historical accounts of the development of the milk industry in the UK. Atkins (2010) provides rich historical detail of milk production and retail in the UK over the last 200 years, highlighting the scientific, commercial and legal influences on the industry’s development. A literature review that went beyond business and management journals – including, particularly, dairy and medical journals – and historical accounts on trade association and dairy company websites were also used to provide background on developments in the industry over the twentieth century. Some international historical reviews of the dairy industry in other European countries provided parallels with the UK. We analysed the secondary literature through a ‘focal actor’ and ‘systems’ theoretical lens.

The second phase of the research required an understanding of the environmental impacts associated with milk production and distribution. The authors had been

previously involved with two such reviews for DEFRA (Foster et al, 2006, 2007) and it was not our intention to conduct a new meta-analysis of the milk PDS, or to detail in this paper the environmental impacts across the PDS. We note above the environmental 'hotspots' (i.e. stages of high environmental impact) of milk production and distribution and as further support point to Tukker et al (2005) who reported that "milk and other dairy products account for around 5% of global warming potential, 10% of eutrophication potential and 4% of photochemical ozone creation potential across the EU....fluid milk is one of the 'top 10' contributors to total impacts for all of the environmental themes considered except ozone depletion".

The third phase of the research was based primarily on interviews with actors from all stages of the milk production and distribution system, probing which organisations have 'focal' power in the PDS system to stimulate eco-innovation and *how* they do it. Between 2008 & 2011 we conducted semi-structured interviews with, farmers tied and not tied to dedicated contracts with supermarkets, agricultural input suppliers (e.g. Growhow), knowledge providers (e.g. ADAS, Reaseheath College, industry consultants) and industry trade associations (e.g. Dairy UK). Our past experience working in the industry meant a non-probabilistic sampling approach (Saunders *et al.*, 2007) could be taken; an initial set of appropriate interviewees was known to us and we used the snow-balling method to identify other knowledgeable informants. We spoke in particular to major retailers (e.g. Tesco, ASDA) including both commercial and technical managers to understand not only the contractual dimension of buyer-supplier relationships, but also the various

vectors used to transfer knowledge and good practice. We supplemented our primary material with an extensive review of current policy and industry initiatives and commentary on these initiatives. Interviewing buyers, suppliers and other relevant organisations in the PDS, together with a review of secondary data, allowed us to triangulate the information and check for consistency (Grix, 2004).

The fourth stage of the research was to consider the alternative future pathways. The focus on anaerobic digestion emerged through our interviews and review of the contemporary literature. The outputs of stages one, three and four of the research approach are detailed in this paper in sections 3, 4 and 5 respectively. We refer the reader to Foster *et al* (2007) for a thorough life cycle analysis of the milk PDS (stage two of our research approach).

3. Co-evolution of the milk production and distribution system

The co-dependent, evolutionary aspects of the milk industry are evident in several studies. Atkins (2010) traces the transformation of what was a variable, perishable, organic fluid evolved to suit calves into a standardised food product sold to humans, loaded with technicity and artificially lengthened shelf life. Milk quality provides the focus of attention throughout Atkins' analysis and he argues that as science and technology revealed and controlled 'nature's secrets', legal standards began to shape the production process of individual farmers, dairies and retailers. For example, Atkins describes: how the path created by developments in analytical tools and techniques underpinned the 1901 Sale of Milk and Cream Regulations on grading the fat content of milk (minima of 3% butter-fat and 8.5% solids-not-fats),

which in turn persuaded farmers to take seriously the composition of their cows' milk; how composition monitoring regimes spread with the establishment of the milk marketing boards in 1933; and how breeding and feeding changed to suit the state-prescribed standard, contributing to a restructuring of the national dairy herd^y. The first two institutions endured: the 1901 standard remained until the implementation of the European Union Single Market in 1993 when the UK accepted standardisation of 3.5% fat minimum, and grading as a form of governance remained until the dismantling of the Milk Marketing Board of England and Wales in 1994. The industry was disrupted first by the deregulation of retail prices for liquid milk in 1984 and then by the dissolution of the Milk Marketing Board (a government-mandated monopsony) ten years later (Dairy UK, 2010). The market for milk supply, contractual arrangements, and supply-chain relationships have since evolved along a new trajectory, forged around supply chains. These supply chains are now controlled to a large degree by the retailers.

Atkins (*ibid.*) also discusses how, in the early to mid twentieth century, the increased movement of milk from the rural farmer to the urban doorstep was supported by an expanding rail network, special railway wagons and slots in the railway timetable; developments in preservation technologies (refrigeration, additives, pasteurisation, glass bottles); and changing wholesale and retail arrangements. Blake (1979) provides a more contemporary account of this path dependency: in the UK in the 1960s and 1970s doorstep delivery propped-up high volume sales and stable overall consumption levels when other countries saw milk consumption decline; regular morning delivery helped keep the milk fresh (before mass ownership of domestic

refrigerators) and arguably led households to continually over-estimate their intake by rounding up their requirements; efficiencies were based on high trippage rates for glass bottles and the system suited the weekly expenditure planning habit of households at the time (when many salaries were also paid weekly); furthermore, dis-economies of scale with respect to weekly cash collection limited individual 'milk round' sizes while depot sizes (for which dis-economies of scale arose above about 30 'milk-rounds') limited the number of 'milk rounds' any one company could control. In the 1980's, doorstep delivery brought most milk to households (78% "twenty years ago" according to Dairy UK 2010). But by 1995 doorstep delivery accounted for just 45% of household milk purchases (MDC, 2004), and the most recent figures show that doorstep delivery now accounts for well below 10% of all liquid milk sales (Dairy UK, 2010). Albert de la Bruheze and van Otterloo (2004) tell a similar story for the Netherlands, recounting how long producer-consumer chains emerged as a result of on-farm milk storage and preservation and milk transportation practices, enabling the concentration of local milk chains into regional and national ones served by industrial milk processing. Direct government intervention (e.g. fiscal incentives and training programmes) and indirect effects (e.g. the introduction of the mandatory 5-day working week) supported the transition. In this case, the milkman-based collection and delivery system using glass bottles was ultimately compromised by the growing number of high rise apartments and the liberalisation of retail trade.

These studies show how change within the milk industry in both the UK and the Netherlands was influenced by a cast of diverse actors and interests (e.g. large dairy

companies, government, retailers), practices (e.g. laboratory, social practices), institutions (e.g. regulation, law) and infrastructures (e.g. transport network, utilities network, even the nature of the housing stock). The role of the state in stimulating innovation through their buying power (one defining characteristic of 'focal actors' for our purposes) is exemplified in the analysis of Albert de la Bruheze and van Otterloo (2004) and Van der Vleuten (2003). They discuss how the emergence of milk as a mainstream drink (not simply confined to babies, infants, the elderly and sick) was stimulated by government supported agricultural research and efforts to improve the international competitiveness of Dutch agriculture (*ibids.*). During the inter-war years government promoted milk as a healthy foodstuff, not just because of the poor public health situation and increased knowledge of the nutritional aspects of milk but also because there was a need to find an outlet for a surplus of milk (*ibids.*). Free milk distribution to primary school children began. After the Second World War, government backed industry as it invested in mechanisation (for storage, preservation, transport) and modernisation (for milking, milk treatment, and milk processing and cattle management) (*ibids.*). In Atkins' (2010) work, the 'focal' role of the state is also apparent: for example, in the inter-war years, the Borough of Plymouth introduced a system of identifying dairy farms that complied with their regulations on milk composition and issued certificates to that effect: farmers were incentivised by a guaranteed market of large firms, hospitals and clubs; doctors would recommend their milk to patients.

In the late 1970's, "not less than 80%" of milk was packed in returnable glass bottles according to Blake (1979). But during the 1970's and into the 1980's packing milk in

plastic bottles and cartons (which did not need to be returned) accelerated, and wholesale delivery by dairy processors to the growing number of supermarkets began (Blake, 1979 and <http://www.wiseman-dairies.co.uk/our-company/company-history/>)^{vi}. Retail prices for milk were deregulated in 1984 (Dairy UK 2010). Since then, the difference between the price of doorstep-delivered milk and supermarket milk has widened continually; supermarket milk was 10.9p per pint cheaper in 1993 (MDC, 2004) but by 2010 it was 21.5p per pint cheaper (Hawkins, 2011). So we can conjecture that the overall trend of the last 25 years for supermarkets to become the principal conduit for household food purchases in the UK^{vii}, the contemporaneous change in food purchase and storage habits, the lengthening “shelf life” of fresh milk and ever-increasing price advantage all acted together to bring the supermarket not just into the liquid milk PDS, but into its foreground.

So today in the UK, nearly 20 years after the dissolution of the MMB, over 70% of all fresh liquid milk is sold by the five largest supermarkets (Foster et al, 2007, Fig 3., p.9). Importantly, the vast majority of this milk is own-label; supermarkets can exert more control over supply chains for own-label products than for branded products. Moreover, competition between processors for retailer contracts squeezes processor margins to the benefit of supermarkets^{viii}. By virtue of this own-label control, the volumes they buy and the long-term dedicated contracts, and their pivotal role as ‘gatekeepers’ to individual consumers, we argue that the supermarkets have become ‘focal’ actors in the milk PDS. The next section considers how the supermarkets have begun to exert their ‘focal’ power in milk production

and distribution over a time period of increasing environmental awareness and concern for the broader sustainability of farming.

4. Accelerating incremental eco-innovation in the milk PDS

Reducing the environmental impacts of milk production was not a key driver of change in the trajectories discussed above. Over the last couple of decades however, concurrent with the increased market power of the supermarkets, we have seen the emergence of an explicit acknowledgement of the need to reduce environmental impacts – whether that is cutting greenhouse gas emissions, reducing waste, protecting biodiversity – whilst maintaining community cohesion and quality of life, and without compromising economic growth. This challenge is arguably more acute in the food industry given farmers' assumed role as 'custodians of the countryside', the necessity of food production and current concerns over food security (see, for example DEFRA 2010a and The Government Office for Science 2011). The need to respond to the challenge of environmental sustainability whilst addressing some of the causes of economic un-sustainability has exercised both government and industry. For example, DEFRA funded a study into the environmental impacts of liquid milk production and distribution (Foster *et al*, 2007); the *Milk Roadmap* (Dairy Supply Chain Forum, 2008), produced by a taskforce involving participants in the existing system, trade organisations and the UK Government, set targets for the reduction of environmental impacts in the system and identified steps to be taken on-route towards these targets. These initiatives, and others, were certainly intended to accelerate the improvement of environmental performance across the

milk PDS and we have seen the supermarkets use their 'focal power' to intervene in the system.

One high profile effect of the shift toward supermarket domination of milk sales can be seen in the allocation of margins across the supply chain. Dewick et al (2010) discussed the imbalance in the power relations and economic returns for actors in the UK milk production and distribution system; Figure 1 shows how - at least until 2007 - retailers increased their margins on the sale of milk while average returns to milk farmers changed little:

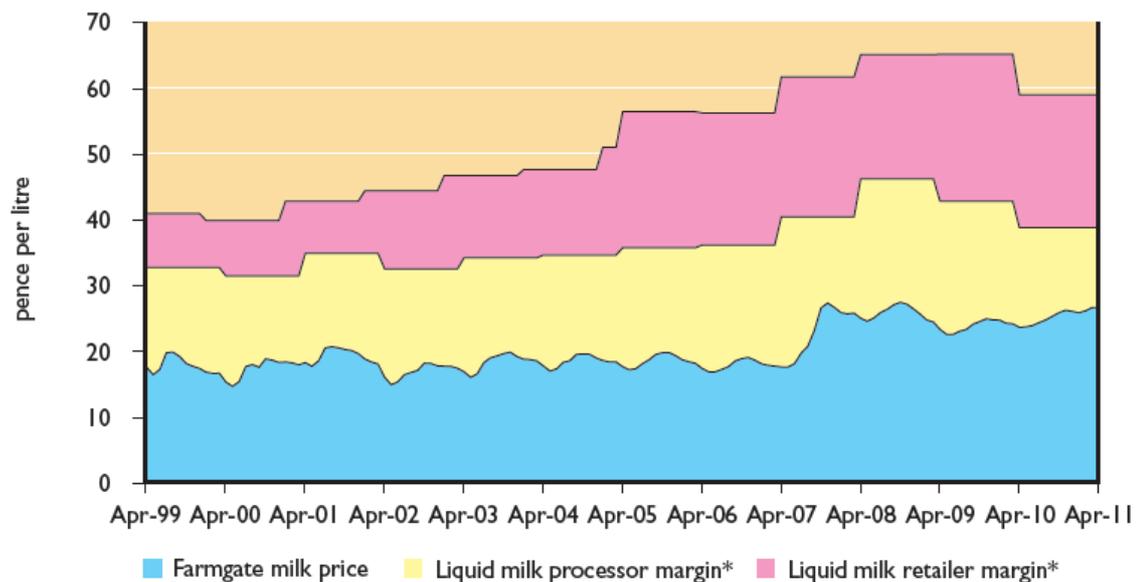


Figure 1: UK milk price margins 1999-2010, from Dairy Co (2011)

*The gross margin equals the difference between the selling price and buying price for milk

Around 2005-7, in response to pressure from farmers' representative groups and the media about the financial health of dairy farms, supermarkets began to establish

long-term purchasing commitments offering higher farm-gate prices to farmers within their own “supplier groups”: dedicated liquid milk suppliers in October 2010, for example, received up to 15% above the average farm gate price (Walsh, 2010). Evidence from the Farmer Intentions Survey (Dairy Co., 2011) suggests that these dedicated supply contracts are popular with farmers: dedicated-supply farmers had typically been on the same contract for longer, more were ‘happy’ with the buyer contract and none of those surveyed wanted to change buyer. Premiums for dedicated suppliers were linked with meeting supermarket demands for improved quality. As noted above, “Quality” is a transient notion in the history of milk. We see in Atkins’ work how the large dairy companies stimulated innovation by dedicating resources to monitoring quality and imposing on suppliers contractual obligations with regard to milk composition and cleanliness; they were, for a time, in Atkins’ words: “the custodians of quality milk”. Today, notions of what constitutes quality milk have moved on. Fat content is associated with cholesterol and heart disease and whilst some notions of purity as a proxy for quality persist^{ix}, other dimensions of quality have emerged e.g. animal welfare, regionally-identified (e.g. milk from Yorkshire, Scotland, Wales) milk for local consumption. These quality characteristics – although often certified and endorsed by independent third parties – are sought by supermarkets in exchange for their long-term commitment to the producer. Definition and control of them are growing elements of the supermarkets’ ‘focal’ role, and reflect their action in that role to stimulate innovation upstream. Coupled with attempts to build collaboration between producers and processors over technical standards, these changes have led to considerable strengthening of relationships in milk supply-chains^x.

A long-recognised characteristic of farms is the wide difference between the performance (against many measures) of the “best” farmers and of the “worst”. The uptake of best practice, for example use of manure management plans or nutrient planning, is widely recognised (not least in the “Dairy Roadmap”(Dairy Supply Chain Forum 2008)) as one route toward the targeted reductions in environmental impact of milk production. And because of its close link to the efficient use of resources (material and energy inputs) environmental best practice is also generally held to improve economic performance. The uptake of best practice is commonly facilitated by the engagement of specialist advisors. In the last century, non-commercial dairy research was dominated by the National Institute for Research in Dairying (NIRD): “the intellectual focus of the clean milk movement” (Atkins, 2010). The NIRD established standards for ‘clean’ milk; it was instrumental in the standardisation of laboratory methods in the bacteriological examination of milk; arranged large scale ‘clean milk competitions’; and offered advice to farmers and reporting to local authorities. More recently, advice to farmers was provided by ADAS (the Agricultural Development & Advisory Service), a part of MAFF, the then Government Ministry for Agriculture, Fisheries and Food. This agency was privatised in the mid 1990s, but the government remained a key provider of such advice through contracted service providers (consultancies). Such advice was available to all farmers. The restructuring of the milk PDS around the supply chains of the supermarkets has led to a change in this provision of knowledge and demonstrates another growing element of their ‘focal’ role. Thus, over the last few years, major retailers have developed supplier-improvement programmes for their long-term supply contracts. These supplier-

improvement groups started with a focus on improving animal welfare but for most the remit has broadened to include the aforementioned improvement of environmental performance. Tesco, for example, has established a “sustainable dairy group” for farmers that supply its own brand milk. The 800-strong farmers group not only disseminates best practice amongst its members but benefits directly from the Tesco funded ‘centre of excellence’ farm at Liverpool University. Research is being conducted into feeding, energy technologies and re-use/recycling and, according to ENDS (2010), *“Tesco expects its milk suppliers to start using the technology by the end of the year”*. Tesco have also measured all of their suppliers’ carbon footprints and plan to provide feedback benchmarking their individual farm performance against others in the supply group. Sainsbury’s, the Cooperative and other major supermarkets, and some of the leading processors^{xi}, have acted in similar vein and have ambitions to go further, helping their suppliers to reduce their carbon footprints. So a new mechanism for the spread of best practice has emerged, to some extent replacing the previous government-funded one^{xii}, although often using the same technical consultants. Indeed, many of these consultants (for example Kingshay, Kite Consulting) have developed environmental performance-measuring and related expertise. Whilst this mechanism may well be considered more discriminatory (or selective) – it is after all available only to those farmers supplying one or other of the supermarkets – the involvement of the supermarkets in creating and facilitating the dissemination of advice to farmers both extends and leverages further their ‘focal’ power to accelerate eco-innovation, sustaining the system by directing advice towards those farmers holding supply contracts to major buyers with public reputations to defend.

We have noted how the evolution of the milk industry since 1994 led to the supermarkets having the 'focal' role in the milk PDS. In these two examples we can see how supermarkets have extended and exerted their 'focal' power to stimulate eco-innovation whilst improving the economic and social sustainability of the milk industry. They have done this by firstly "closing" their supply chains (establishing sets of dedicated suppliers) and then driving improved environmental performance in this stable supply base through technical requirements within their contractual arrangements (an example of 'triggering demand') and secondly by engaging interactively with processors, farmers and research centres to create and disseminate knowledge and good practice through fora for dedicated suppliers and other processes such as webinars (an example of 'interactive buyer-supplier' innovation). These examples continue long-running trends in the industry also and can be considered to be incremental (but accelerated) in nature. The next section reflects on the challenges presented by a more disruptive eco-innovation; disruptive in the sense that it doesn't fit with the evolved structure of the industry but one which could extend the 'focal' role of the supermarket into system re-building'.

5. Disruptive eco-innovation in the milk PDS

Cow excrement (manure) accumulates on farms when cows are indoors for milking or over winter. Since it contains both nitrogen and phosphorus, the resulting slurry has traditionally been spread on farmland - partly for fertilisation, partly for convenience. Poor storage and uncontrolled slurry spreading have been associated with pollution of the wider environment. Even when good practice is implemented,

slurry storage and spreading involves greenhouse gas emissions which constitute around 5% of the overall “carbon footprint” of liquid milk (Foster *et al* 2007, Table 7, p.16). Feeding slurry into an anaerobic digester represents an alternative method for handling this waste which avoids these emissions. Anaerobic digestion (AD) converts undigested material into “biogas” (mostly methane) which can be used as a fuel, potentially displacing fossil fuels in the wider energy supply system, leaving a more concentrated, nitrogen-rich liquid that can be used as fertiliser. Implementation of AD for slurry handling can reduce the environmental impacts associated with milk production, particularly greenhouse gas emissions. However cattle slurry has a relatively low energy density compared to other potential feedstocks for AD plants: Hopwood (2010) quotes potential biogas yield as being 25m³/fresh tonne for cattle slurry compared to 80 m³/fresh tonne for poultry litter and 202 m³/fresh tonne for maize silage.

There are two modes of uptake for anaerobic digestion (AD) commonly discussed in studies of the industry (Dairy Supply Chain Forum, 2008) and the technology (Royal Agricultural Society of England, 2011; NFU, 2011): centralised AD (centralised at, or very close to, the dairy-processing site) and on-farm AD. If handling manure, the centralised mode requires transfer of slurry from farms to the processing site: it offers the potential of scale efficiencies and co-treatment of dairy processing and dairy farming wastes. Centralised AD plants are owned and operated by organisations within the dairy industry or by new entrants to the industry. For example, from within the dairy industry, BV Dairy have been involved in a DEFRA funded AD demonstration project. BV dairy processes 35 million litres of milk per

year sourced from 35 farms (DEFRA, 2010b); waste liquids from the dairy (but seemingly not waste from farms) are converted to biogas in an AD plant and this gas fuels a Combined Heat & Power unit which produces the electricity and heat needed for dairy operations (http://www.bvdairy.co.uk/anaerobic_digestion.html^{xiii}). The involvement of new entrants is reported by Zglobisz et al (2010) in discussing broader (non-dairy) AD initiatives that are the fruits of collaboration between biogas technology proponents, food producers and supermarkets and mostly aimed at handling food waste. Regardless of ownership and control, location of the centralised plant is critical for its viability (with respect to the availability of inputs, the availability of other options for their management and the availability of uses for heat and power produced). For any centralised plant taking slurry from farms either contractual or hard infrastructure connections between the farms and the centralised AD plant would also be needed. These constraints, coupled with the need to comply with waste regulations, create barriers for centralised AD plants that take slurry from farms to occupy more than a small niche within the dairy industry.

On-farm AD systems are likely to be smaller in scale than centralised plants; at first glance this seems a more flexible route for the introduction of AD as environmentally-friendly manure management. It does however require farmers to access the skills necessary to operate what is effectively a biochemical processing plant. Moreover, the economics of operating on-farm AD plants, and the payments available for electricity exported to the National Grid are reported to be such that single-farm units are unlikely to be viable without a dramatic reduction in the capital costs of plant (ENDS, 2010, p.21; Farm Futures, 2010). Furthermore, the relatively

low energy content of manure, which is generally available only for half of the year when cows are housed indoors over the winter, makes it a poor candidate as the sole feedstock for an AD plant, so a mixed input of energy crop and manure provides a better economic return (Farm Futures, 2010). Most examples of single farm, slurry-fed AD facilities we identify are grant financed with energy output for 'domestic' use only^{xiv}. Current UK waste management regulations place obstacles in the way of farmers considering investment in AD taking food waste as feedstock, just as they do for centralised plants. It seems then that a grass-based dedicated dairy farm would need to shift some land into arable production or collaborate with (an) arable farm(s) to achieve a good return on an investment in AD under current conditions.

In the light of these considerations, we identify two further pathways to successful uptake of farm-level AD:

First, there is what we might term the 'co-operative route'. One or more dairy farmers collaborate(s) closely with geographically-proximate arable farmers to develop an AD plant on a scale sufficient to be viable and to allow engagement of the skills needed to operate it. In this model, the individual farms remain dedicated to their existing specialisations, diversifying their businesses by investment in a co-operative venture (an energy business) to which each farm is a supplier. The "Blackdyke" Cooperative Group (Storr, 2010) is an example of this option being implemented. In this case the AD plant is located on one of the participating farms. Another example is "Sustainable Youlgrave", a voluntary community group that is supporting (both single and) shared on-farm AD with five local farmers^{xv}.

Close collaboration between geographically-adjacent farmers for the development of infrastructure occurred in the Netherlands as part of the dissemination of milk tanks on farms (Albert de la Bruh ze and van Otterloo, 2003). The installation of a multi-farm AD plant would arguably be easier if collaborative structures, such as locally-based farmer co-operatives, were in place already. Farm co-operatives are, however, relatively rare in the UK; Atkins & Bowler (2001) (p.59, Table 5.2) state that in the UK 4% of milk is marketed through farm co-operatives, whereas in France the proportion is 50%, in the Netherlands it is 84% and in Denmark 91%. The reason why cooperatives are few and far between is not clear and has been attributed to various factors, from UK farmer’s psyche (proud and independent) to competition laws and legal structures of cooperatives^{xvi}. Co-operatives might also facilitate entrepreneurial activities of farmers to vertically integrate into processing, or promote more regional production and consumption, challenging the current purchase of milk through supermarkets and allowing farmers to capture more of the value added along the milk chain. Currently, and in contrast again to the dairy industries in other European countries, there is little formal concentration (i.e. vertical integration) between stages in the UK. In the absence of collaborative arrangements, it seems unlikely that this route will flourish without the involvement of a ‘systems integrator’ to provide resources and knowledge to facilitate renewable energy projects^{xvii}.

Second, there is what we might term the “expand & diversify” route for individual dairy farms. In this case, an individual farm expands to incorporate arable crop production (possibly for cattle feed and AD feedstock) and to a point at which AD

becomes viable and energy supply becomes a significant part of the farm business. This would represent a major expansion for the average dairy farm in the UK; the average herd size in the UK was 113 in 2009, up from 72 in 1996 (Dairy Co. Datum^{xviii}), while Rural Futures (2010) estimated that on-farm AD would be viable for a farm with a 300-head dairy herd and producing around 2000 tonnes of maize silage per year. For example, Kemble Farms in Gloucestershire, a mixed dairy and arable farm, operates an on-farm AD facility and uses inputs from their herd of 700 dairy cows and ~2500 tonnes of maize silage per year and 450 tonnes per year of glycerol (from the production of biodiesel)^{xix}. Very large scale farms based on predominantly cereal feeding of dairy cows would of course offer greater economies of scale and more easily justify investment in the various skills required efficiently to operate arable agriculture, cattle husbandry and biochemical plant in an interconnected manner. The 3700-head farm proposed in Lincolnshire during 2009/10 (known as Nocton Dairies) exemplifies this route, and did indeed incorporate an AD plant in the plans but the controversial project was abandoned in 2011 because of Environment Agency concerns about pollution risks^{xx}.

Up-scaling and concentration have a long provenance in the dairy industry going back to the standardisation of milk composition and restructuring of the national herd. In their own right, efforts to raise yields and increase cow longevity (to reduce culling rates and the burdens associated with breeding replacements) have contributed to reduced greenhouse gas emissions at the primary production stage of the system. The drive to maximise productivity from farmed area, coupled with higher resource efficiencies achieved at larger farms, is both a continuation of

industry trends and offers some economic and climate change improvements. It is, however, in tension with other environmental and social concerns and so potential for further movement – and, particularly, acceleration – along this trajectory may well be limited. In terms of the environment as people experience it, concentration disfavours both the multiplicity of farm units that many would say characterises the UK landscape and the maintenance of non-productive areas that nurture biodiversity. Public opinion, shaped by strong advocates such as Compassion in World Farming, RSPCA and Friends of the Earth, seems currently to be that concentrated farming leads to welfare problems for cows (including increased mastitis, increased lameness and increased infertility) and that cows *should* be grazing outdoors (a theme that underpinned many objections to the Nocton Dairies proposal).

Reflecting on these routes to on-farm AD, what opportunity is there for supermarkets to exercise their ‘focal’ power and facilitate eco-innovation? The “cooperative route” would require a radical restructuring of the milk PDS and the relationships within it. This could involve emergence of stronger farmer-farmer or farmer-processor links or a new entrant acting as a systems integrator to facilitate horizontal, local co-operation among farmers. Given the path dependency and lock-in around the current system (as evidenced by the Farmer Intentions survey noted above), a reconfiguration of the industry around cooperatives looks unlikely to flourish, especially when there appears to be little incentive for the ‘focal’ supermarkets to encourage the reconfiguration.

Given prevailing public opinion and the public relations sensitivity of the supermarkets, the “expand & diversify” route would need considerable effort in consumer education to bring a sceptical public around to thinking that larger unit farms were more sustainable. On the other hand, milk production costs on such units are likely to be lower than on the current average farm offering the incentive of improved margins for both farmers and supermarkets. This route also offers the potential for more accelerated improvement in the quality and best practice trajectories noted above. It may even, if tensions with other issues can be managed, be the most ecologically-efficient one^{xxi}. The emergence of on-farm AD within the existing supply chain arrangements is perhaps most likely in the short term. Supermarkets like Tesco are monitoring the use of AD on their dedicated supply farms but could go further to accelerate the uptake of the technology. The Royal Agricultural Society of England (2011) report, for example, noted the potential for “relevant organisations such as supermarkets” to partially (or wholly) fund capital grants or rolling loans with preferential terms, facilitating access to capital currently held up by a technology characterised as new and high risk and supplied by firms with little financial security. Providing access to capital for smaller on-farm systems (which don’t involve the PR considerations of an ‘expanded and diversified’ farm) seems arguably the most likely route for the supermarkets to exercise their ‘focal power’ where both farmer and supermarket benefit.

So whilst existing trajectories of ‘quality’ improvements and best practice are underpinned by the current supply chain structure of the milk PDS and some eco-innovation seems to be accelerated by the concentration of ‘focal’ power into the

hands of supermarkets, extensive uptake of the environmental opportunity presented by AD seems likely to hinge on some further reconfiguration of the industry or the extension of supermarkets 'focal' role into the capital market. Which path is followed will also influence the scale of environmental performance improvement.

6. Conclusions

This paper has considered the importance of understanding the provenance of an industry when assessing how innovation can be accelerated and redirected to bring major, long-term reductions in the environmental impacts associated with production/distribution systems. We argue that the co-evolution of the industry with the increasing power of 'focal' actors – those whose behaviour can lever more innovative and environmentally sustainable practices and change the nature of competition – necessarily facilitate some eco-innovation pathways whilst holding-up others. Our analysis has focused on the milk industry in the UK.

In innovation terms, the trajectory described in Sections 3 and 4 can best be understood in terms of an emerging sectoral system of innovation. Consistent with analyses of other sectoral systems, much of the innovation in the milk PDS described relates to dynamism of the industry boundaries and the actors and institutions therein as opposed to changes in the product, which, despite some new product development, to all intents and purposes can be considered a commodity. Our analysis has centred on the 'focal' role of multiple retailers (supermarkets) and how they deploy their resources and competencies in purchasing and supply chain

management to stimulate eco-innovation upstream along 'quality' and 'best practice' trajectories. Breaking down how 'focal actors' can use purchasing power to stimulate innovation, we can observe the mechanisms they use to design new contracts that benefit farmers and specify environmental improvements ('triggering demand'), their investment in knowledge creation (R&D) through links with universities and veterinary organisations and their creation of fora and other vectors of information sharing and knowledge integration ('interactive buyer-supplier' innovation). Taking this approach helps us understand better the potential and limits associated with the role of 'focal actors' in a way that the sectoral systems, socio-technical and global value chains approaches do not. Although public policy has contributed to a more sustainable milk production and distribution system – e.g. by commissioning empirical based research (e.g. Foster et al, 2007), encouraging collaboration across the industry (e.g. Dairy Supply Chain Forum, 2008) and the development of environmental expertise in farm advisory community – we can see how the emerging role of the 'focal' supermarkets has usurped the role of other actors (e.g. local authorities, central government, universities and research institutes) in stimulating eco-innovation, particularly around knowledge and knowhow transfer. But that is not to say there has not been an important role for institutional regularity (and disruptive change), echoes of which ripple through the analysis (e.g. specifications regarding milk composition, competition law, regulations on milk buying) enabling the entrance of the supermarkets and creating the lock-in and path dependency that characterises the evolution of the industry over the last few decades. Indeed, the path creation event that shaped how the industry is what it is today was the entrance of the supermarkets into the production and distribution

system following deregulation in the 1980's and 1990's and the subsequent restructuring of the PDS around their supply chains.

The pursuit of sustainability targets by the major supermarkets has changed 'quality' and 'best practice' approaches across a wide and distributed production base in a manner akin to Lowe and Gereffi (2009). A move into the space of capital provider for AD, enabling the creation of a new, more sustainable, infrastructure would support further reconfiguration of the industry and elevate supermarkets 'focal' role to 'system re-builders'. But, as the analysis above has shown, there are considerable institutional path-dependencies and other factors (e.g. inappropriate and insufficient financial incentives; over burdensome regulation) that inhibit such changes. Many innovation studies tell us that disruptive, path creation events are few and far between; what's notable in the development of milk, like many other industries, is how much remains the same over long periods of time and how change emerges incrementally along established trajectories. This means that by relying on existing actors to chart a path towards sustainability, the industry risks entrenching existing structures and power relationships, which may inhibit the emergence of new structures that could be more sustainable across a range of themes.

Acknowledgements

This work was supported by Tesco through the Sustainable Consumption Institute (www.sci.manchester.ac.uk). The sponsor had no involvement in the study design, in the collection, analysis and interpretation of data, in the writing of the report and in the decision to submit the article for publication.

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ⁱ In Van der Vleuten's (2003) account of the construction of the food chain (a second-order 'Large Technical System') in the Netherlands by food industry actors using basic transport and energy infrastructures already in place (the first-order LTS), the network emerges without any single, identifiable "system builder" co-ordinating the process (in contrast to other examples such as the electricity supply system).

ⁱⁱ <http://www.dairyco.net/datum/milk-supply/milk-production/world-milk-production.aspx>, last accessed October 2011

ⁱⁱⁱ <http://archive.defra.gov.uk/foodfarm/food/industry/sectors/milk/dairyindustry/>, last accessed October 2011

^{iv} <http://www.dairyco.net/datum/consumer/uk-dairy-consumption/uk-dairy-consumption.aspx>, last accessed October 2011

^v The genetic diversity of cows was compromised by the need for high yielding cattle that would produce a quality satisfactory to the market. The efforts of the British Holstein Cattle Society, founded in 1909, produced a breed of cow with these characteristics, which went on to dominate the UK herd: accounting for 20% of the cow population in 1947, 76% in 1970, 95% in 2010.

^{vi} Wiseman website last accessed October 2011

^{vii} See Lang and Heasman (2004), Table 4.7 p166, which documents this trend in terms of market share

^{viii} Figure 1 shows that the processors have seen their margins squeezed as the majority of retailers retendered their contracts in 2010/11.

^{ix} Take Arla's Cravendale milk for example. On their website (www.milkmatters.co.uk, last accessed October 2011) Arla claim that "Cravendale is purer than other milk...because they don't just pasteurise the milk, they also finely filter it to make it purer....and because we remove more of the bacteria that turn milk sour, it lasts a lot longer too".

^x The retailers have driven developments in this area (e.g. Waitrose's group of dedicated milk suppliers was established first, some 10 years ago; Tesco's more recent group is probably the largest).

^{xi} Dairy Crest, for example with their 'White Gold Scheme' has similar relationships with their suppliers (see http://investor.dairycrest.co.uk/ir/dcg/html/corporate-responsibility/mr_farms.htm, last accessed October 2011).

^{xii} The latter remains, e.g. in delivery of the CAP requirement for advice on "cross-compliance" measures by the Rural Development Service in England. Technical advice to Dairy Farmers is also provided by DairyCo's 20-strong "Extension Team". DairyCo is a not-for-profit organisation funded by a levy on all milk produced by farmers (0.06p per litre in 2020).

^{xiii} Last accessed October 2011.

^{xiv} For more information see DeFRA (2010b) and Royal Agricultural Society of England (2011).

^{xv} For more information on Sustainable Youlgrave, see <http://www.sustainableyoulgrave.org/>, last accessed October 2011

^{xvi} See <http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenvfru/uc952-ii/uc95201.htm> (last accessed October 2011) and www.thisismoney.co.uk/money/news/article-2033430/Farmers-set-ops-deal-supermarkets.html (last accessed October 2011).

^{xvii} To this end, Community Renewable Energy (CoRE), a social enterprise, has played such a role for the Blackdyke Cooperative Group. See <http://www.corecoop.net/>, last accessed October 2011

^{xviii} Historical average herd numbers for the UK are available at <http://www.dairyco.org.uk/datum/on-farm-data/cow-numbers/uk-cow-numbers.aspx>, last accessed October 2011

^{xix} Kemble Farms is one of the case studies discussed in the report by Royal Agricultural Society of England (2011). The Farm received an initial 32% grant from the Department for Energy and Climate Change, the remainder financed by the farm: current estimates suggest a capital payback after 7 years (the AD facility commenced in September 2008). Further information is available on their website <http://kemblefarms.co.uk/>, last accessed October 2011.

^{xx} Nocton Dairies dedicated website (<http://www.noctondairies.co.uk/industry-views.html>) has ceased to be active but there is much commentary on the proposed development available on the internet.

^{xxi} Provisional calculations apparently put the expected “carbon footprint” of milk from Nocton Dairies more than 25% below values commonly obtained for milk from good UK producers